TYNDP

Ten-Year Network Development Plan 2016

EXECUTIVE REPORT

ENTSO-E AISBL

Avenue de Cortenbergh 100
1000 Brussels
Belgium

Tel +32 2 741 09 50
Fax +32 2 741 09 51
info@entsoe.eu

www.entsoe.eu

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Executive Report

The 2016 edition of the 10-year network development plan (TYNDP) builds on the 2014 edition and offers a view on what grid is needed where to achieve Europe's climate objectives by 2030.

Even if local generation, demand response, storage and energy efficiency will play an increasing role, the studies show that an extension of the current grid is needed to allow the shift of large quantities of renewables to the main consumption centres.

The TYNDP 2016 foresees around 150 billion euros of investments in grid infrastructure supporting 200 projects in transmission and storage.

The TYNDP 2016 explores the possibility of a power system where 80% of the emissions will be cut by 2030.

Final TYNDP 2016 after public consultation

The draft TYNDP 2016 package (executive report, insight reports and project assessment sheets) was first published for consultation in June 2016. ENTSO-E received over 300 comments, which helped improving the TYNDP package. ENTSO-E experts carefully considered these comments, and produced this updated draft of the TYNDP, which was submitted to ACER for their opinion.

All the comments received, as well as detailed ENTSO-E response for each of these comments and explanations on how they were (or why they were not) taken into account are available in the TYNDP 2016 consultation log, available on ENTSO-E website. Detailed logs of all changes between the consultation version of the TYNDP and this current version are also available in separate files on ENTSO-E website.

A particular focus was put by ENTSO-E experts to improve the quality of all transmission and storage project assessment sheets. When necessary, the description of the system needs, of the project, and explanations on the CBA results have been updated and further developed.

A number of changes were made to this executive and to each of the 12 insight reports. Among other changes, a new chapter was added to the executive report: "User's Guide to a new, updated and enriched TYNDP for electricity". This new chapter is a response to several stakeholders comments requesting clarifications on the content of the TYNDP package, the assessment process and results, or the link between the TYNDP and the selection of Projects of Common Interests.

List of abbreviations

- ACER - Agency for the Cooperation of Energy Regulators
- CBA - Cost Benefit Analysis
- DSR - Demand Side Response
- EC - European Commission
- ENTSOE - European Network of Transmission System Operators
- GTC - Grid Transfer Capacity

- PCI - Project of Common Interest
- RES - Renewable Energy Sources
- SEW - Socio-Economic Welfare
- SoS - Security of Supply
- TSO - Transmission System Operator
- TYNDP - Ten Years Network Developement Plan
- V1 V2 V3 V4 - Visions 1, 2, 3 and 4 (the name of the 4 scenarios used to build the TYNDP 2016)

The TYNDP: mapping the Energy Union

> “The EU has set itself the targets, by 2030, of reducing domestic greenhouse gas emissions by 40% […], reaching at least 27% energy savings, [and]at least 27% renewable energy (RES) penetration at EU level” *(Energy Union Package)*

The Energy Union package sets ambitious goals for the overall energy supply by 2030 in Europe. These goals can, however, translate differently for the power sector, depending on the implemented energy policy. For example a strong switch of end users from fossil fuels to electricity, especially in transportation (e.g. electric vehicles) and heat (e.g. heat pumps) by 2030, can compensate for the introduction of more efficient appliances, and make electricity consumption keep on growing in Europe. High renewable energy sources (RES) development may also appear easier in the power sector. Thus, the same “27/27/40” goals by 2030 for the total European energy supply can result in different scenarios for the power sector alone.

The consultation process on scenario development for the TYNDP 2016, therefore, concluded to focus on an extensive exploration of the 2030 horizon (year N+15), and ensure continuity with the TYNDP 2014 by only adapting, but keeping the basis of, the storylines of the previous TYNDP four 2030 Visions. A new mid-term “Expected progress” scenario (year N+5) is added as an intermediate step to any of the 2030 Visions (The TYNDP is published in 2016, but scenarios are commonly performed in round years. Therefore, N+15 refers to 2030 (instead of 2031) and N+5 to 2020 (instead of 2021)).

For a detailed explanation of the scenarios, how they were built or to find specific figures, check the Scenario Report published in 2015

The 2030 Visions are not forecasts of the future, but rather plausible future states selected as wide ranging possible alternatives so that the pathway realised in reality falls with a high level of certainty within the range described by the Visions. The span of the four Visions is large and meets the various expectations of stakeholders. They differ mainly with respect to

- The trajectory towards the Energy roadmap 2050: Visions 3 and 4 maintaining a regular pace from now until 2050, whereas Visions 1 and 2 assume a slower start before an acceleration after 2030. Fuel and CO_2 prices favour coal over gas in Visions 1 and 2 compared with Visions 3 and 4.
- The consistency of the generation mix development strategy: Visions 1 and 3 are based upon each individual country’s energy policies though still with a minimum harmonised approach across Europe; while Visions 2 and 4 assume a stronger top-down pan-European construction, based on new optimisation methods specifically developed for this TYNDP 2016.

The TYNDP scenarios include a significant development of renewable electricity sources, supplying **45% to 60%** of the total annual demand, depending on the Vision. These are paired with a huge reduction in CO_2 emissions (**-50% to -80%** from the 1990 levels, depending on the scenario, see Figure 1). Compared with the TYNDP 2014, the span of the four Visions is of course reduced, adapted to the Energy Union goals by a closer horizon.

The TYNDP 2016 scenarios are also designed to reflect increasing shares of active demand users, concerted efforts to steer storage and synergies of load and generation by prosumers. These aspects are not placed in a separate scenario but are intrinsic to the four Visions. From Vision 1 to 4 the share of electric vehicles and heat pumps ranges from negligible to 10% of peak load by 2030. Related to this, the potential for demand response rises from 5% in Vision 1 to 20% in Vision 4. The most RES oriented scenario therefore also covers the most means to accommodate RES at local/distribution levels, with TYNDP results showing the impact on the pan-European transmission grid.

In every Vision, the TYNDP 2016 tests whether the European extra high-voltage grid is capable of transferring power from generation facilities to load centres in numerous situations. It identifies the possible bottlenecks and the associated investment needs, assesses the costs and benefits of (jointly) proposed reinforcements, both for the 2020 and 2030 horizons and thus puts every investment project into a common perspective. Note that the TYNDP covers investment projects already subject to clear investment decision or approval, as well as proposals which require further analysis. This TYNDP proposes strategies to meet the EU interconnection targets in every Member State, which are set at a ratio of interconnectivity over installed generation of 10% by 2020, and 15% while accounting for trade flows and costs by 2030.

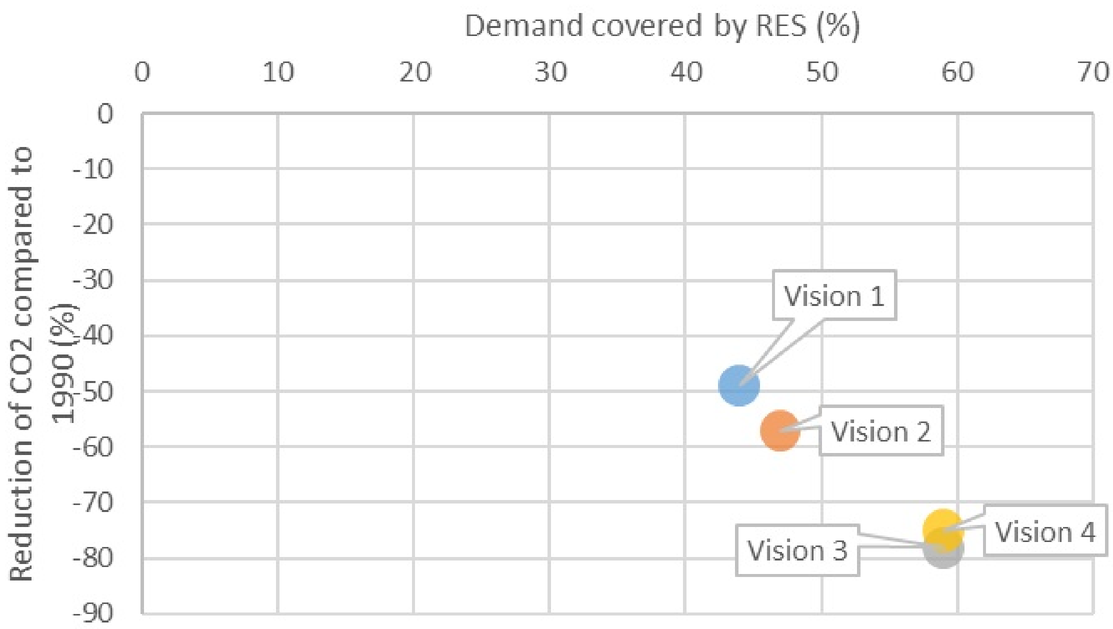


Figure 1 All 2030 Visions matching the renewables objectives of the electricity system. Note that while in this figure V1-2 and V3-4 seem close, they show a strong differentiation in the spatial distribution of generation.

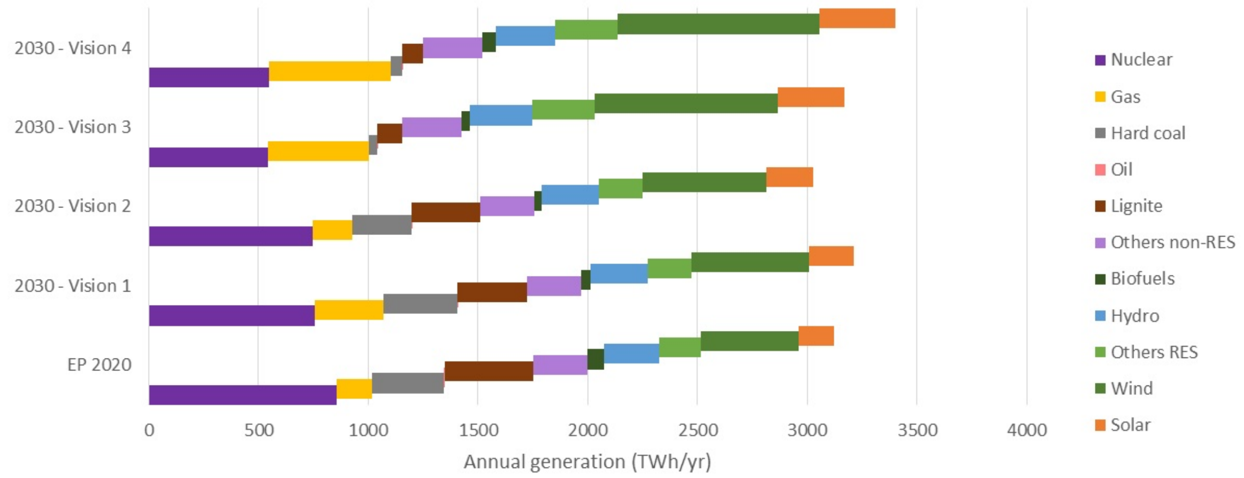
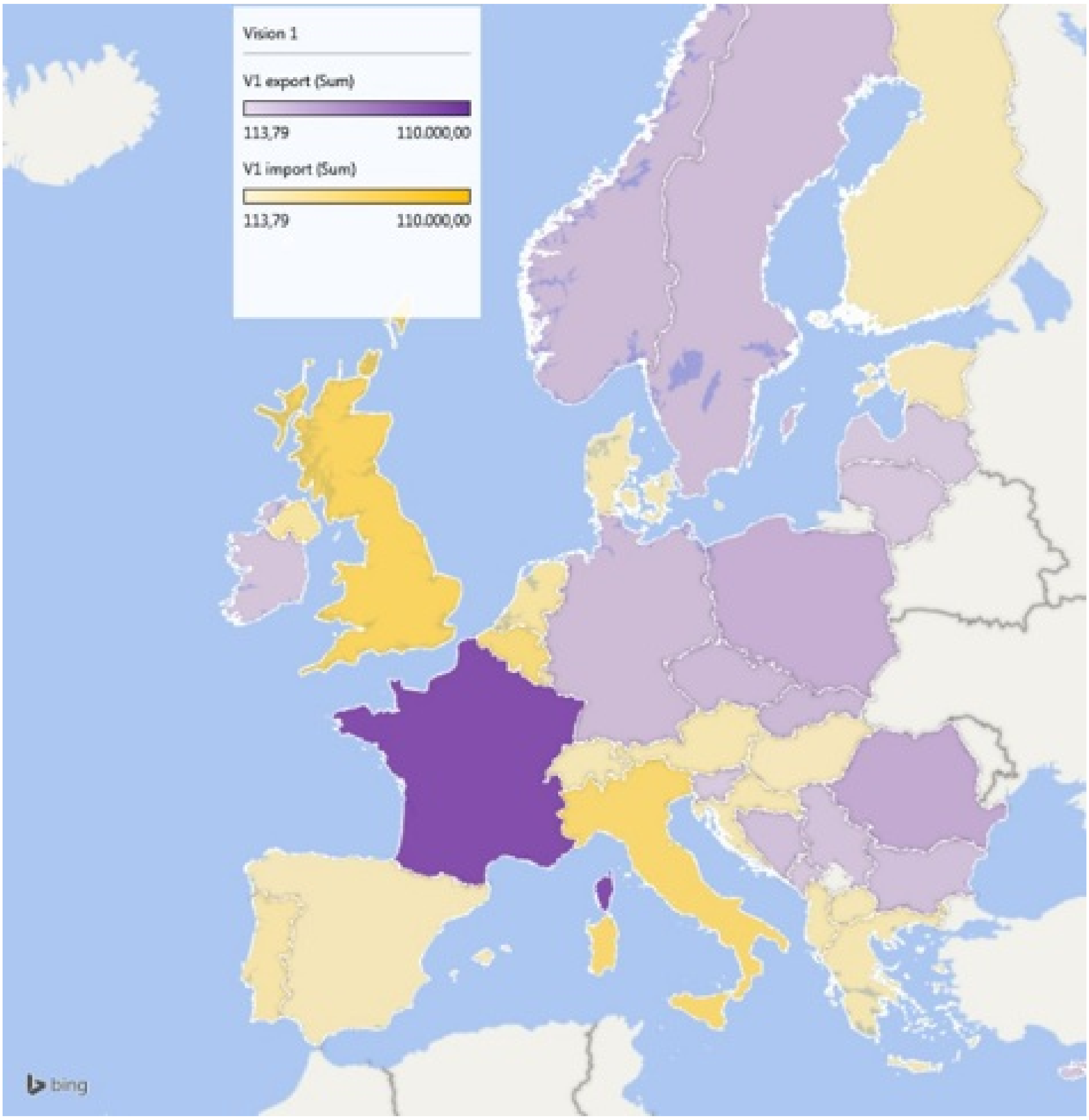


Figure 2 Annual generation in each scenario – breakdown per technology class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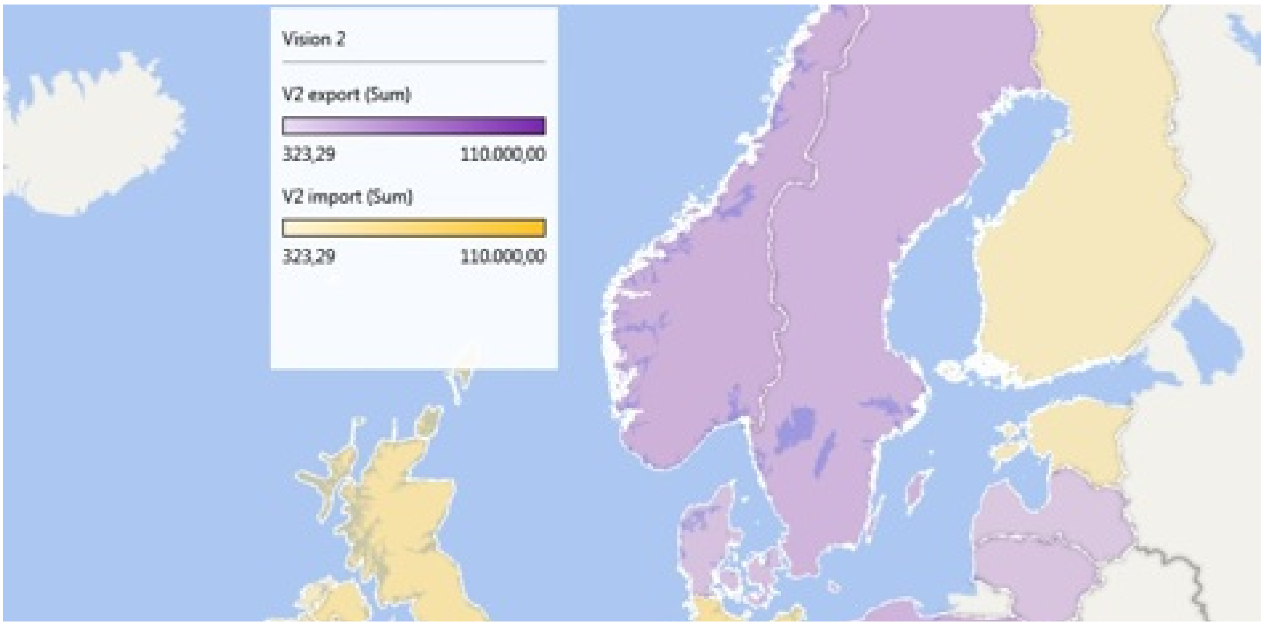
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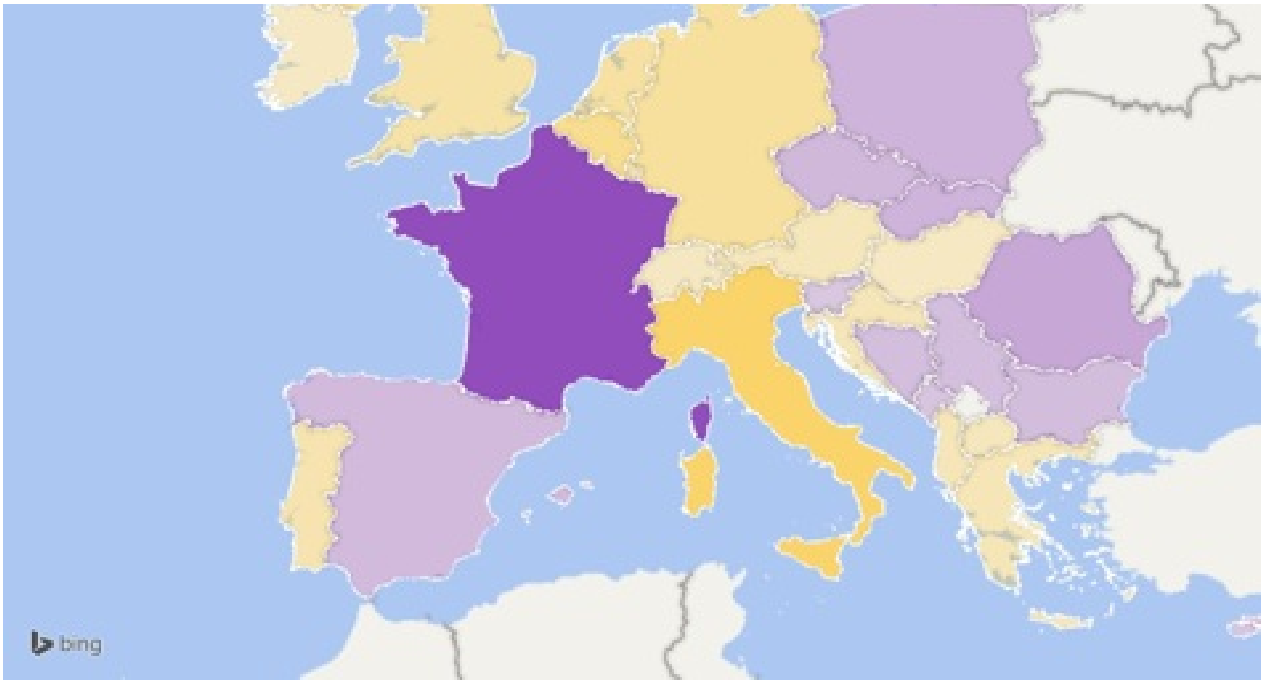

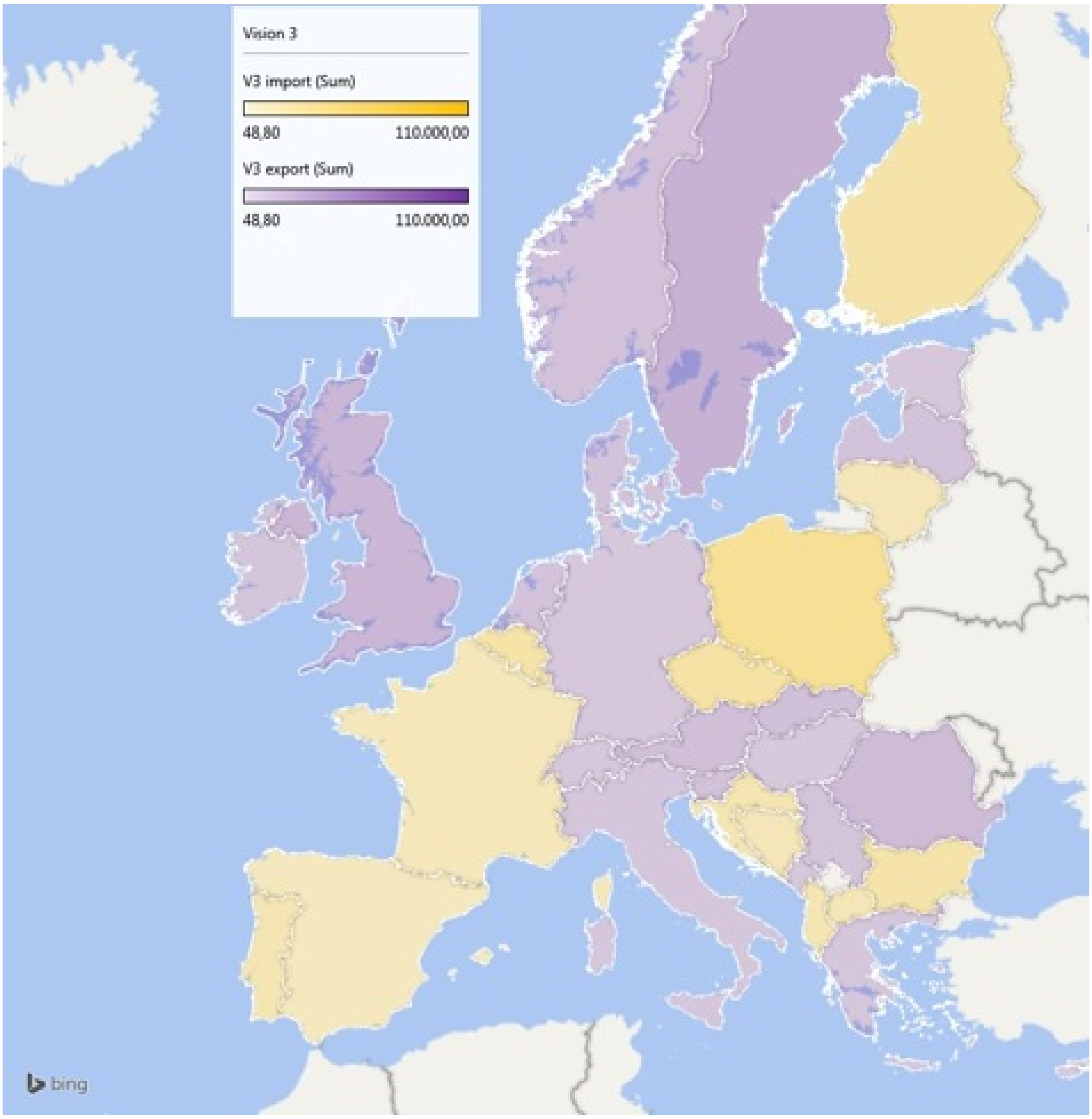
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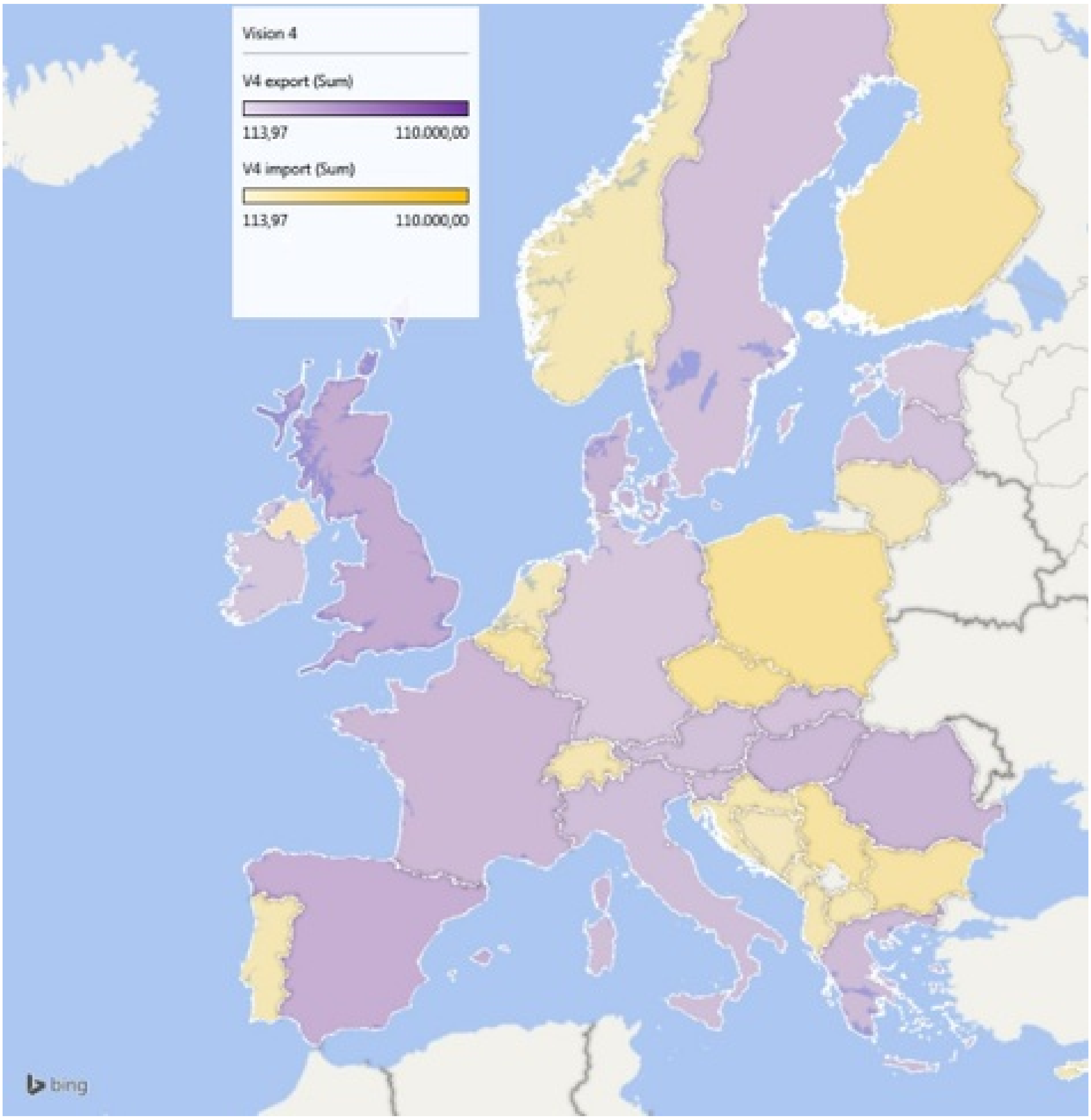


Figure 3 - All visions show different views in which countries become importing or exporting on an annual basis. These differences are even more pronounced when looking at hourly flows. All of this impacts the various TYNDP analyses of market integration, RES facilitation, and system reliability.

27% RES in Europe’s energy supply by 2030 means more grid

> “We concluded that more transmission grid is needed to ensure RES development by 2030; and in this respect they prove relatively cheap, compared with generation and storage” *(J. Vande Putte, Greenpeace)*

Variable RES uptake is the major driver for grid development by 2030. The generation fleet will experience a major shift in the next decade with the replacement of much of the existing capacities, probably located differently and further from load centres, and involving high RES development. This transformation of the generation infrastructure is the major challenge for the high-voltage grid, which must be adapted accordingly.

Local smart grids will help to increase energy efficiency and improve the local balance between generation and load. Nevertheless, ENTSO-E forecasts larger, more volatile power flows, over a larger distance across Europe, mostly North-South driven by the aforementioned energy transition with increasing importance of RES development, and sometimes (depending on the Vision) West-East. The power flows are therefore very large in particular in the high-RES Visions 3 and 4.

Most transmission investment needs are linked to RES-integration developments, either where the direct connection of RES is at stake or because the network section or corridor is a bridge that links RES and load centres.

To answer these investment needs, the TYNDP 2016 compiles €150 billion investments of pan-European significance, of which €80 billion is for projects already endorsed in national plans and/or intergovernmental agreements by 2030[1]. The figures are in line with the previous analysis of the TYNDP 2014. This effort is significant for the financial means of transmission system operators (TSOs). Still, it only represents about 1.5-2 €/MWh of power consumption in Europe over the 15-year period, i.e. about 2% of the bulk power prices or less than 1% of the total electricity bill.

This investment scheme has, however, a significant positive impact on European social welfare. The created market integration will reduce bulk power prices by 1.5 to 5 €/MWh (depending on fuel and CO2 cost assumptions per scenario).

In addition, it helps avoid 30 to 90 TWh of RES-spillage[2] globally, reducing it to less than 1% of the total supply. In the 50 - 80% of carbon emission reduction in the electricity sector by 2030 compared with 1990, up to 8% is enabled by the TYNDP infrastructure.

TYNDP2016 market flow studies show that in the various 2030 scenarios the portfolio of mid-term and long-term grid infrastructure investments result in a reduction of over 40% of the number of congestion hours (as compared with the existing grid situation). This shows the support TYNDP investments bring to a more integrated European energy market. Figure 1 also shows how the TYNDP portfolio reduces border average marginal price differences.), and ensure N-1 security (example give for Vision 3). The individual TYNDP project sheets also give further insight in how marginal price differences across borders fluctuate across the year.

Investing in the project portfolio represents generally a payback for society after 20 years in a rather conservative scenario. The TYNDP 2016 thus confirms the main findings of the previous releases of the TYNDP. It also completes them in new respects by exploring and presenting additional elements.

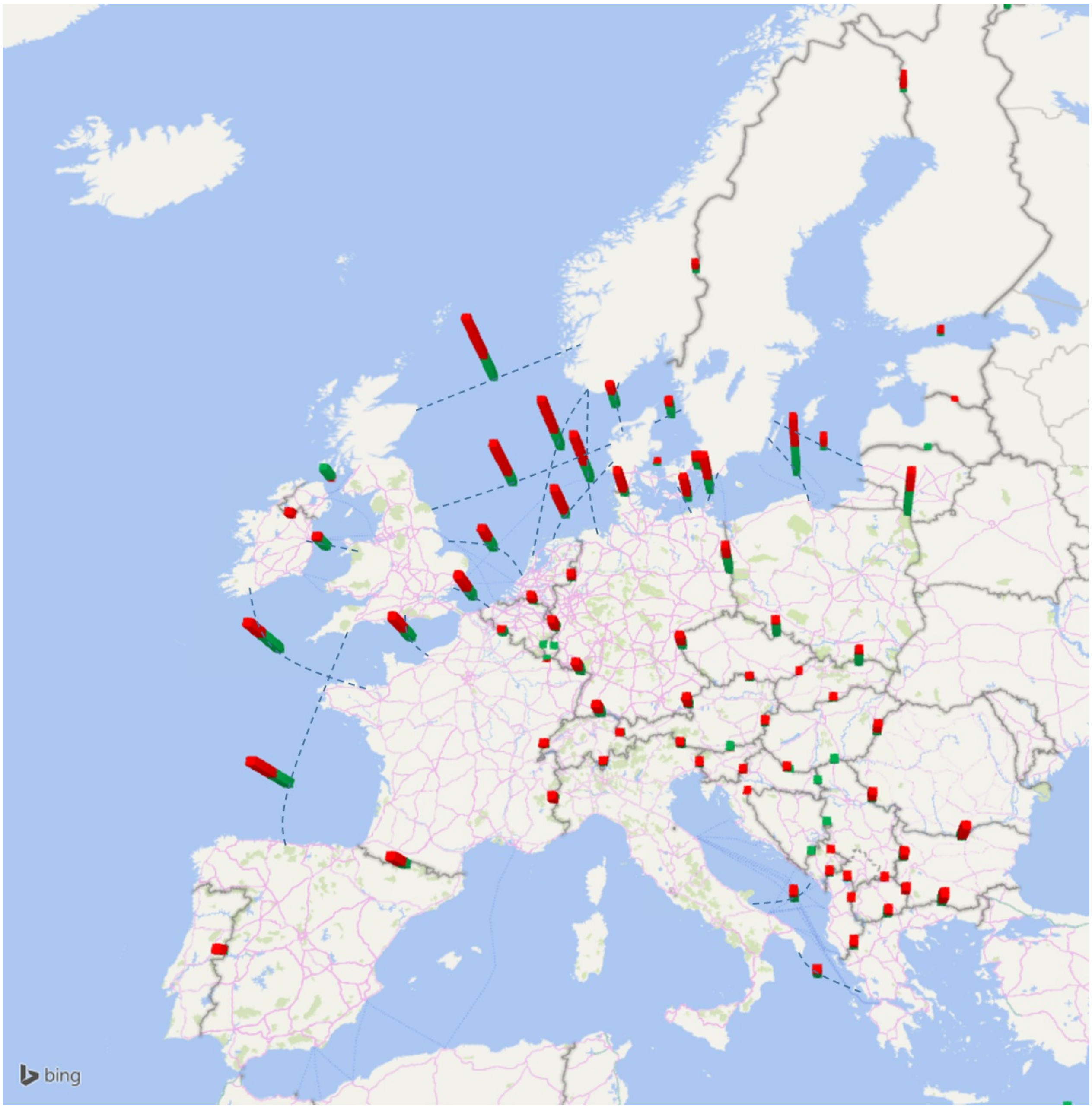


Figure 4 - Reduction in the yearly average of hourly marginal cost spreads in Vision 3, illustrating the benefit of TYNDP investments for European market integration. The total bar height represents the average price spread at each border in Vision 3 without the TYNDP investments; the green bars represent the remaining spread with the market capacity delivered by TYNDP investments.

Footnotes:

> 1. These projects of pan-European significance must however be completed at regional or national level to achieve an overall consistent development of the whole energy system. ↩

2

> [2]. Electricity production from RES that is curtailed i.e. which do not reach the consumer due to grid constraints ↩

Main barriers for power exchanges in Europe

> "The stronger the RES development in large scale, the stronger the power flows and the transmission capacity needs from the periphery of Europe, with higher RES potential, towards its heart, where most of the load centres are" *(G. Sanchis, e-Highways 2050 project leader, Nov/15)*

Past releases of the TYNDP used to pinpoint four "electric peninsulas" – namely Ireland and Great Britain, the Iberian Peninsula, Italy and the Baltic States.

The TYNDP 2016 reconfirms those needs. The presentation in this edition has been reshuffled in order to ease the third Projects of Common Interest (PCI) identification process in 2017. In view of the upcoming PCI selection process, it is necessary to guarantee a stable framework as well. Those projects already listed as PCIs, and for which a final investment decision has been taken, require no further re-assessment.

This new presentation highlights the main "boundaries" in the European system where projects complete each other to develop the transfer capacity of one corridor; or, conversely, where projects compete with each other, should the target capacity be lower than the capacity delivered by all of them. Other investment needs of pan-European relevance have in most cases only one project at stake, but they can have in principle the same level of priority; even if they are also of high strategic relevance for the development of the infrastructure corridors, they can be reviewed in a simpler manner, independently from all others. The regional reports and project sheets in this TYNDP package give further insight in the relation between these boundaries, identified investment needs, and proposed priority investments.

The main boundaries are as many main barriers to power exchanges in Europe. They obey a globally radial pattern: tensions on the grid occur between regions of Europe, where potential for RES is high (hydro and wind in Scandinavia; wind in Scotland, Ireland, to Spain and Italy; solar in Mediterranean countries) and densely populated, power consuming areas in between. These barriers appear mostly where geography has set natural barriers: seas and mountain ranges, more difficult to cross.

The **10 main barriers for power exchanges**, hence interconnection challenges, are:

- Wind development in Ireland and Great Britain will create high variations of power infeed on the two islands, inviting interconnecting them together further (1), and the two with the Scandinavian hydro-storage or to mainland Europe (2), (3), which represent both a large outlet for surpluses or a source for back-up capacity conversely.
- Further interconnection of Nordic countries and their hydro-storage, with mainland Europe, especially to mitigate wind infeed variations along the North Sea (4) and Baltic Sea (5) coasts.
- Interconnection of the Baltic States to Europe (part of 5), to secure their supply from the West.
- East and South interconnection of Poland with Germany, the Czech Republic and Slovakia (6), to increase market capacities.
- Interconnection of the Iberian Peninsula with mainland Europe (7), while providing appropriate synergies between the Spanish and Portuguese power systems, where most of the solar potential in Europe lies as well as a significant wind potential .

- Further interconnection of Italy with its neighbouring countries: to link the Italian RES capacities and load with the Alpine hydro-storage on the North frontiers, and to connect the Italian system and main islands to the heart of the European market, to the Balkans and North African countries (8).
- Further interconnection of South-East Europe with Central Europe, to allow for mutual support (9) nowadays hindered by a low capacity.
- Further interconnection across the Balkan peninsula (10), taking advantage of the high RES potential in the East (e.g. Romanian wind, Greek solar) to supply load centres in the West, from Serbia through Montenegro to Italy.

There exists an 11th boundary between the European ENTSO-E interconnected power system and its neighbours. **Europe could benefit from additional, cheap, generation surpluses at its outskirts, South and East**, and/or exchanging of RES generation in an unbalanced situation. This would increase the need for stronger interconnection downstream, on the concerned boundaries mentioned above.

Regarding internal German boundaries, the analysis of TYNDP 2016 shows that reinforcement of these does have large European benefits. The TYNDP 2016 therefore underlines the need for realizing the already planned internal German projects, which will resolve future internal bottlenecks. For the status of these projects, see the project assessment sheets.

No	Boundary
1	Ireland - Great-Britain and Continental Europe
2	Great-Britain – Continental Europe and Nordics
3	Nordics - Continental Europe West
4	Nordic/Baltic to Continental Europe East
5	Baltic integration
6	Central East integration
7	Iberian peninsula integration
8	Italian peninsula integration
9	South-East integration
10	Eastern Balkan

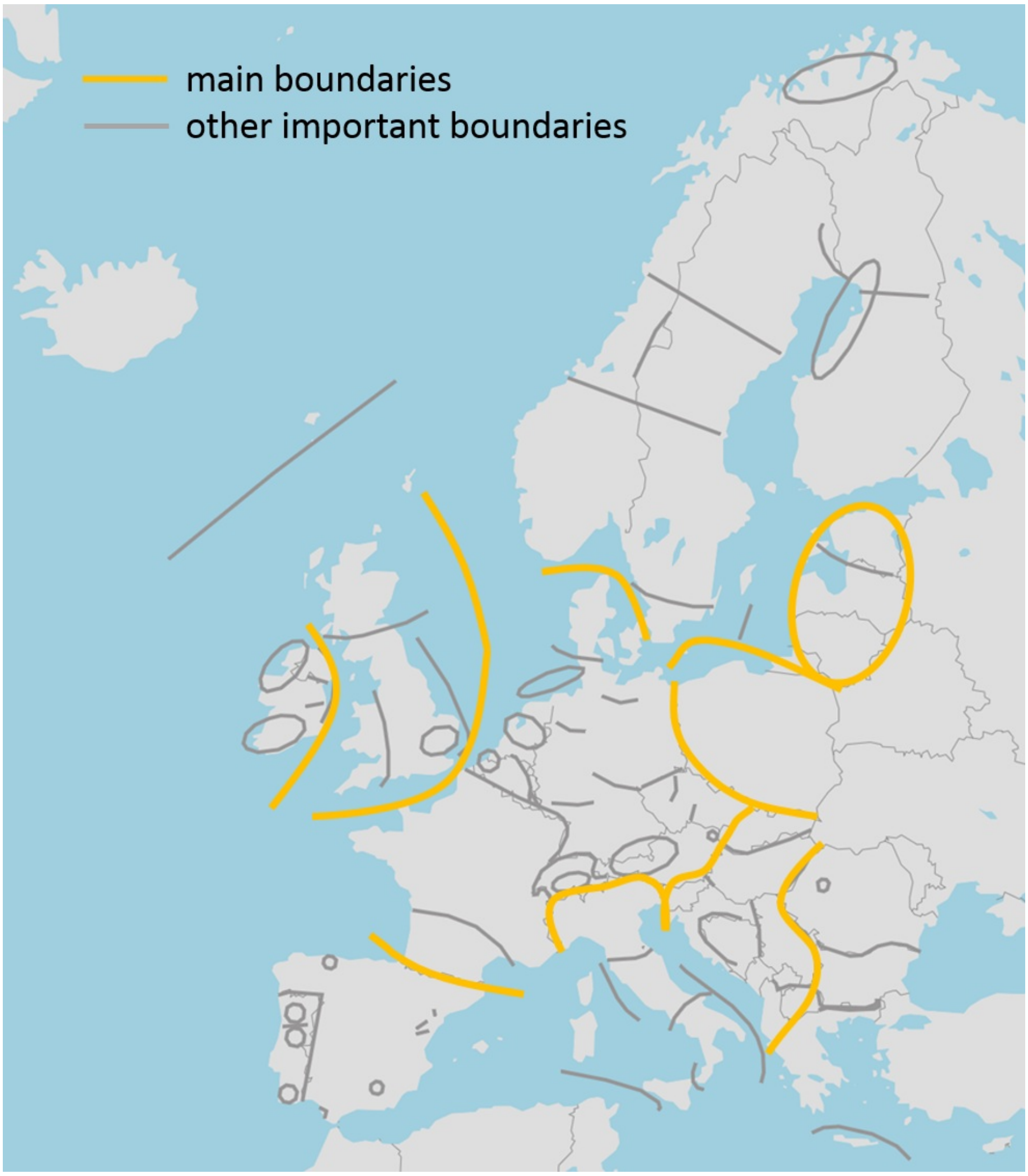


Figure 5 Investment needs and boundaries/barriers; 10 main ones (yellow) and several regional ones (grey)

The TYNDP project proposals address these 10 boundaries and barriers, as well as many more regional ones (see Figure 3). The TYNDP analyses give insight into the market/grid capacity enabled by these projects, as well sensitivities for these boundaries. The TYNDP project capacities added up **may be lower or greater than the target capacity that a well-integrated Internal Electricity Market would require**. As set forth in the Energy Union package, the optimal interconnection target capacity by 2030 shall "*take into account the cost aspects and the potential of commercial exchanges in the relevant regions*". This is specifically what the Cost Benefit Analysis (CBA) of the TYNDP deals with.

2030 targets for interconnection capacities

> “Notes that Europe’s energy system has evolved ... in particular, renewable energy sources have been developed across the continent; recommends, in this context, that the 15% target, based on installed capacity for 2030, should not stand alone, and that it should be assessed carefully and thoroughly to ensure that it is fit for purpose and is pertinent and feasible; asks ... to assess the setting of regional, complementary targets and to find better qualitative and quantitative benchmarks, such as trade flows, peak flows and bottlenecks, that highlight how much interconnection is needed." (European Parliament, ITRE, Dec/15)

Driven by RES development concentrated at a distance from load centres, and allowing for the required market integration, interconnection capacities should double by 2030 in Europe, on average. Discrepancies however, are high between the different countries and scenarios.

The proposed set of projects fulfils the 10% interconnection capacity goal (compared with the installed generation capacity for every Member State) by 2020, with one exception: Spain remains a critical concern in this respect, due to unique technical challenges in the area, and with reinforcement projects scheduled to be commissioned only by the middle of the next decade with enough political compromise.

For all four refined 2030 Visions, the TYNDP 2016 fine-tunes the interconnection target capacities for every main boundary by 2030 reported in the TYNDP 2014, based on additional TSO co-ordinated studies (see figure opposite). The interconnection level is optimal in this analysis when the societal economic benefits brought by an additional project fail to overcome its costs. This principle however, is complex to implement in practice, and the approach here considered is a simplified one as only Socio-Economic Welfare (SEW) is considered.

In spring 2016, a dedicated Interconnection Targets Expert Group was set up by the EC to provide guidance and explain how accounting for trade flows and costs may make interconnection targets by 2030. The right order of magnitude for reinforcement cost figures is relatively easy to appraise for every border; the main difficulty is a comprehensive appraisal of benefits (strictly financial and others) of projects.

In particular, the present CBA methodology is designed for an “energy only” environment, where the generation mix is harmoniously developed, and captures operation cost savings in generation in a completely competitive market without considering market agent’s strategies to optimize their project portfolio revenues; it must, however, be completed by capital expenditures savings in back-up generation capacity, especially in a context of high RES development and other benefits that can be difficult to monetize. The “capacity” and “hedging” value of interconnectors can be significant for islands or peninsulas. It is however difficult to appraise and it is only mentioned in the comments to the CBA of the concerned projects, beyond the strict CBA requirements.

Therefore, the TYNDP 2016 can only provide an order of magnitude regarding the interconnection target capacity per border by 2030, with a narrow range depending on the Vision. But it also supplies transparently all computational bricks useful to support the 3rd PCI selection process in 2017. In particular, for every boundary, the relation between annual SEW is given as a function of the increasing capacity (GTC) and can be compared with the annuity of capex and opex of projects.

Such optimal interconnections targets ensure that the corresponding investment in transmission is profitable for Europe. The grid capacity will differ from one place to another, depending on the local environment. Even with such a reinforced grid, there will, however, remain congestions from time to time (because the additional market convergence benefit is too small to justify an additional investment). Most of the time, power exchanges will use only part of the interconnection capacity, while bulk prices in neighbouring price zones converge (and losses are reduced thanks to the extra capacity). In a well-integrated Internal Electricity Market, it is economically sound that the grid is sized so that the load factor of every grid element is lower than 50%, though it sounds like a paradox (this simplification is used by many TSOs across Europe to dimension their grid). This way though, the grid can at once cope with the volatility of power exchanges (with from time to time very strong flows) and meanwhile mitigate the induced losses (thanks to the extra capacity and hence a lower resistance).

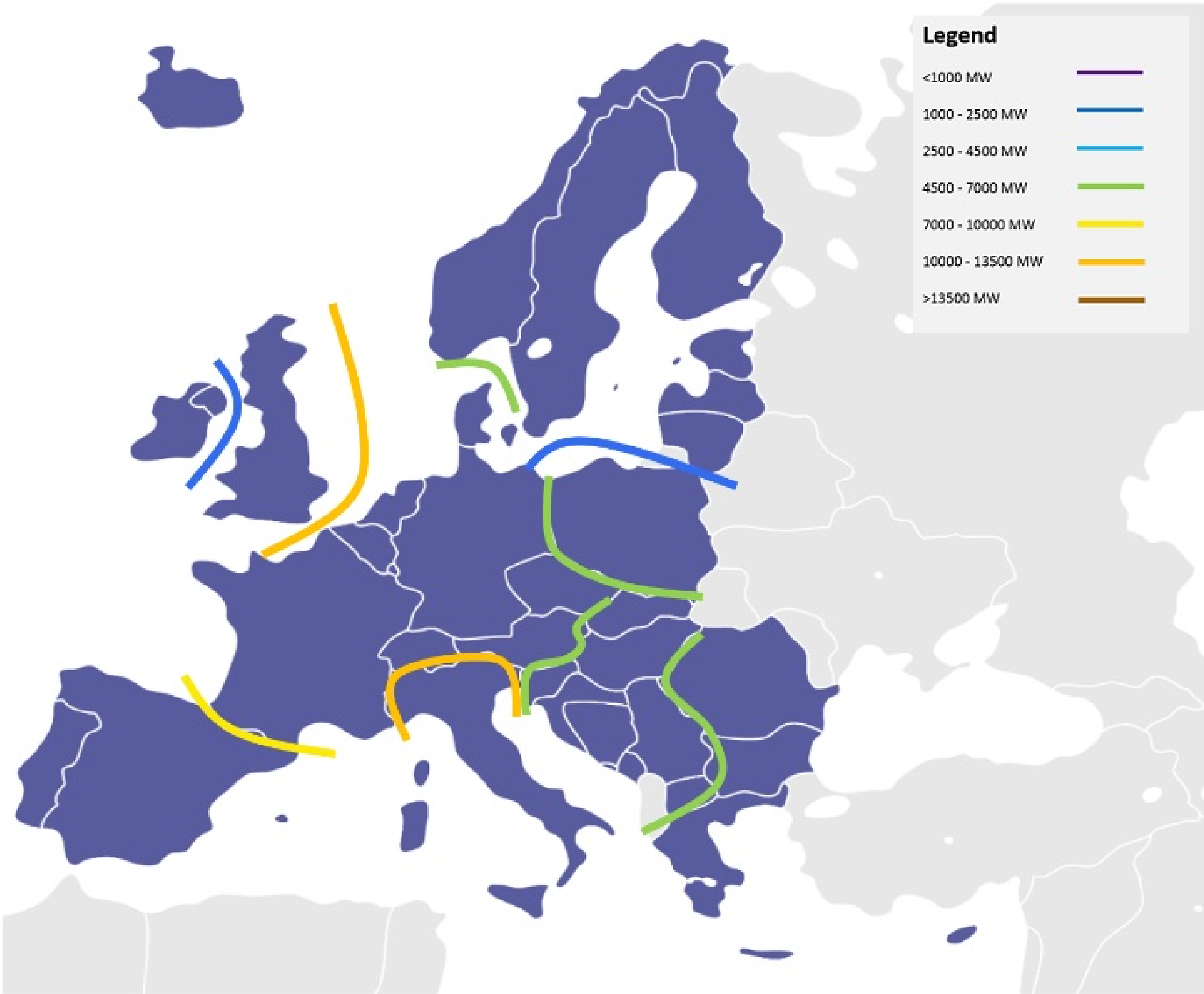


Figure 6 – 2030 Vision 1 target capacities

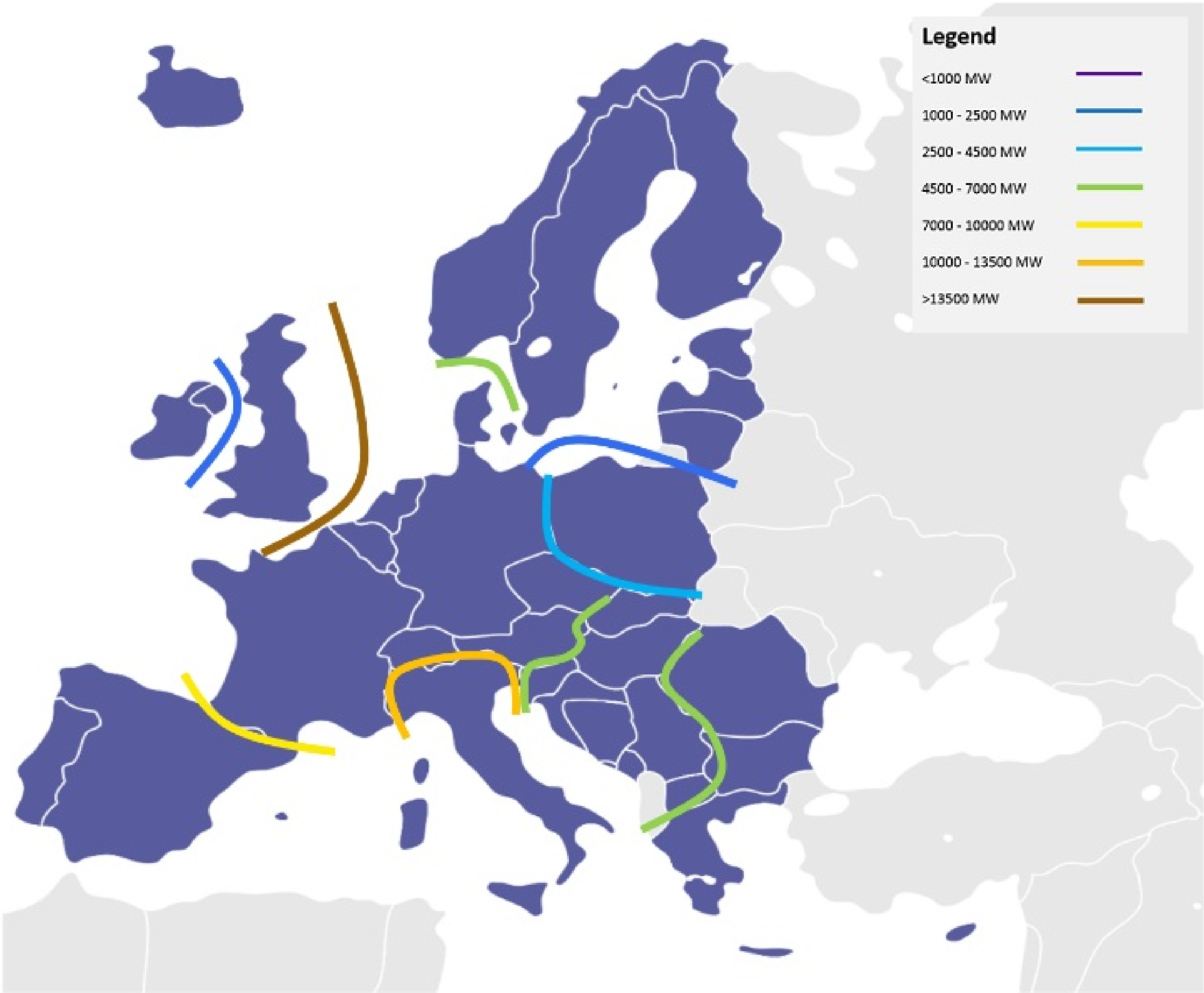


Figure 7 – 2030 Vision 2 target capacities

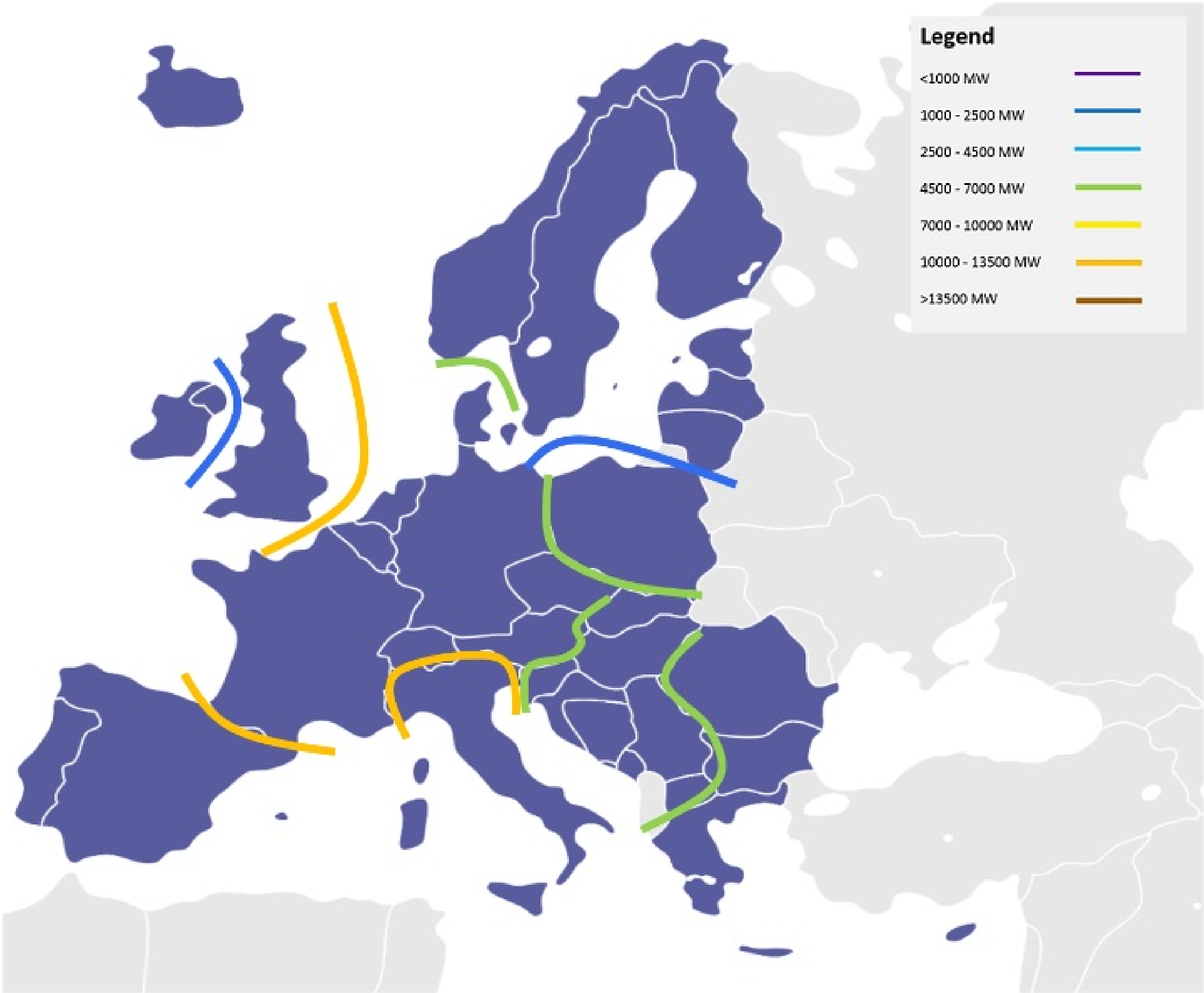


Figure 8 – 2030 Vision 3 target capacities

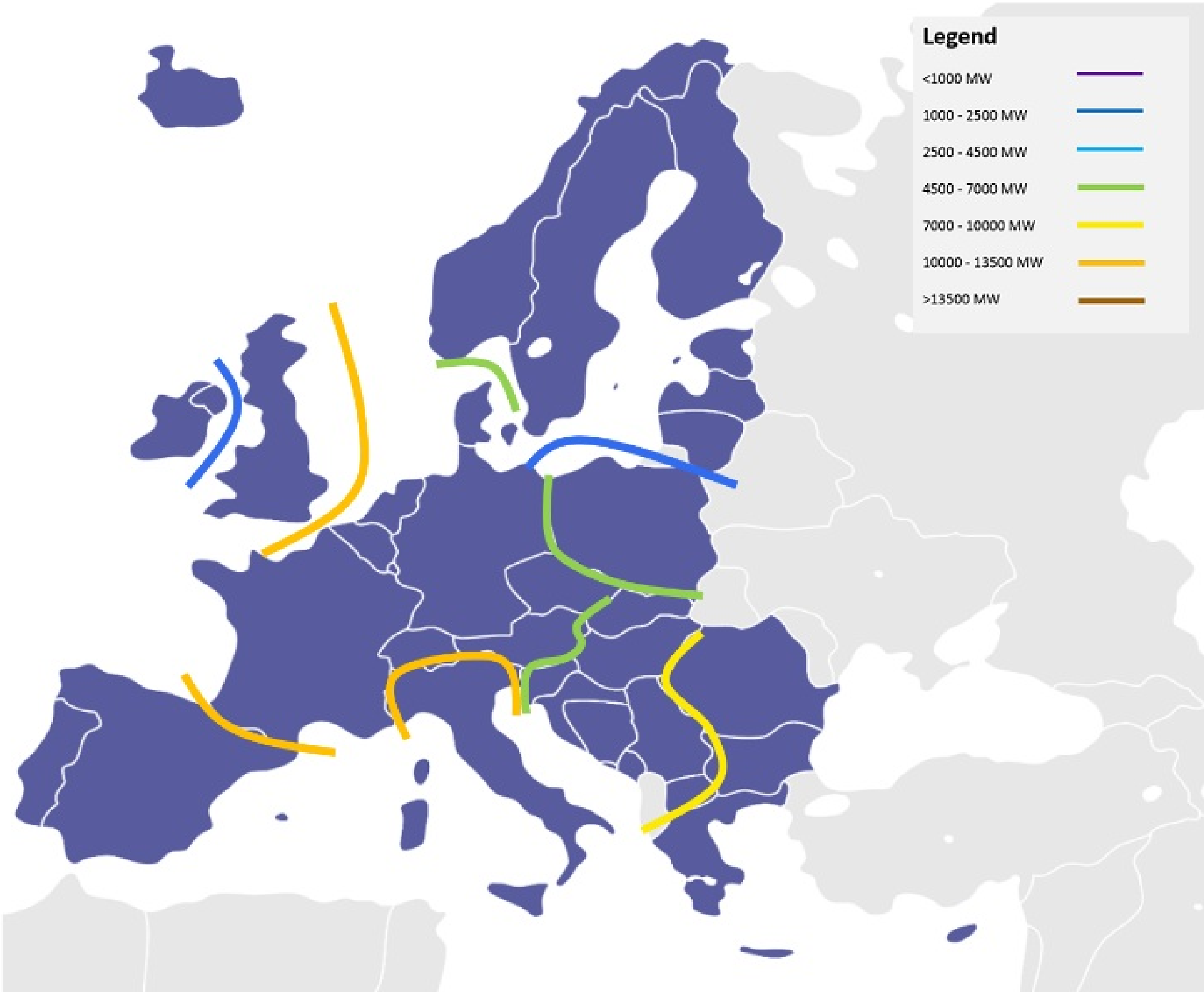


Figure 9 – 2030 Vision 4 target capacities

When comparing the four vision target capacities with the TYNDP grid capacities delivered (as assessed via the project CBAs), it gives a view on whether the TYNDP grid portfolio is adequate in all scenarios, part of the scenarios or, none at all.

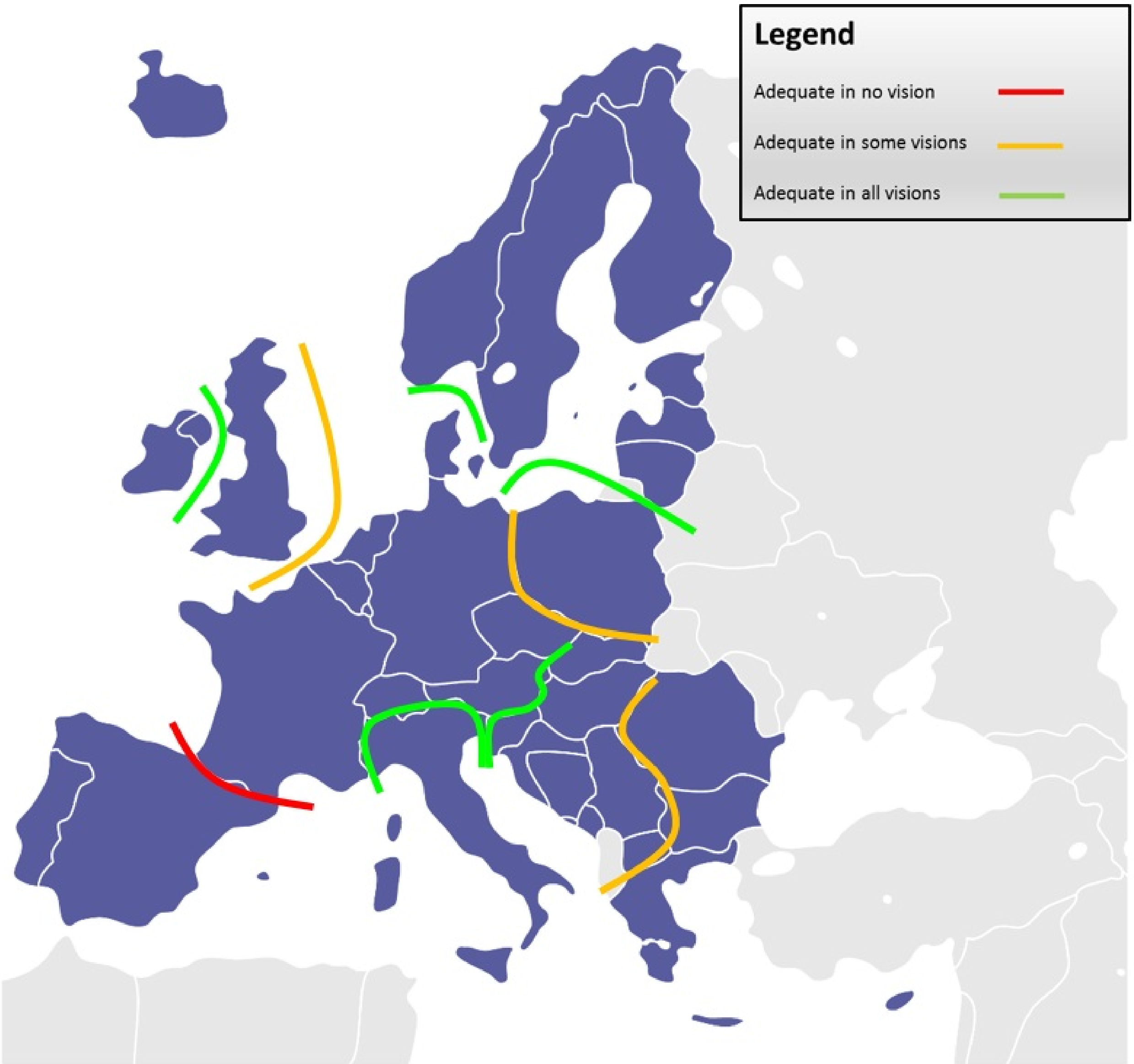


Figure 10 – 2030 Transmission adequacy

A resilient portfolio of tailor-made investment solutions

> "Future electricity grids will rely more on technologies that confer resilience and flexibility of operation than historical grids, so technology development must continue, even for relatively mature functions." *Richard Charnah, T&D Europe*

The TYNDP provides a resilient picture of reinforcements on transmission grids, confirming in 2016 the TYNDP 2014 project portfolio. Some exceptions exist, mostly "concept projects" that were in a very early phase in 2014 that have proved technically unfeasible since. Still, the TYNDP2016 process has continued analysing several long-term scenarios and planning cases, and identified new TYNDP project proposals in the Regional Investment Plans 2015, mostly tagged as 'future projects' in the CBA analysis.

To come to that conclusion, thousands of market situations considering practically all hazards that may affect the power system have been simulated and processed for every scenario. Frequent situations or rare ones resulting in particularly extreme flow patterns (e.g. peak loads in winter or summer, with extreme but likely low or high wind/solar generation) are then spotted. The grid's ability to withstand them is then tested, with possible remedial actions, and when these fail to solve the congestion it points at investment needs.

The complete grid modelling enables an accurate appraisal of every bottleneck and allows the most appropriate solution to be designed. To solve investment needs, TSOs have proposed tailor-made grid reinforcement solutions adapted to every specific situation. As a result, a large range of available technologies is implemented.

For 15% of the cases, upgrade of existing overhead lines can prove sufficient to achieve the required capacity increase with a limited impact on crossed areas. Increased grid transfer capability does not always match with increased network length thanks to restructuring; and when the network length increases, it is by 40% underground or subsea.

Conversely, DC technology is required to cross seas. In certain situations, it is also implemented onshore or to transport large amounts of energy on new interconnection corridors. These new DC lines set new operating challenges that TSOs are investigating, be it to ensure the safe operation of parallel AC and DC assets or to coordinate and optimise the use of several DC links to create an offshore grid across the northern seas.

Project designs thus resort to cutting edge technologies. Some of them are demonstrators of new technology and world premieres: the largest DC VSC equipment, the longest subsea DC interconnector, the longest AC cable route, DC and AC parallel operation, etc. are all part of the European grid in coming years.

Aside from the proposed extra high voltage investments, TSOs also contribute to the development of smart grids: the latest electronic tools and IT systems help optimise the operation of existing assets and especially monitor, forecast and control distributed RES and load management. The implementation of Dynamic Line Rating also appears as a project of pan-European relevance in this TYNDP 2016.

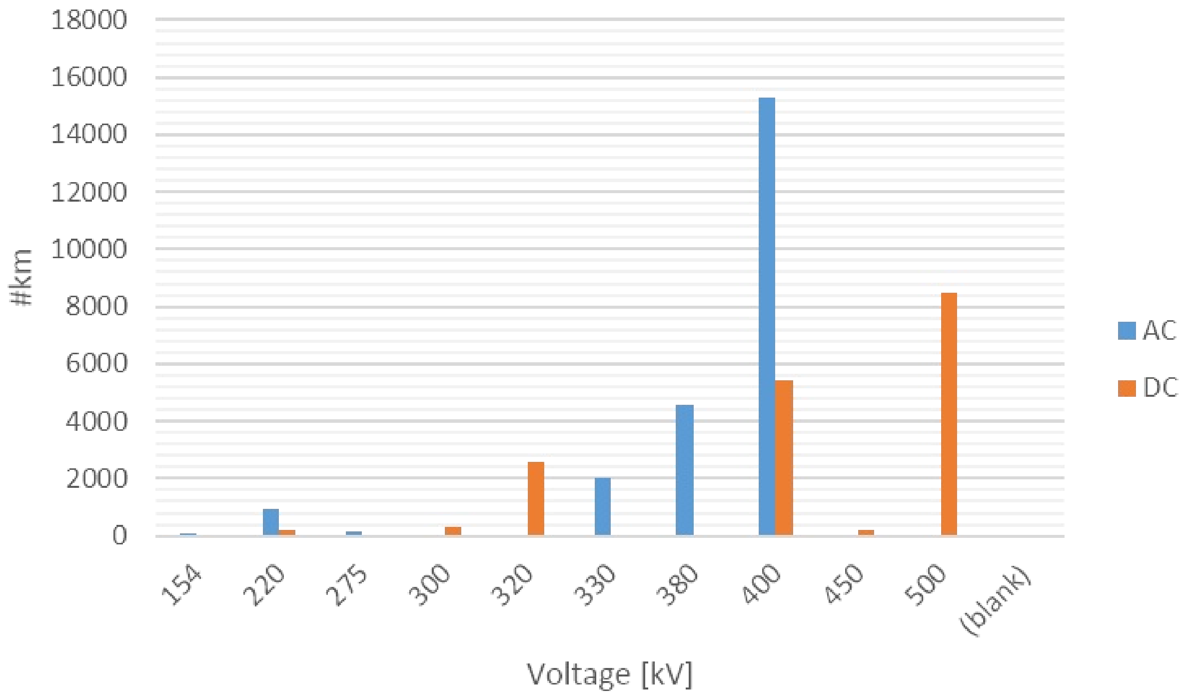


Figure 11 – TYNDP 2016 project portfolio – breakdown by technology and voltage

Figure 12 – TYNDP 2016 project portfolio – breakdown per technology and year of commissioning

Type of element	Number of elements (total)	Number of elements (new)
Overhead Line	248	159
Phase-Shift Transformer	7	5
Subsea Cable	49	45
Substation (incl. converters)	57	33
Underground Cable	15	15

Table 1 Overview of main elements

A positive environmental impact

> "Grids are the enabler of further renewable energy development, thus contributing significantly to the fight against climate change. I am an advocate for strong stakeholder cooperation on all levels of grid planning - from the TYNDP and PCIs to national grid development plans and local projects - because it does not only contribute to gaining public support, but also to the delivery of better projects for the environment." *(A. Battaglini, RGI, Nov/15)*

The project portfolio has **a positive environmental impact**. The grid has an indirect but important positive effect on CO2 emissions, as it is a prerequisite to the implementation of clean generation technologies. By either directly connecting RES, avoiding spillage or enabling more-climate-friendly units to run, the project portfolio contributes directly to up to 8% of the CO2 decrease by 2030, and indirectly drives decarbonisation by facilitating RES connection in an integrated European market.

Grid extensions foreseen in this plan represent an increase in the **total network length of less than 1%/yr.** The figure is relatively low, but a must to accommodate **the 1% to 2.5%/yr installed generation capacity growth rate** (depending on the scenario), on top of a transition of the existing fleet.

Moreover, one third of the new grid asset lengths are subsea cables and 15% are upgrades of existing equipment. TSOs optimise the routes in to avoid interferences with urbanised or protected areas as much as possible. In densely populated countries or where a significant share of the land is protected such as Belgium or Germany, this is a challenge. As a result, **less than 4% (resp. 8%) of the total routes of TYNDP projects cross urbanised (resp. protected) areas**, i.e. less than 2000 km (resp. 4000 km).

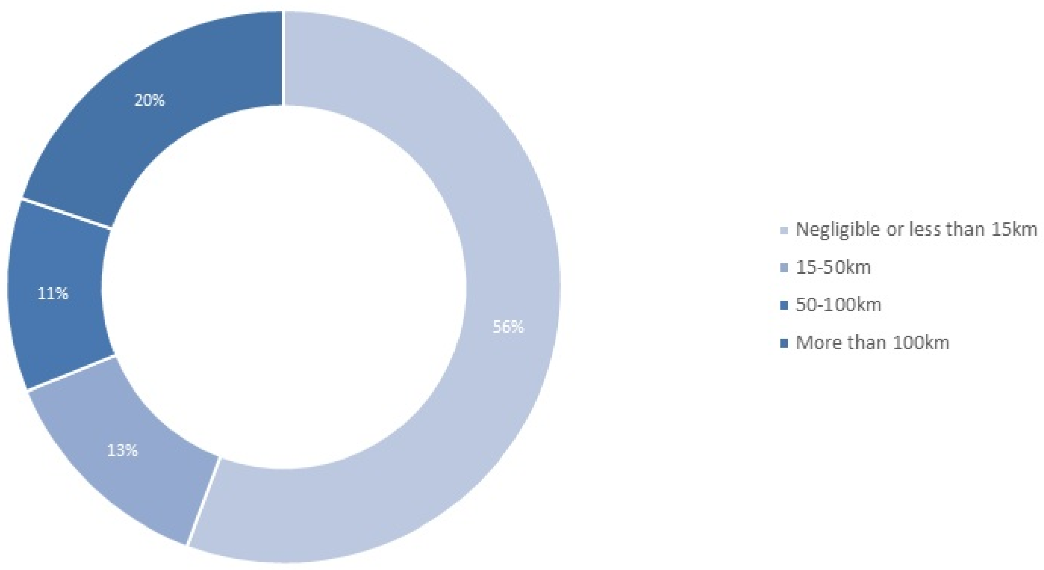
Transmission losses are not expected to vary significantly in the coming 15 years with the implementation of the plan as multiple effects will neutralise each other. On the one hand, building new transmission facilities or shifting voltage levels upwards reduces the overall electrical resistance of the network; on the other hand, the relocation of generation facilities further from load centres, specifically for wind or hydro energy, increases the transmission distance and system losses. HVDC interconnectors on average (and especially for long-distance projects) have a more substantial loss increase as compared to other TYNDP projects.

Projects of pan-European significance are hence key to making an energy transition in Europe possible, with a positive impact on the environment and minimum residual effect.

The energy transition is hindered by project commissioning delays. With still long authorisation procedures, completing grid development in time for RES integration is a challenge.

A key issue is to make the most complete information possible about transmission projects as easy as possible to access to European citizens that are directly affected by the construction of new lines, to foster buy-in for the new infrastructure and political support. In this respect, based on the suggestion of the Network Development Stakeholders Group, the TYNDP 2016 provides in the online interactive version of the project maps all project routes and the main protected or urbanised areas.

Environmental indicators of the CBA are present in each project assessment sheet. Besides, links to complementary information available locally (in national language) are provided when available, to make the project assessment sheets also useful for local consultation beyond PCI selection.



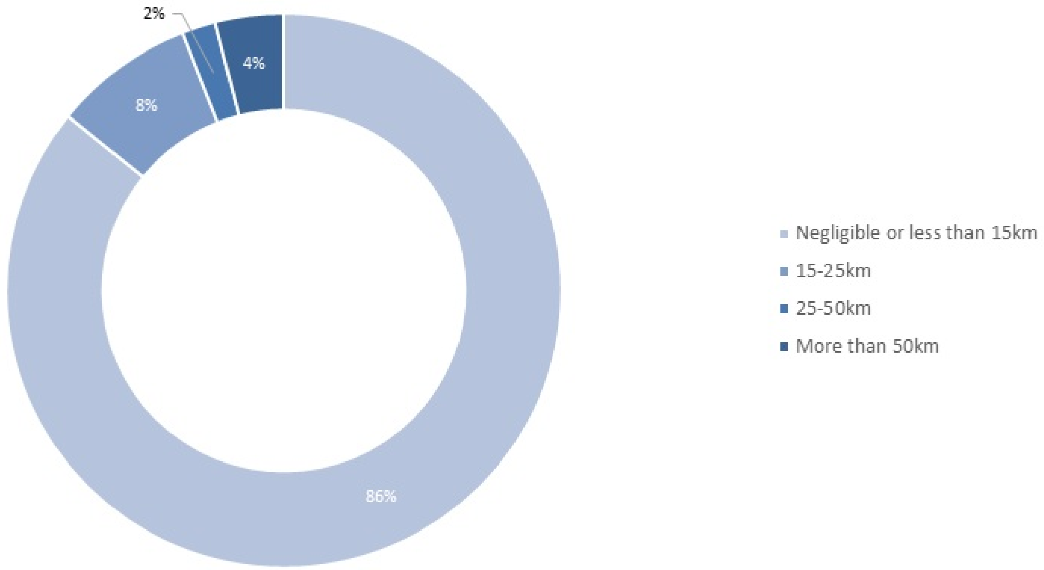


Figure 13 Breakdown of projects depending on their length across sensitive areas (top chart: crossing environmentally protected areas; bottom chart: crossing dense urban areas)

Energy transition requires grid, grid requires everyone’s support

> “The PCI label will sound great to a banker’s ear… if it was granted for a longer and stable period of time” *(P. Bernard, Friends of the Supergrid, Jun/15)*

The TYNDP 2016 ,unfortunately, confirms the trend identified in the previous TYNDPs, with moderate progress: about 25% of TYNDP investments suffered delays in the past two years (compared with 33% in 2014), though more are being rescheduled (22% now compared with 12% in 2014). TYNDP monitoring also shows that of the TYNDP2014 investments in a design or permitting stage two years ago, at present 20% are under construction, and 5% has been commissioned. Making the comparison with TYNDP2012, these levels are respectively 30% and 10%. Implementation monitoring also shows that of the TYNDP2016 investments presently in design or permitting phase, on average these items have faced a delay of one year since 2014, and three years since 2012.

The framework for Projects of Common Interest is promising but is only beginning to generate its effect and take momentum. It is still being implemented, with first annual feedbacks from EC to Member States about implementation and tuning. All or most PCIs now in the authorisation process appear to meet the 3,5-year timeframe set for getting all authorisations. Still, the alignment of national procedures for cross-border projects may require further harmonisation, as some authorisations may fall off the 3,5-year timeframe. Experience will show where inconsistency issues may require improvements in the future. It is also important to note that PCI best practices could be applied to national transmission projects which are crucial to the achievement of Europe’s targets for climate change, renewable energy and market integration.

Connecting Europe Facility, the European Bank for Investment and specific funds are ready to support project promoters. **Financing becomes less of a structural issue**, but can remain critical for some projects.

** ENTSO-E recommendation on the PCI selection process ** **A stable regulatory framework** is essential to ensure grid reinforcement can be completed in time. In this respect, the PCI 2-year review could be improved by focusing, aside from new candidates, on PCIs affected by a change of consistency or commissioning date (or pre-defined additional conditions). In other words, a PCI would keep its label as long as it stays on-track, securing the perspective of the concerned investors, which is the first key for success. In practice, PCIs post final investment decision would focus on construction, with a due reporting but sparing the resources needed for re-assessment. The second key is to foster a better understanding of why’s and how’s of projects and **support from local citizens and politicians.** Some project promoters developed **innovative solutions** to bring the project local credit: dedicated citizens’ jury, national parliament’s support, holistic area development scheme along the project route, crowd-funding of transmission projects… Every solution today depends directly on the project background. They are also being further structured through R&D projects (e.g. Best path, Best grid), debated at conferences and may soon reach maturity. Hence, ENTSO-E welcomes the creation of the **Copenhagen Infrastructure Forum:** it will be a key tool to share experience, suggest improvements to the legal framework, and catalyse the implementation of innovative project management. If energy and climate objectives are to be achieved, it is of utmost importance to get **political support on all levels.**

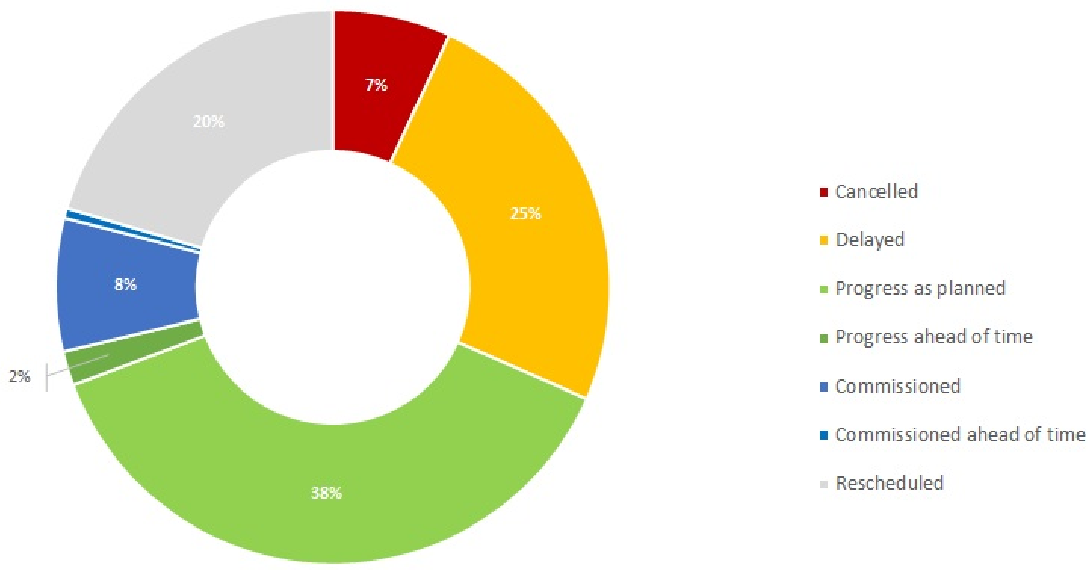


Figure 14 Evolution of TYNDP 2014 project portfolio

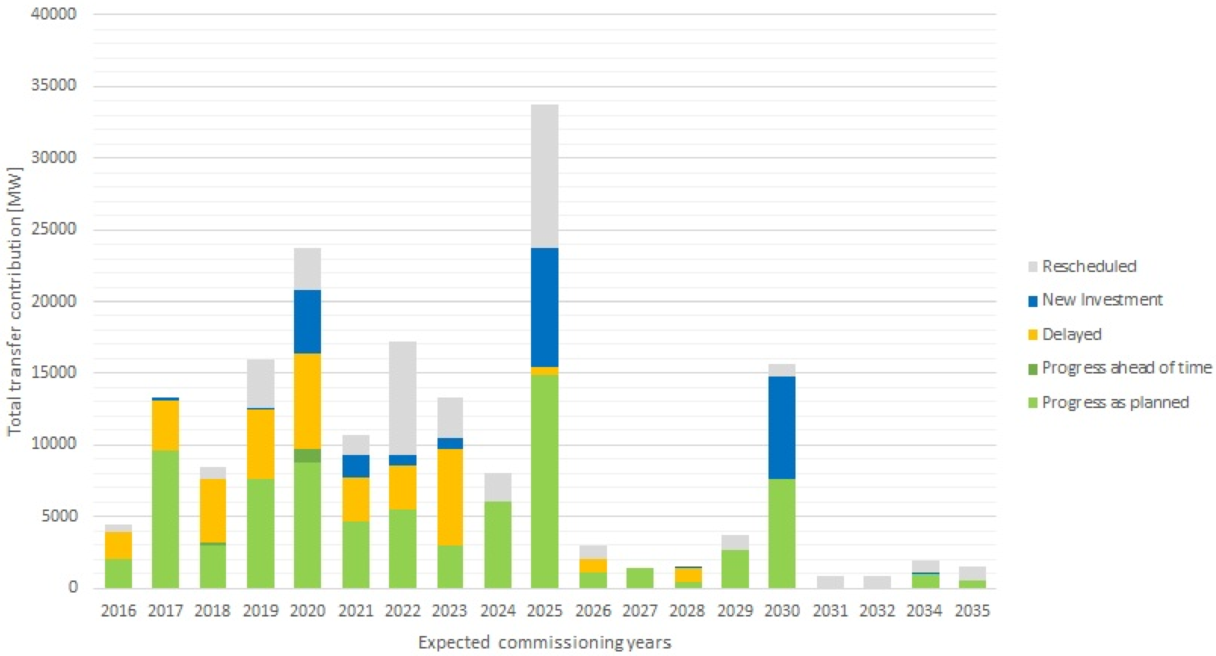


Figure 15 - Additional grid transfer capacities introduced by TYNDP investments in the coming decades; with a note of the present (2016) status of these investments

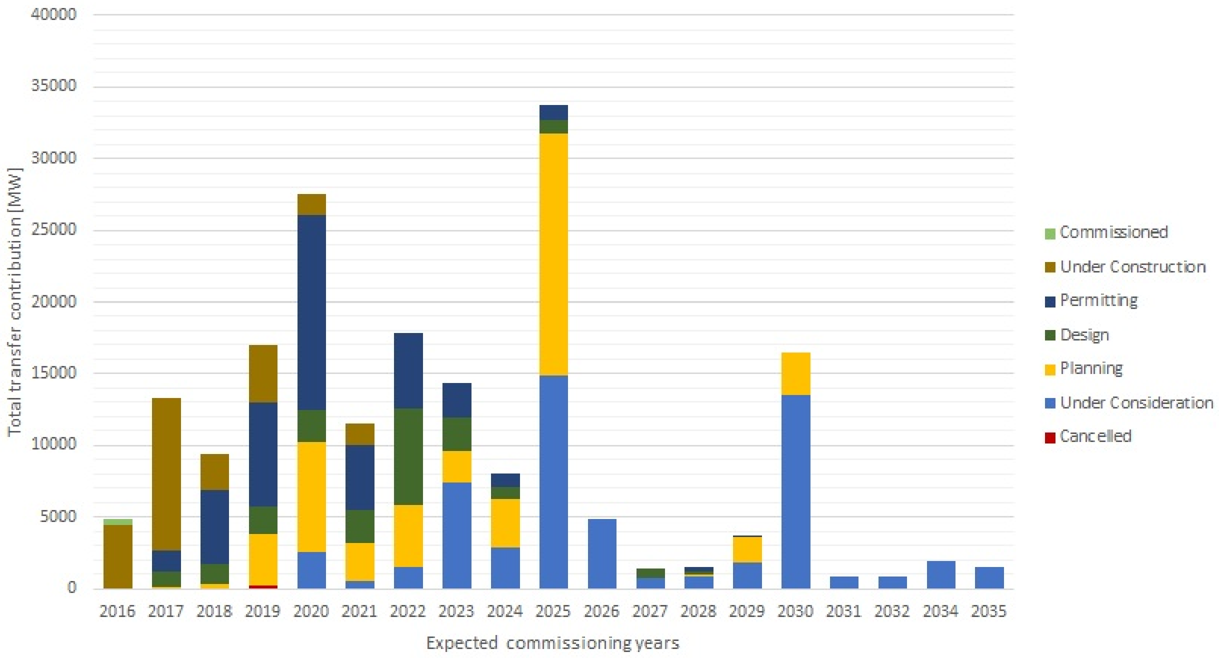


Figure 16 - Additional grid transfer capacities introduced by TYNDP investments in the coming decades; with a note of the progress since 2014

2030 system operation and market design are still to be invented

> “The traditional assumption that grid inertia is sufficiently high […] is not valid for power systems with high RES shares […]. Frequency dynamics are faster in power systems with low rotational inertia, making frequency control and power system operation more challenging.” *(A. Ulbig et al, ETH Zürich, Apr/14)*

45% RES generation by 2030 is a shift of paradigm for the power systems. Stronger interconnection will help Europe make the journey; however, it still leaves us with many issues to be addressed.

The volatility of RES infeed may result in steep variations of residual load. Added flexibility is required from all system components in operation: conventional generation units, as well as new Demand Side Response schemes or storage facilities. Appraising flexibility requirements falls beyond the possibility of the steady-state analyses of the TYNDP with one-hour timeframe resolution. The dynamic system behaviour under severe contingencies (and especially the frequency stability) would also require complementary studies.

The TYNDP 2016 Visions assume that appropriate means to control frequency and voltage will simply be operational by 2030 (e.g IT devices on solar and wind units to simulate inertia to control frequency despite a lower involvement of conventional generation), in part by implementation of pan-European network codes for grid connection, operational guidelines, enhanced TSO/DSO interfaces, and technology progress. This is however a factor likely to challenge the consistency of the generation assumptions[1].

From today’s situation towards 2030, as the connected capacity of RES increases, and as their contribution to the energy mix increases, the total inertia of the system will be reduced for extended periods of hours if no measures are implemented[2]. Today’s situation is close to the 2020 views provided in the above figures.

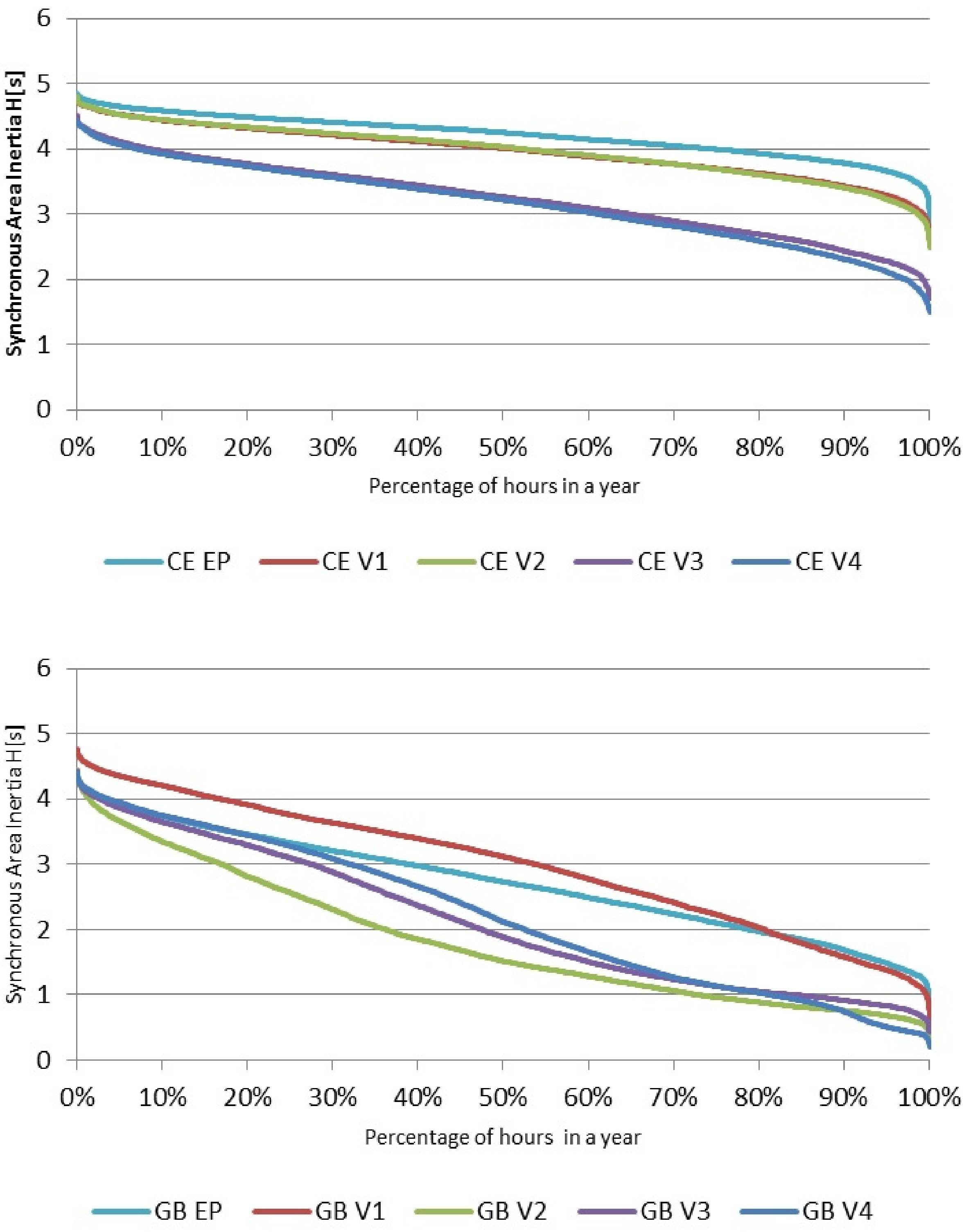


Figure 17 Percentage of hours in a full year where estimated inertia is above a given value. Synchronous area equivalent inertia H[s] is calculated on the basis of online generators capacity. Examples of Continental Europe and Great Britain synchronous areas. EP2020 and 2030 Visions: V1 "Slowest Progress"; V2 "Constrained Progress"; V3 "National Green Transition"; V4 "European Green Revolution"

Market simulations mimic an energy-only environment, where all generation means are assumed to be remunerated at the marginal market price. With RES penetration around 50% in the 2030 Visions, the energy-only market fails to pay back generation assets. A key underlying assumption in the TYNDP Visions is therefore that other mechanisms are at play to remunerate generation assets, such as subsidies, Capacity Remuneration Mechanisms or equivalent.

This means the TYNDP 2016 studies analyse only one part of the total economic value of the power sector. Therefore, the projects' socio-economic benefits computed according to the CBA methodology appear underestimated. This bias of the methodology is on the prudent side. This adds to other methodology assumptions which are already conservative: i.e. the marginal assessment compared with rather high reference capacity regardless of the commissioning time; or a set of less contrasting Visions; or a lower fuel and CO_2 prices assumption compared with TYNDP 2014, making the 2030 bulk power flow prices ranging from 50 to 75 €/MWh.

Complementary aspects of many project (its "capacity" or "flexibility" value, e.g. linked to remaining average price differences and price difference standard deviations) are displayed in their project assessment sheet, to enable a complete profitability evaluation in the 3rd PCI list selection debates.

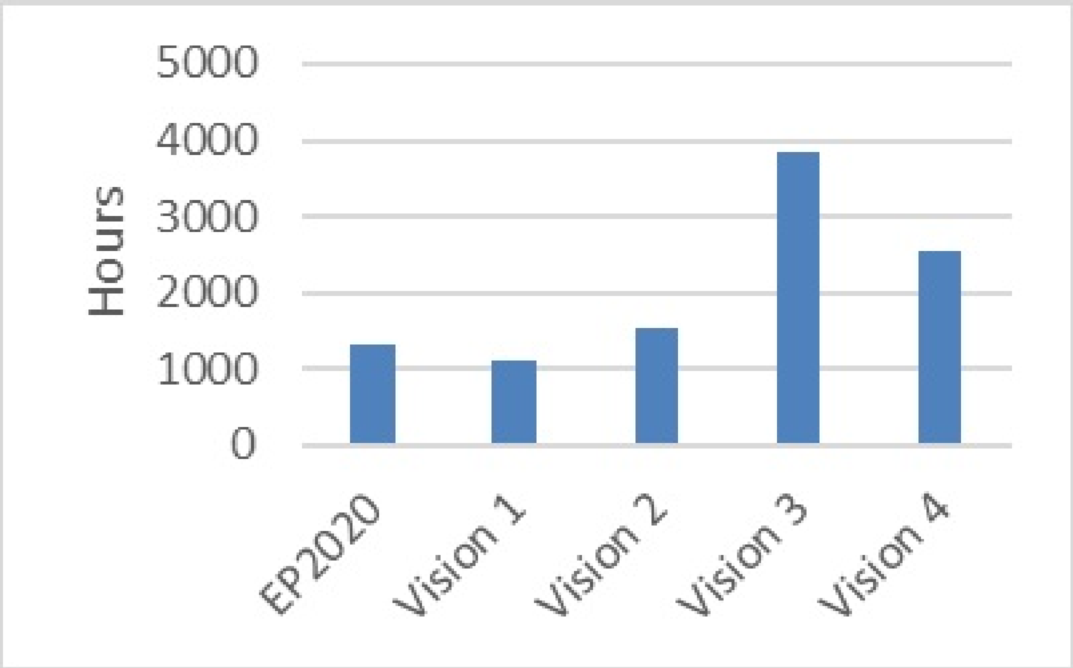


Figure 18 Number of hours in the 2030 Vision with at least one country having its generation dispatched at zero-marginal cost

Footnotes:

> 1. Potential power disruption triggered by a lack of flexibility with regard to adequacy studies (see Mid-Term Adequacy Forecast reports links). They call for appropriate reserve sizing and by exception for additional interconnection capacity. ↩

> 2. See the Viability of Energy Mix Insight Report for more insights on the technical and economic challenges and what solutions can be implemented to tackle them link ↩

The TYNDP 2018 is already on the way

> “What we assume today sets the frame under which the future is analysed. This is the reason why ENTSOG encourages all stakeholders interested in the future gas and electricity infrastructures and in scenario development to participate in the ENTSOs scenario development process.” *(Jan Ingwersen, ENTSOG General Manager, 12.05.2016)*

An international benchmark in 2015 showed that the European TYNDP stands unique world-wide in terms of number of TSOs collaborating, total number of customers served, methodologies to tackle long-term challenges, and transparency of data and process.

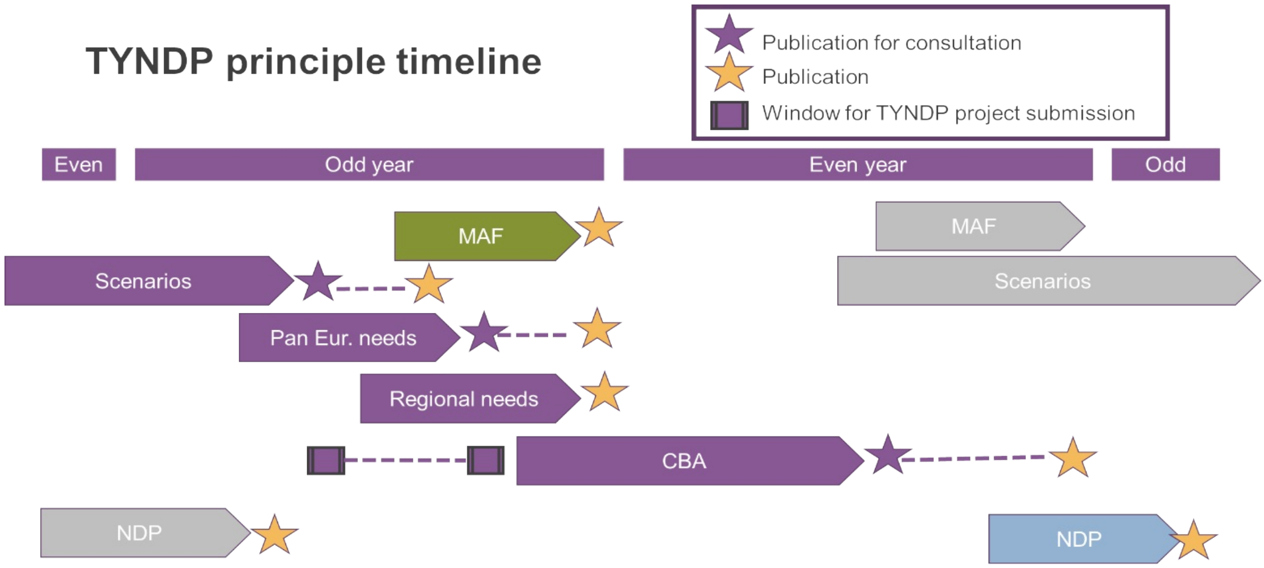
Still, the TYNDP is a living object, bound to evolve to meet stakeholders’ rising expectations. For example, scenarios storylines will have to answer the still open questions about power system operation and profitability issues that are today answered in an overly simplified manner; market modelling will also evolve consistently with rising concerns about the Security of Supply (SoS) or increasing Demand Side Response (DSR).

The feedback from the 3rd PCI list selection process in 2017 will also be essential.

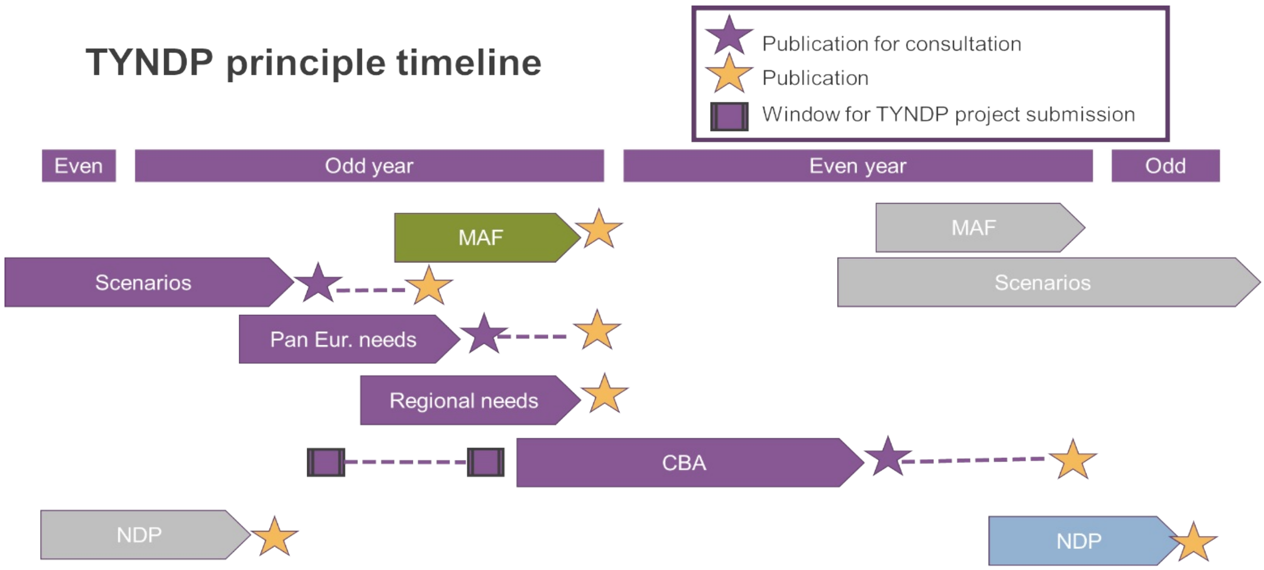
The scope of the TYNDP 2018 can already be outlined. It has been discussed in the Network Development Stakeholders Group. All stakeholders were invited to contribute to it in the consultations organised by ENTSO-E in 2016[1]:

- The two ENTSOs join forces to propose a combined process (scenario building, milestones) to deliver their respective TYNDPs in two-year time. An interlinked gas and electricity modelling shall be finalised in 2016.
- The TYNDP shall more than ever focus on identifying longer-run pan-European relevance system needs (beyond 10-15 years).
- The TYNDP will also feed the PCI selection process, by supplying CBA of projects expected to be commissioned in the decade or so (hence focusing on 5-10 years horizons).
- The scenario building starteds in May 2016, with a consultation on study horizons and scenarios outline. Recommendation from ACER and EC shall be complied with, especially the articulation with the Mid Term Adequacy forecast by 2025), and the reference to an EU scenarios for 2030. In order to maximise output and resources utilisation, ENTSO-E recommends to explore new 2040 scenarios and corresponding investment needs; and make projects CBA assessments for two mid-term study years (2025, 2030). The “Scenario development report” will be compiled and consulted in the first half of 2017.
- The identification of system needs will rely basically on pan-European market-studies (to derive target capacities, but also indicators of system inertia, ramps, adequacy issues, etc.), joined with regional analyses, in particular regional network studies (to characterise better every need, possibly analyse the evolution from ten-year to longer run horizons, and possibly propose reinforcement concepts). The “identification of system needs” package (one pan-European report and Regional Investment Plans reports) shall be compiled and consulted by the end of 2017.

- The CBA is updated in 2016, with a first draft put in consultation by ENTSO-E in Spring and will be submitted to ACER and EC later for validation and implementation for the TYNDP 2018.
- Subject to the dedicated EC guidelines, ENTSO-E proposes to organise two windows for project promoters to ask for TYNDP assessment, one in June 2017 (based on which the reference grid will be set up), and one in late 2017 until early 2018, before the end of the assessment phase in June 2018.



TYNDP principle timeline



System needs identification
Pan European report and Regional Investment Plans

User's Guide to a new, updated and enriched TYNDP for electricity

> "Make it more synthetic, easier to read, and all-in-one!" *(practically, all surveyed TYNDP stakeholders)*

What is the TYNDP, and what is its role in the European energy policy governance?

Grid development is the core instrument for achieving the Energy Union goals. All Europeans aspire to more security of supply, affordable energy prices and sustainable development.

The 10-year network development plan (TYNDP) that ENTSO-E publishes every two year presents how to develop the power grid in the next 15 years so that it can effectively contribute to achieving these different and sometimes competing goals.

The TYNDP is the outcome of a two-years process, starting with the development of scenarios or visions of how the European power system might look in 2030. Over 200 experts Europe-wide carried out regional exploration studies[1], pan-European analyses and assess projects to reinforce the grid submitted throuh a European wide call for candidatures .

The present publication complies with the requirements of Regulation (EC) 714/2009, which tasks ENTSO-E with developing a non-binding Community-wide 10-year network development plan, aimed at providing a vision of the extra-high voltage grid in 10-15 year time; and Regulation (EU) 347/2013, making the TYNDP the sole basis for the selection of PCIs.

What is the link between the TYNDP and the selection of PCIs?

The Regulation (EU) No 347/2013 that the PCIs are selected from the TYNDP list of transmission and storage projects. It is the European Commission and not ENTSO-E who selects and adopts the list of PCIs. The PCIs follow a separate process from that of the TYNDP. [2]

Annex III 2(3) of Regulation (EU) 347/2013 on guidelines for trans-European energy infrastructure stipulates that "…for all … Union lists adopted, proposed electricity transmission and storage projects … shall be part of the latest available 10-year network development plan for electricity, developed by the ENTSO for Electricity …"

This means that a promoter willing to have a project labelled as a PCI first needs to apply for the project to be included in ENTSO-E's TYNDP. For example only projects which are listed in this TYNDP 2016 will be considered by the Commission for its 2017 PCIs list.

Regulation (EC) 714/2009 on conditions for access to the network for cross-border exchanges in electricity -defining the ENSTO-E legal mandates- gives to the TYNDP a wider scope: to provide a transparent picture of the European electricity transmission network to support decision-makers with regard to grid investment at regional and European level.

The PCI process is led by the EC.

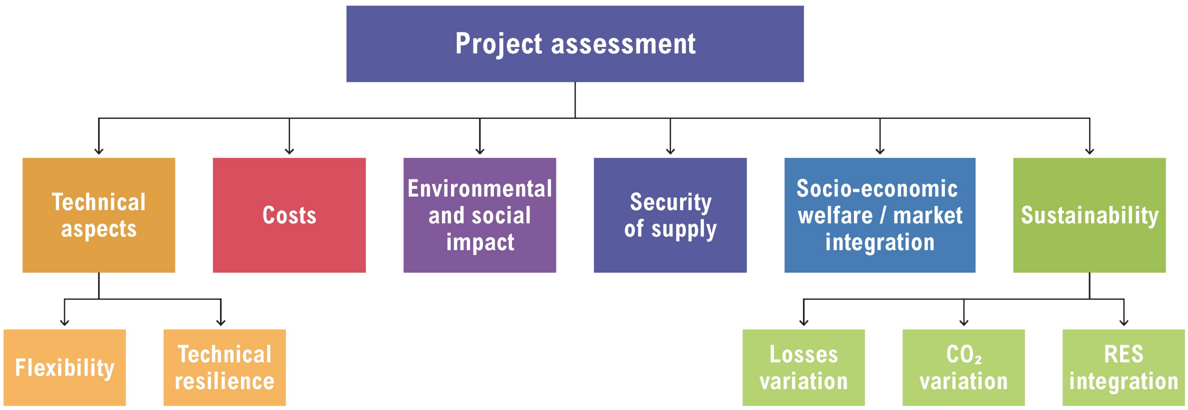
Please visit the EC website for information on how to apply for the PCIs.

How are projects assessed?

Each project included in the TYNDP is assessed using the pan-European CBA methodology. As such the benefit of each TYNDP project is assessed against nine indicators ranging from socio-economic welfare to environmental impact.

Transmission projects are by their nature multi-purpose. Originally, the main goal of cross-border electricity interconnections was to contribute to security of supply. Interconnectors were built to allow for mutual support in case of supply disruptions, thereby ensuring the reliability of electricity supply. Their role in improving social welfare has received growing attention over the last 20 years. More recently, and given the ambitious renewable-energy and CO2 targets of the EU, the integration of electricity from RES and CO2 mitigation appear as new motives for transmission projects. The majority of TYNDP projects contribute to all indicators, proving this multi-purpose characteristic of transmission projects.

The scheme below shows the main categories that group the indicators used to assess the impact of projects.



Some projects will provide all the benefit categories, whereas other projects will only contribute significantly to one or two of them. Other benefits, such as benefits for competition, also exist. These are more difficult to model, and are not explicitly taken into account.

The benefits indicators are:

- B1. Improved security of supply (SoS) is the ability of a power system to provide an adequate and secure supply of electricity under ordinary conditions.
- B2. Socio-economic welfare (SEW) or market integration is characterised by the ability of a power system to reduce congestion and thus provide an adequate GTC so that electricity markets can trade power in an economically efficient manner.
- B3. RES integration: Support to RES integration is defined as the ability of the system to allow the connection of new RES plants and unlock existing and future “green” generation, while minimising curtailments.
- B4. Variation in losses in the transmission grid is the characterisation of the evolution of thermal

losses in the power system. It is an indicator of energy efficiency and is correlated with SEW.

- B5. Variation in CO2 emissions: is the characterisation of the evolution of CO2 emissions in the power system. It is a consequence of B3 (unlock of generation with lower carbon content).
- B6. Technical resilience/system safety is the ability of the system to withstand increasingly extreme system conditions (exceptional contingencies).
- B7. Flexibility is the ability of the proposed reinforement to be adequate in different possible future development paths or scenarios, including trade of balancing services.
- S.1. Environmental impact characterises the project impact as assessed through preliminary studies, and aims at giving a measure of the environmental sensitivity associated with the project.
- S.2.Social impact characterises the project impact on the (local) population that is affected by the project as assessed through preliminary studies, and aims at giving a measure of the social sensitivity associated with the project.

Detailes explanations about each of the indicators and the way costs are taken into acount are available in the [ENTSO-E Guideline for Cost Benefit Analysis of Grid Development Projects] (https://www.entsoe.eu/Documents/SDC%20documents/TYNDP/ENTSO-E%20cost%20benefit%20analysis%20approved%20by%20the%20European%20Commission%20on%204%20February%202015.pdf). Important information relating to the CBA can be found in:

- Cost Benefit Analysis Methodology – Frequently Asked Questions, and
- Cost Benefit Analysis Methodology – Key Issues

[both available on this page] (https://www.entsoe.eu/major-projects/ten-year-network-development-plan/CBA-Methodology/Pages/default.aspx)

What is new in the TYNDP 2016?

The TYNDP 2016 builds on the 2014 release, paving the way to the Energy Union 2030 goals set up in October 2014; accounting for the feedback received from stakeholders, especially DG ENER and ACER through consultations, public workshops, bilateral meetings and regular meeting of the Network Development Stakeholder Group (NDSG); and, on this basis, further improving methodologies and contents. Notwithstanding the usual analyses, from investment needs identification to transmission adequacy assessments, the main improvements are:

- five scenarios are investigated, with four 2030 “Visions” comparable in main storyline to those of the TYNDP 2014 but refocused to the EU 2030 goals, updated with various evolutions, and designed with new methodologies; as well as a new 2020 “Expected Progress” scenario.
- Thanks to dedicated public workshops, the CBA methodologies have been complemented with more transparent rules to define the reference grid for projects assessments.
- The TYNDP 2016 projects list has been set throughout a public process from March to October 2016 under the aegis of the EC, and the active supervision of the NDSG, acting as ethical committee[3].
- The NDSG has also suggested making project assessment sheets more relevant to local communities, with maps of every project in its local environment and links to complementary national information.
- Project promoters have been invited to complete the ENTSO-E CBA results with their own information and comments to build self-supporting projects assessment sheets and better support the establishment of the 3rd PCI list.

- In addition, prior to investigating grid development issues, power system profitability and operational concerns by 2030 are analysed in a dedicated section of the report.

Although the TYNDP remains a heavy package in its entirety, every page or section is meant to be read stand-alone, and the reader is invited to browse the TYNDP webpage, flip through the reports and focus on the parts that trigger his or her interest.

What is in the TYNDP package?

The core of the TYNDP package is the result of the assessment of each transmission or storage project in Europe. See the section below “How to read a project sheet” for more details on this.

The TYNDP and the economic and technical studies performed to produce it generate a great quantity of valuable information on the future of the European power system. Along with the project assessment themselves, these results form the basis of the “TYNDP package” which Executive Summary you are reading now. This package is also composed of several insight reports which provide further regional analysis for key areas and allow to go further on the topics described below.

Stakeholder engagement

The TYNDP is a collective exercise. The quality of its output very much depends on ENTSO-E's ability to engage as early and as extensively as possible with all parties that have an interest in how the power grid is designed. Learn how ENTSO-E did it in 2016 and how it plans to increase participation in 2018.

Future system perspectives

Where does one start to plan network development 15 years ahead? How to make sure the assumptions used are realistic and at the same time future-looking enough? How to broaden the scope of possibilities but maintain a sufficient level of feasibility? Learn how long-term grid planning is done in the TYNDP.

A push for Projects of Common Interest

Why does Europe need an infrastructure push even with more local generation, storage and demand response? Is European regulation on infrastructure delivering its promise? What could be done differently to ease the building of priority projects?

Technologies for transmission system

Current advances in technology offer project promoters many opportunities to implement new solutions to cope with future network development, that is defined in the TYNDP. Together with current technologies, innovative technologies will be incorporated with the existing infrastructure. These technologies have their own learning curves and innovation cycles. Project promoters, regulators and policy makers need to understand something of each technology and their availability by the time of project development.

Viability of the energy mix

The energy mix has been and is facing significant changes accross Europe, with a signficant increase of production of electricity from renewable sources. While it leads to significant reduction of CO2 emissions of the power sector, it creates some additional challenges both from the technical and economic point of view, which are described further in this Insight Report.

The link between system adequacy and the TYNDP

Are there risks to Europe's pan-European adequacy in the next 5 to 10 years? Why is it important to assess adequacy at a pan-European scale? What methodology is ENTSO-E using and does it cater for the rapid change in Europe's generation mix?

Data and expertise as key ingredients

The TYNDP is an open process. This report will give you the list of data sources and tools used by the ENTSO-E experts to make the TYNDP and what you can freely access to support your own research.

Focus on the Nordic and Baltic Sea

Looking at what is driving grid development in the Nordic and Baltic Sea region: integration of the Baltic power systems, enabling North to South power flows? Impact of planned nuclear decommissioning in Sweden and Finland?

North Seas - regional planning

What congestions is the TYNDP tackling in the North Seas region? What progress for the North Sea Offshore Grid? What about a new long term West-East corridor?

North-South interconnections in Western Europe - regional planning

How to plan a grid to manage the connection of large renewable plants in the North and in the South? How to move large quantities of renewables accross long distances? See how the energy transition is a game changing network development in Western Europe.

North-South Interconnections in Central-East and South-East Europe

Building power bridges between Eastern and Western Europe; relieving the bottlenecks in Central Europe; see what grid development the Central East and the South East regions are facing.

Baltic Synchronisation

How to integrate further the Baltic countries in the European power system? What about the desynchronisation with the Russian power system? What infrastructure solutions for a secure and competitive Baltic power system? What other ENTSO-E publications are necessary to get a full picture?

The Cost Benefit Analysis Methodology and other related documents

The TYNDP builds on other documents which are published along the two years process. These documents are therefore not part of this final TYNDP package, but are necessary to get a full picture and dive into how ENTSO-E obtains the TYNDP results.

As requested by the Regulation (EU) No 347/2013, ENTSO-E elaborated a Cost Benefits Analysis (CBA) methodology to assess the transmission and storage infrastructure projects included in the TYNDP (see section above on projects assessment).

The CBA was drafted by ENTSO-E after consultation with stakeholders. It was then sent to ACER and the European Commission for opinion and to member states for information. Following the opinions received, the CBA methodology was revised and finally adopted by the Commission in early 2015.

The Scenario Development Report:

This Scenario Development Report (submitted to public consultation in summer 2015) explores possible future situations of load and generation, interacting with the pan-European electricity system. These scenarios are the baseline on which TYNDP2016 projects have been assessed. The report aims at providing insights on how the scenarios have been developed and how infrastructure needs are linked to choices in future energy policies.

The Regional Investment Plans

The six ENTSO-E Regional Investment Plans were developed from September 2014 to June 2015 as part of the TYNDP 2016. These reports include the main infrastructure challenges and needs of every region in Europe by 2030. They were consulted during summer 2015 and the final versions can be accessed below.

- Regional Investment Plan 2015 North Sea region — FINAL
- Regional Investment Plan 2015 Continental South West region — FINAL
- Regional Investment Plan 2015 Continental South East region — FINAL
- Regional Investment Plan 2015 Continental Central South region — FINAL
- Regional Investment Plan 2015 Continental Central East region — FINAL
- Regional Investment Plan 2015 Baltic Sea region — FINAL
- TYNDP 2016 – Consultation review of Project Candidate list and Regional Investment Plans 2015

How to read a project assessment sheet?

Project sheets contain everything there is to know about each transmission or storage project in Europe which applied to the TYNDP. You can access to all project sheets at once, or visit ENTSO-E's interactive map and click on any project to access its project sheet.

Each project sheet contains the following information:

- A general description of the project, and a map
- Information about each investment in the project, including the length of transmission line, the contribution of the investment to the project gross transfer capacity, the current status of the investment, and the status in previous TYNDPs.
- Information about which investment needs are fulfilled by the project
- Detailed results of the Cost Benefit Analysis, as well as an explanation of how to interpret these

results.

Footnotes:

[1]. See Scenario Development Report 2015, providing the detailed description of the TYNDP 2016 scenarios; and the six Regional Investment Plans 2015, depicting more thoroughly the various investment needs for grid development in the coming future. link ↩

[2]. In total 172 transmission projects have been submitted and found compliant with the EC's draft guidelines, of which 15 were also promoted by non-ENTSO-E members. link ↩

Annex - TYNDP boundaries

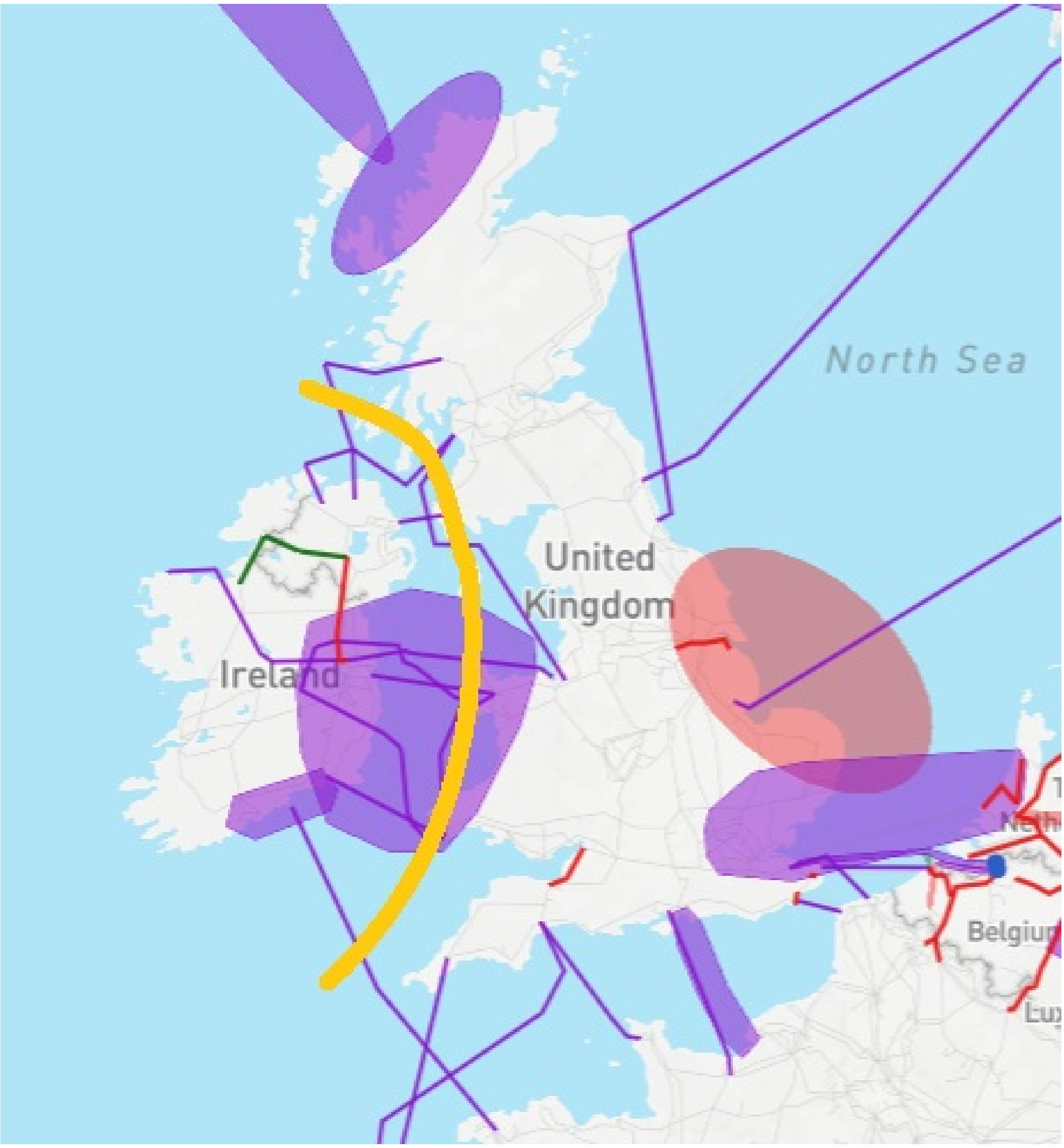
- Ireland - Great-Britain
- Norway and continent - Great-Britain
- Nordic - mainland West
- Nordic/Baltic to Continental Europe East
- Baltic states integration
- Central East integration
- Iberian peninsula integration
- Italian peninsula integration
- South-East integration
- Eastern Balkan border

Ireland - Great-Britain and Continental Europe

Stronger interconnection of the Irish system with Great Britain and Continental Europe.

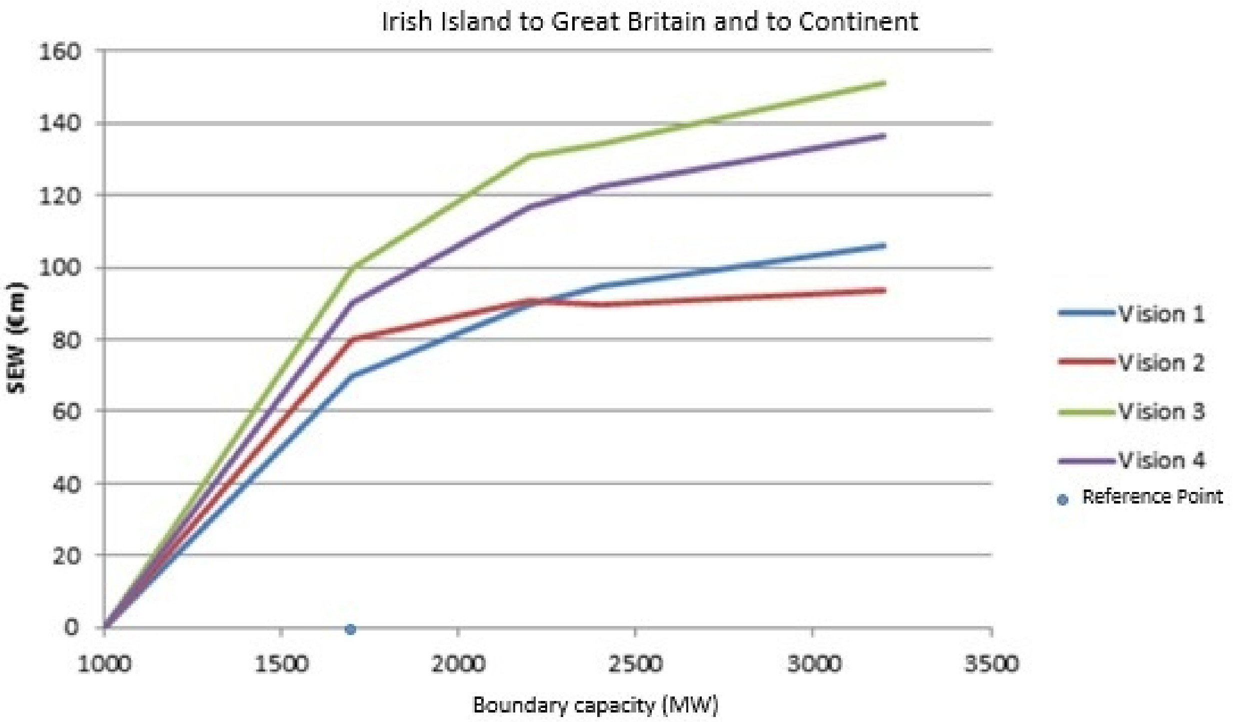
Two 500 MW HVDC interconnectors currently exist between both jurisdictions in Ireland (IE/NI) and Great Britain (GB). Numerous third party future projects are also proposed for this border in TYNDP 2016. Furthermore, there is a long term project to connect Ireland to Continental Europe. There are significant renewable energy resources on the island of Ireland; the development of interconnection capacity across this boundary will allow these resources to be exploited. Investments in the boundary also play a role in the development of the Northern Seas Offshore Grid.

TYNDP findings



The analyses show that projects between both Ireland and GB, and Ireland and Continental Europe, have high benefits. Some of the proposed projects make use of the dedicated connection of renewable generation in Ireland to supply GB, enhancing their associated benefits.

Welfare and Capacity



The detailed TYNDP project CBAs show that the future projects typically provide SEW contributions of 20 – 50 MEuro/year, however, those projects which incorporate large quantities of additional renewable generation provide over 200 MEuro/year. The existing capacity across the boundary is 1000 MW. In 2030, including all TYNDP 2016 mid-term and long-term projects, the reference capacity is 1700 MW. As shown in the graph, there are drivers for additional interconnection from Ireland to both GB and Continental Europe. This is mainly true of Visions 3 and 4, which also have the largest levels of renewable generation in Ireland. However, the total capacity of the proposed future projects is in excess of the required capacity. There are price differences between Ireland, Great Britain and Continental Europe across all Visions. When considering Ireland and Great Britain, Ireland has lower prices than GB in all visions, with the exception of Vision 2, where GB is marginally cheaper. This is reflected in the SEW values in the CBA assessments of the third party future projects across this border; the values for Vision 2 tend to be the lowest. Considering Ireland and Continental Europe, prices in Continental Europe are marginally cheaper in Visions 1 and 2. For Visions 3 and 4, prices in Ireland are cheaper by a more significant amount. This is again reflected in the SEW values in the CBA assessments for projects on this border.

Interconnection target for 2030

The planned investments will allow the reference capacity to be met by 2030. The analysis shows that there is potential for further capacity by 2030. However, given uncertainties in the exploitation of the large RES resource of the island of Ireland, as well as potential large scale demand connections, no definitive 2030 target is provided here.

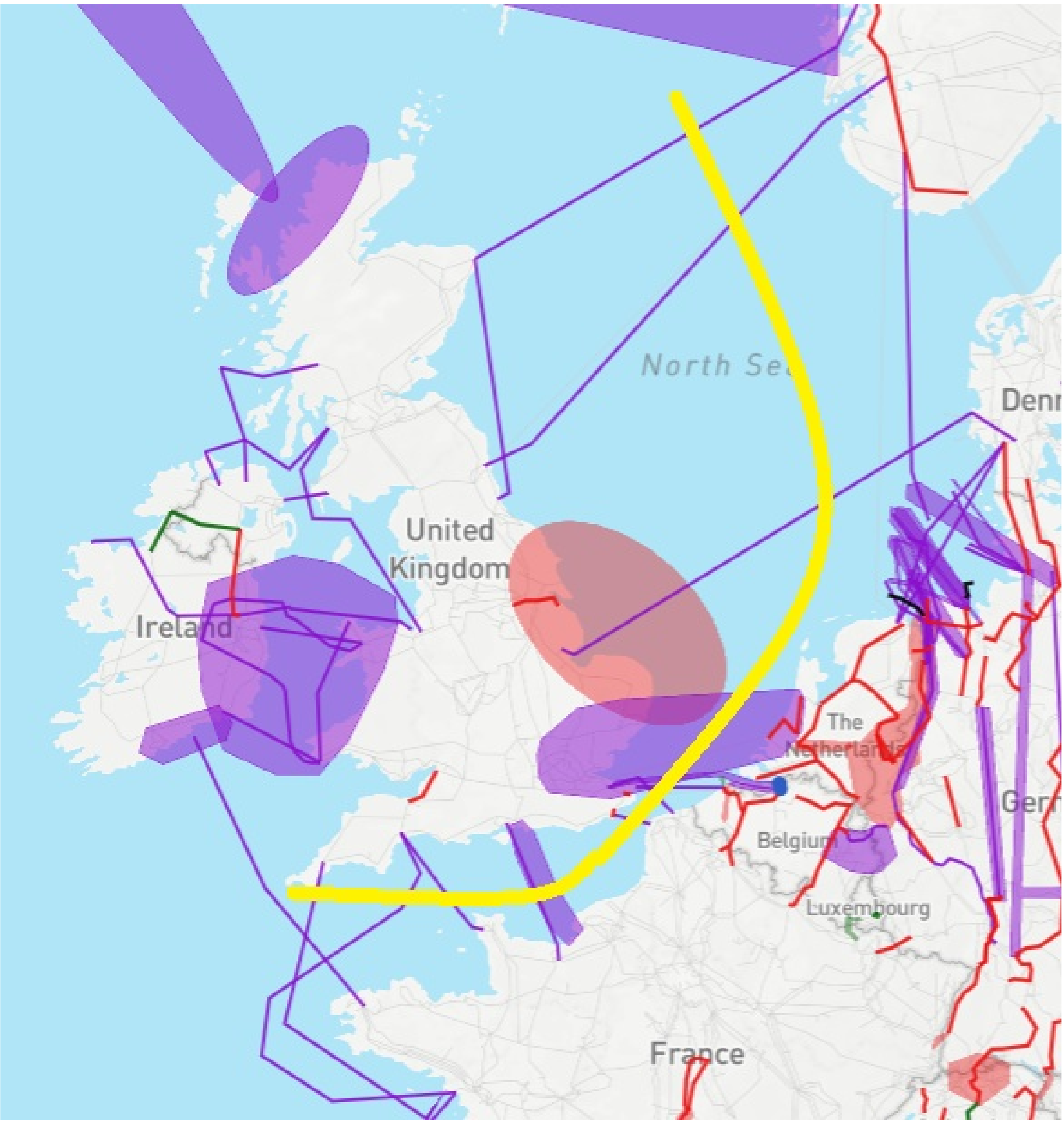
Project ID	Name	GTC Direction 1	GTC Direction 2
107	Celtic	700	700
189	Irish Scottish Links on Energy Study (ISLES)	1000	1000
286	Greenlink	700	700
287	Greenwire South	1300	1300
289	MAREX UK-Ireland Interconnector	1500	1500
290	Greenwire North	1000	1000
292	Greenconnect	700	700
295	Gallant	500	500

Great-Britain – Continental Europe and Nordics

Linking the markets of Great Britain with Continental Europe and the Nordic region.

The generation shift from coal to gas and from thermal to renewables is the main driver for increasing interconnection capacity between the different systems making up the North Sea region. Integrating the British system towards both the Continental and the hydro-based Nordic system, allows benefiting from the complementariness between their generation mix structures. Hence, developing new interconnections across this boundary is important to achieve the desired European market integration as well the integration of renewable energy, preparing for a power system with lower CO2-emissions for most of the Visions. Investments in the boundary play a key role in developing the Northern Seas Offshore Grid Infrastructure and will improve security of supply in the whole region, e.g. during times of low wind, high demand, dry years. In addition, HVDC projects in particular add flexibility to the systems due their controllability.

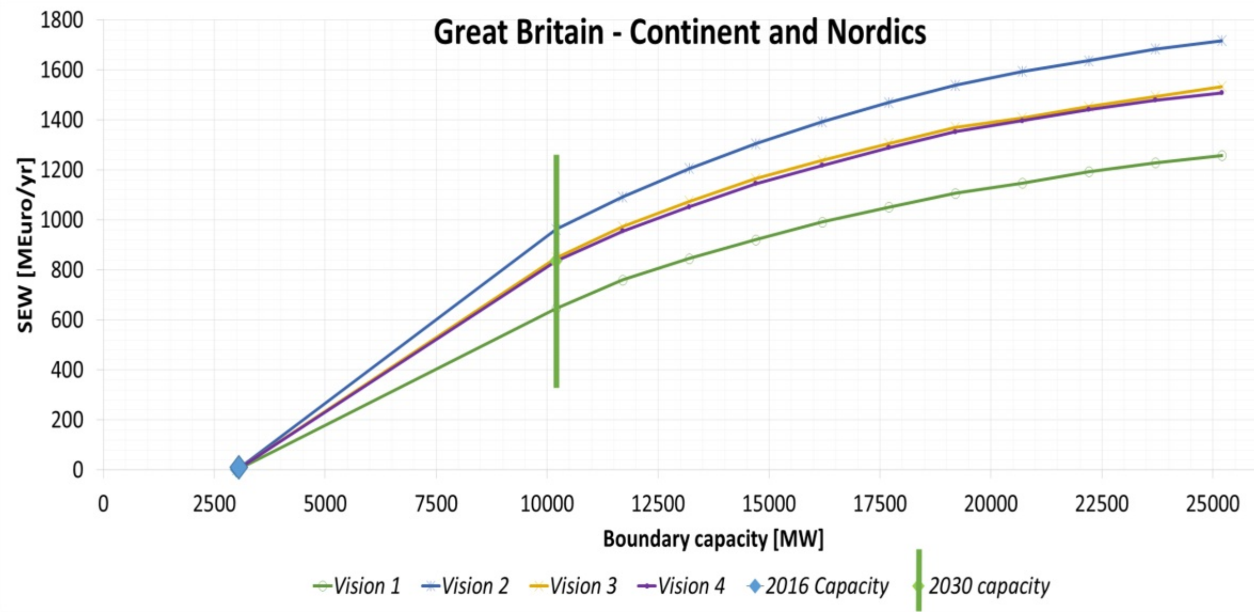
TYNDP findings



The analyses show that projects between the Nordic and British systems do have high benefits, however there are also high costs due to the long distances. Substantial price differences remain bween the Continental and British systems depending on the Vision.

In gas before coal market conditions, projects between the systems lead to decreased CO2-emissions. However, in visions with low CO2-prices where coal is cheaper than gas as e.g. in Vision 1, the projects may lead to an increased coal-fired production and subsequently increased CO2-emissions.

Welfare and Capacity



Market based capacity analysis performed in the TYNDP 2016 shows a significant potential for increasing the capacity between the British, Nordic and Continental systems. At the same time, it is important to pay attention to the scenario assumptions. Bringing CO2, oil , gas, coal prices down to 2016 level will influence the SEW values in a negative direction. The SEW values would be smaller than the values identified for 2030. The CO2 price assumptions for 2030 are higher than the ones seen today. Higher CO2 prices create larger marginal cost price differences between the different generation technologies. Having a look at the SEW related to increasing boundary capacity, the values of the different visions indicates that fuel mix is the main driver for price differences hence they drive the SEW-values.

Great Britain is a net importer, mainly from the continent, in both Visions 1 and 2, but less in Vision 2 given the higher amount of offshore wind in GB in that scenario. In the greener Visions 3 and 4, Great Britain turns into a net exporter, mainly to the continent. This is mainly caused by the different fuel mix in GB as compared to the continent. The main driver for the lower prices in GB in Visions 3 and 4 is the relatively large share of gas fired generation in GB.

Today's capacity across the boundary is 3GW (blue dot), while the reference capacity for 2030, including all TYNDP 2016 mid-term and long-term projects, is about 10 GW (green vertical line). Projects not being part of the reference capacity, usually less mature projects or those being built beyond 2030 are indicated on the right hand side of the green vertical line.

Interconnection target for 2030

Making the balance between social welfare gain and infrastructure investment costs for higher levels of interconnection, the level of interconnection is above 10 GW for all Visions. The present and planned investments show that the reference capacity might be reached by 2030, even though this includes projects of more than 7 GW.

Project ID	Name	GTC Direction 1	GTC Direction 2
25	IFA2	1000	1000
74	Thames Estuary Cluster (NEMO)	1000	1000
110	Norway-Great Britain NSN	1400	1400
121	2nd interconnector Belgium - UK	1000	1000
153	France-Alderney-Britain	1400	1400
167	Viking DKW-GB	1400	1400
172	ElecLink	1000	1000
190	NorthConnect	1400	1400
247	AQUIND Interconnector	1800	1800
260	New Great Britain - Netherlands Interconnector	1000	1000
261	Long-term conceptual "West-East corridor" in North Sea		
271	Long term conceptual North Seas Offshore grid infrastructure		
285	GridLink	1500	1500
294	Maali	600	600

Nordics - Continental Europe West

Interconnecting the hydro-based Nordic system (NO/SE) with the thermal/nuclear/wind-based Continental system

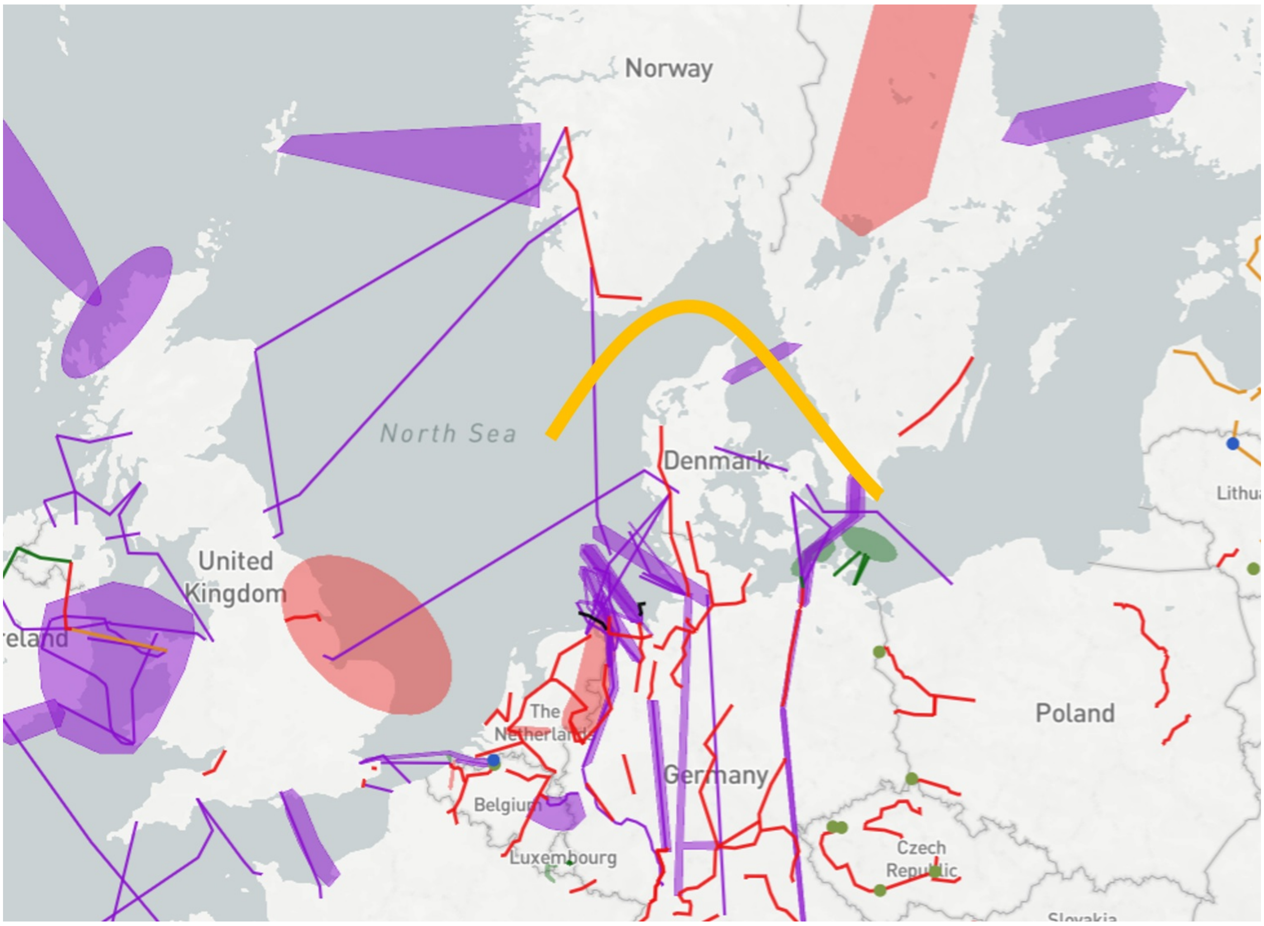
The main drivers for investments in this region are to integrate the hydro-based Nordic system with the thermal/nuclear/wind-based Continental system. This will improve the security of supply both in Norway/Sweden in dry years as well as for the Continental system in periods with negative power balance (low wind, high demand etc.). In addition, the boundary is important both for European market integration, facilitating renewable energy and preparing the power system with lower CO2-emission.

TYNDP findings

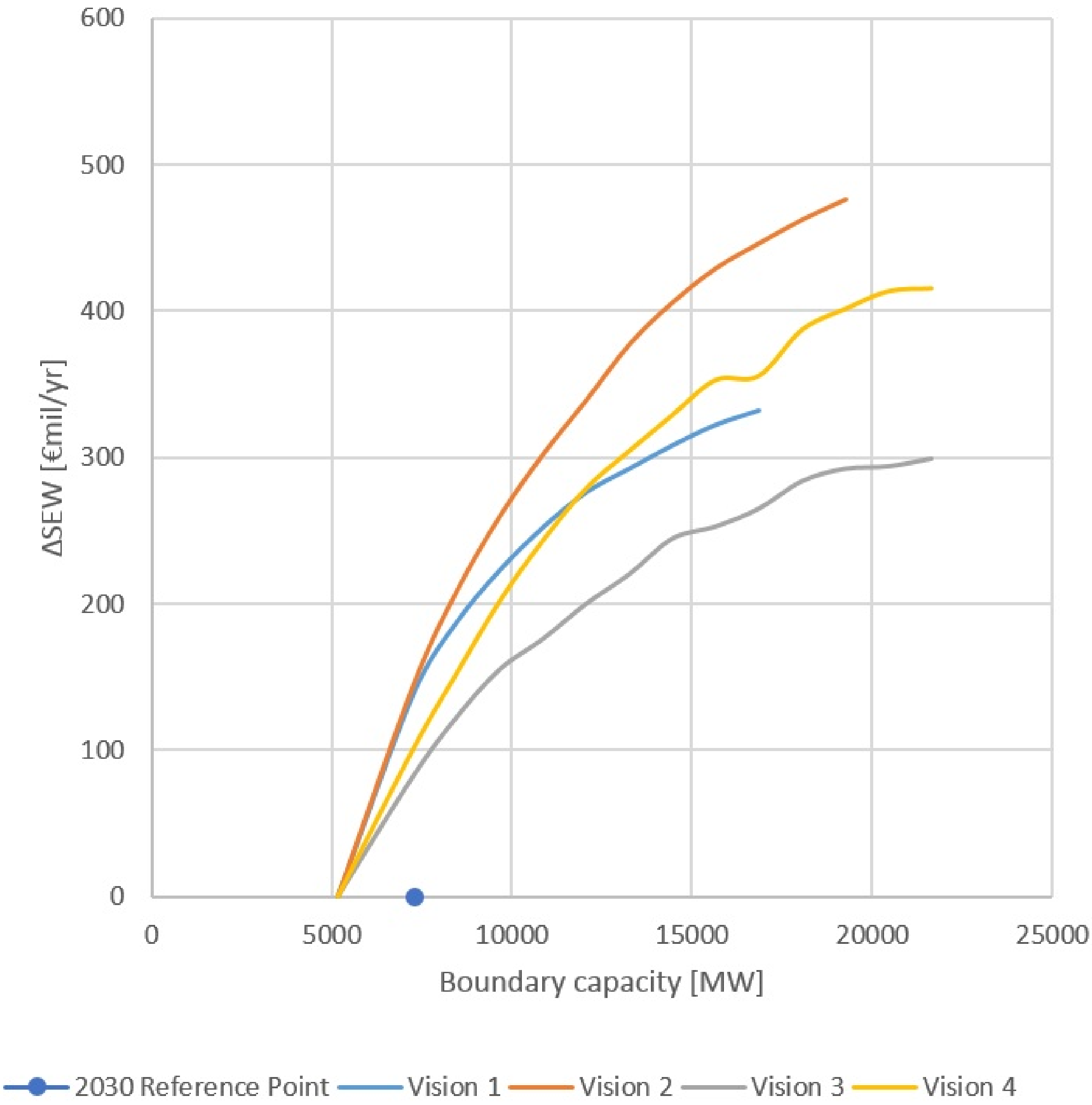
The analyses show, that projects between the Nordics and the Continental system do have a reasonably good socio-economic cost/benefit ratio. However, the values are very dependent of the basic price-assumptions (CO2, coal, gas) as well as the energy-balances in each system hence the price-differences between the systems.

In general, projects between the systems leads to decreased CO2-emissions. However, visions with low CO2-prices, may lead to increased coal-fired production and subsequently increase CO2-emissions.

Welfare and Capacity



Market based capacity analysis performed in the TYNDP 2016 shows the potential for increasing the capacity of the Nordics and Continental system. At the same time it is important to pay attention to the assumptions. Bringing CO2, oil, gas, coal prices down to the 201 level will influence the SEW-values in a negative direction. Having a look at SEW/GTC values in the different visions indicates that the energy-balance of the different visions both for the Nordics and Continental countries is the main driver for price differences in the visions hence they drive the SEW-value of connecting the Nordic and Continental systems. The Nordic surplus is very high in Vision 2, which results in a high price difference and subsequent high SEW/GTC-value.



In general, SEW values for projects towards the Nordics are underestimated because studies only take into account an average hydrological year.

Interconnection target for 2030

Making the balance between social welfare gain and infrastructure investment costs for increasing levels of interconnection, the optimal level of interconnection ranges from 4,5 GW to 7 GW. The present and planned investments show that the target capacity will be reached by 2030.

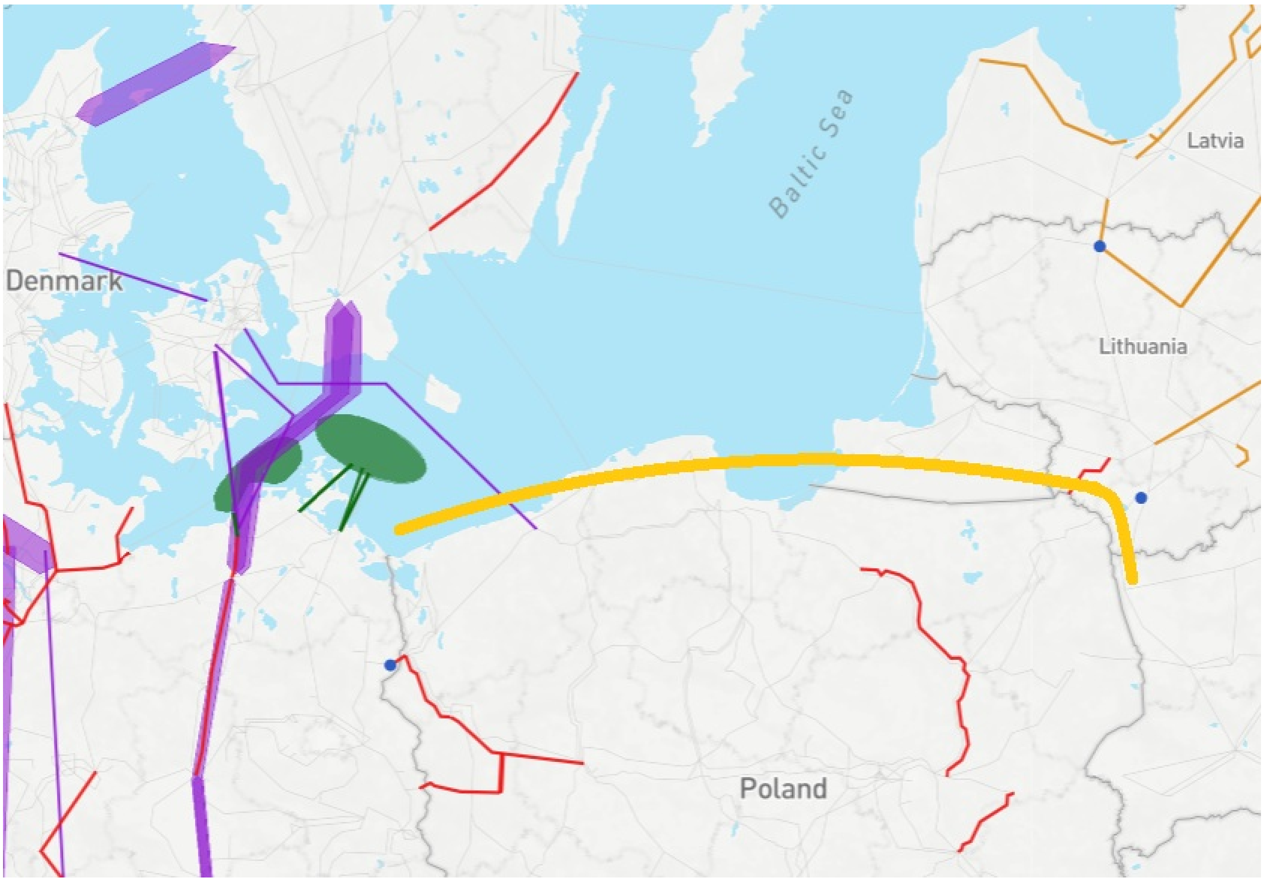
Project ID	Name	GTC Direction 1	GTC Direction 2
37	Norway - Germany, NordLink	DE-NO: 1400	NO-DE: 1400
238	Kontiskan 2	SE3-DKW: 350	DKW-SE3: 350
267	Hansa PowerBridge 2	SE4-DE: 700	DE-SE4: 700
176	Hansa PowerBridge 1	SE4-DE: 700	DE-SE4: 700

Nordic/Baltic to Continental Europe East

Enhancing market flows between North and South

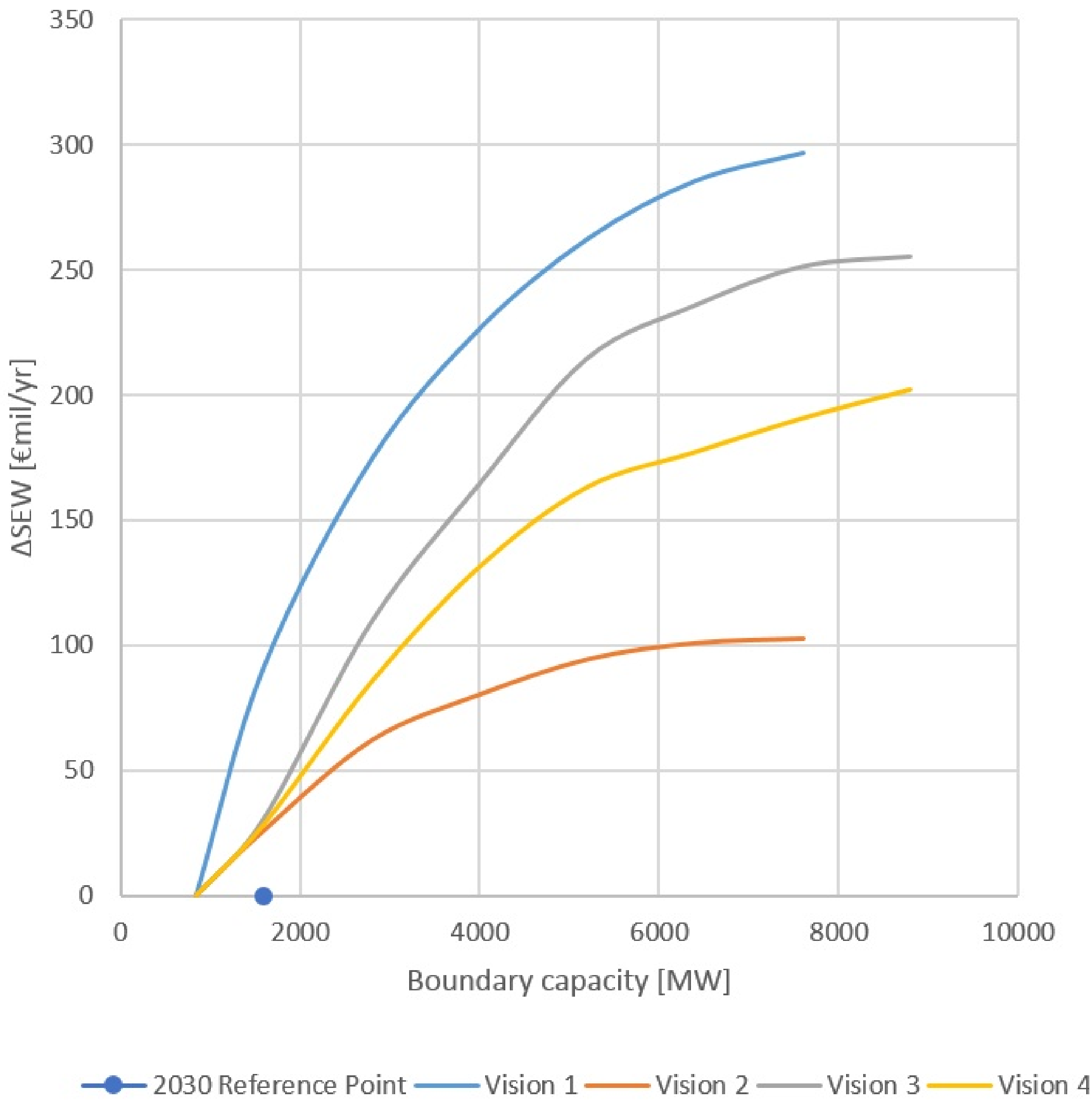
The drivers for investments in this region are to decrease price-differences between the Nordics/Baltics and the Eastern part of the Continental system as well as to decrease overall CO_2-emissions.

TYNDP findings



The analyses show a large potential for decreased CO_2-emissions when integrating Nordics with Continental Europe East. However, the emissions are dependent on the Visions. Low CO_2-prices lead to increased coal-fired production hence increased emissions.

Welfare and Capacity



Nordics/Baltics towards Continental Europe East

Detailed TYNDP project CBAs show that the average SEW contributions per project across this boundary range from 35 to 80 MEuro/year. This corresponds to about 50 MEuro/year per additional GW of transfer capacity.

Interconnection target for 2030

Making the balance between social welfare gain and infrastructure investment costs for increasing levels of interconnection, the optimal level of interconnection ranges from 1 GW to 2,5 GW between the Nordics/Baltics and the Continental Europe East. Compared with the present and planned investments this shows a potential for further projects.

The common planning studies also identified that extra capacity between Sweden and Poland showed potential from a socio-economic welfare point of view. This cross-border was, however, not nominated to TYNDP 2016 because there are already several interconnectors between southern Norway and southern

Sweden to the continent and further studies are needed to verify the technical feasibility of additional interconnections.

Projects assessed Project 123 - LitPol Link Stage 2 - GTC PL/LT: 1000 MW GTC LT/PL: 500 MW Project 234 -DKE-PL-1 - GTC contribution PL-DKE: 600 MW GTC contribution DKE-PL: 600 MW

Baltic Integration

Enhancing Security of Supply of Baltic States.

The driver for investments in this region is to integrate the Baltic States further into the European market, enhance energy security, and decrease dependency on non-ENTSO-E countries.

TYNDP findings

The further integration of the Baltics presents huge geo-political interest. Three alternatives are being studied; (1) synchronization with the Continental system (2) synchronization with the Nordic system and (3) Baltic synchronous area supported by HVDC-links.

Welfare and Capacity

Based on the assumption that the capacities towards the Baltics are not increased in the alternatives, the market-based socio-economic welfare values are zero.

Interconnection target for 2030

Because of the lack of significant price differences between the Baltics system and surrounding areas, where security of supply issue is the most important, from the market perspective development of interconnectors for the Baltic States is not beneficial. Future projects for this region will be dedicated to improving security of Supply.

Projects across the Boundary

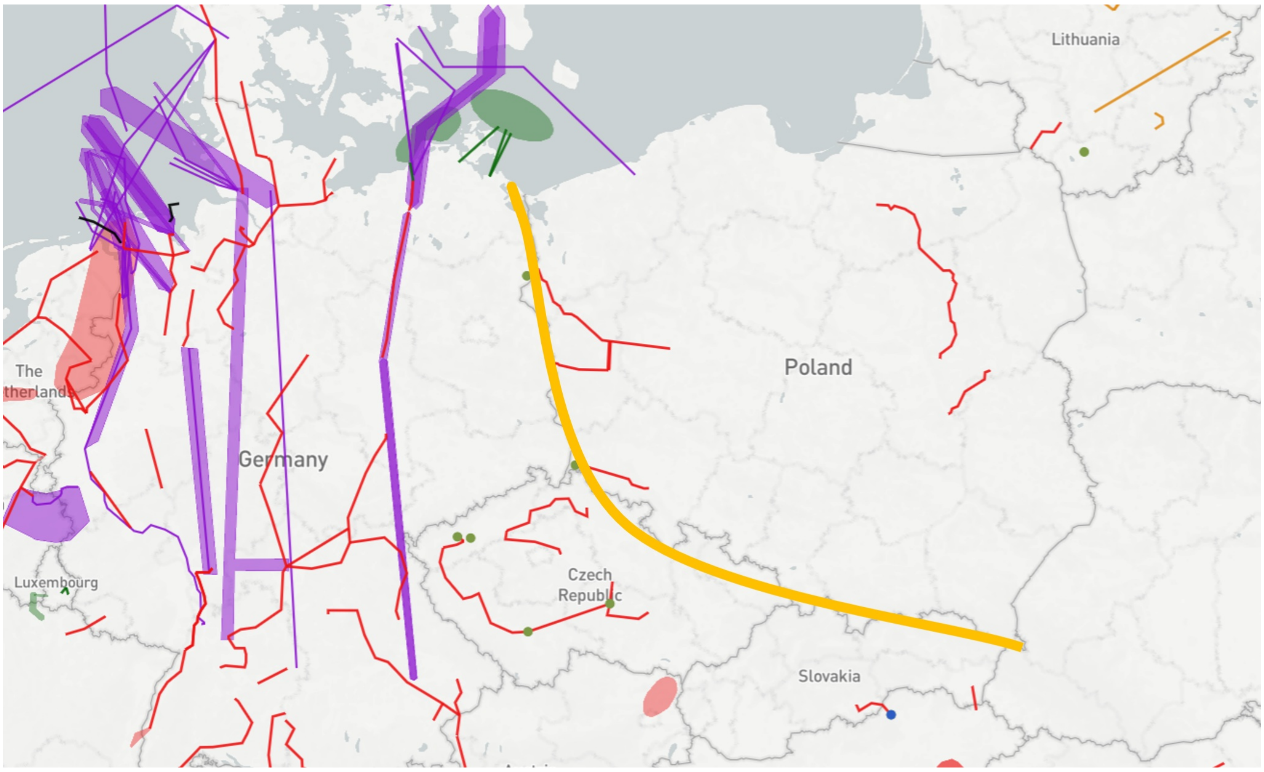
Project 124 – NordBalt Phase 2 – GTC SE4/LT 0 MW GTC LT/SE4 0 MW Project 170 – Baltic synchronization

Central East integration

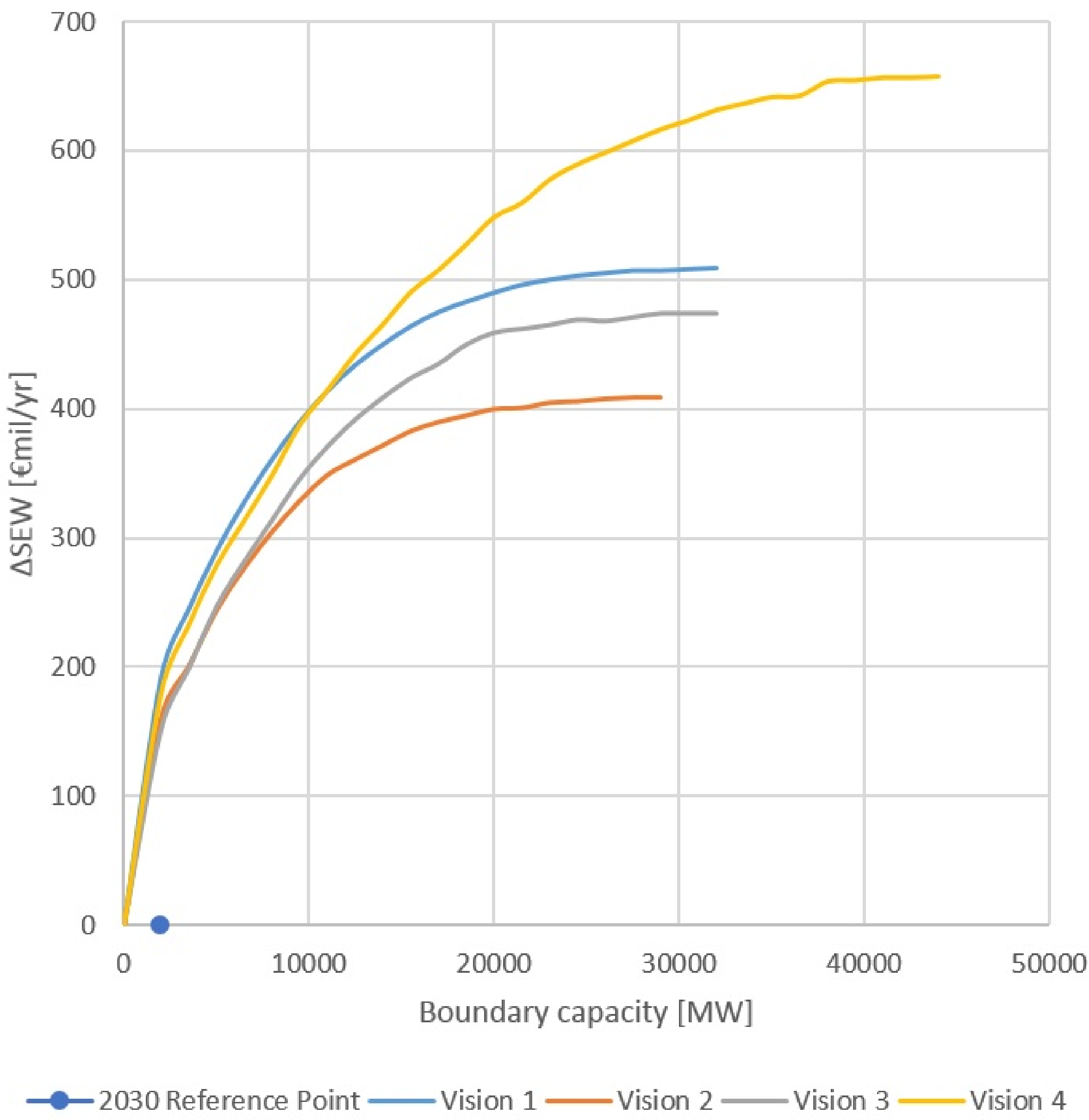
Strengthening the grid in Central Eastern Europe between Germany, Czech Republic, Slovakia and Poland.

The driver for investments in this region is to decrease price-differences between Poland and the neighbouring countries as well as to increase security of supply.

TYNDP findings



The analyses show that prices in Poland are strictly related to CO2-prices. Self-sufficiency of Poland allows sustaining a high level of security of supply at the expense of high energy prices. The emissions are dependent on the visions, where low CO2-prices lead to increased coal-fired production, hence increased emissions. Implementation in Poland of high-efficiency coal technology allows a signifiicant decrease od emissions levels.



Welfare and Capacity

Detailed TYNDP project CBAs show that average SEW contributions per project in the perimeter of this boundary range from 40 to 82MEuro/year. This corresponds to about 95 MEuro/year per additional GW of transfer capacity.

Interconnection target for 2030

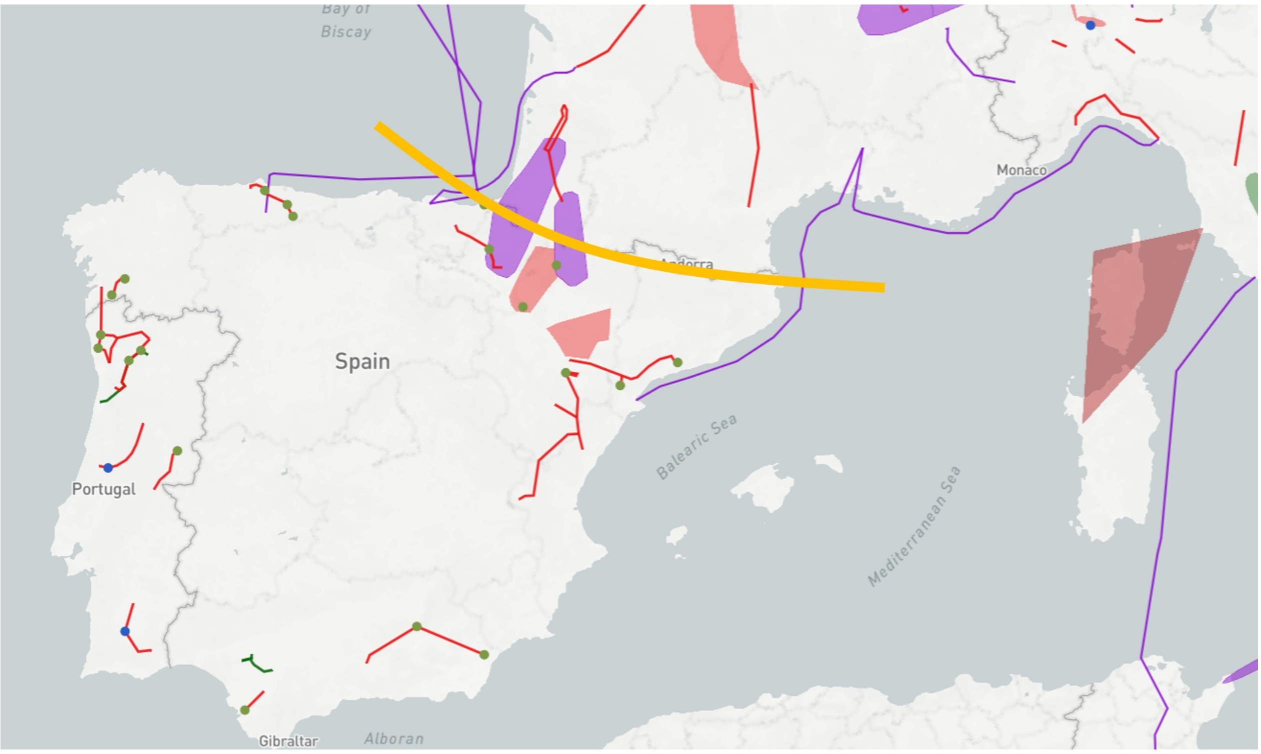
Making the balance between societal welfare gain and infrastructure investment costs for increasing levels of interconnection, the optimal level of interconnection ranges from 2,5 GW to 4,5 GW. Compared with the present and planned investments this shows a potential for further projects.

	Project ID	Name	GTC Direction 1	GTC Direction 2
Central East	94	GerPol Improvements	DE-PL: 500	PL-DE: 1500
Central East	229	GerPol Power Bridge II	DE-PL: 1500	PL-DE: 0
Central East	230	GerPol Power Bridge I	DE-PL: 1500	PL-DE: 500

Iberian Peninsula integration

Interconnecting the Iberian market (MIBEL)with the rest of Europe.

TYNDP findings

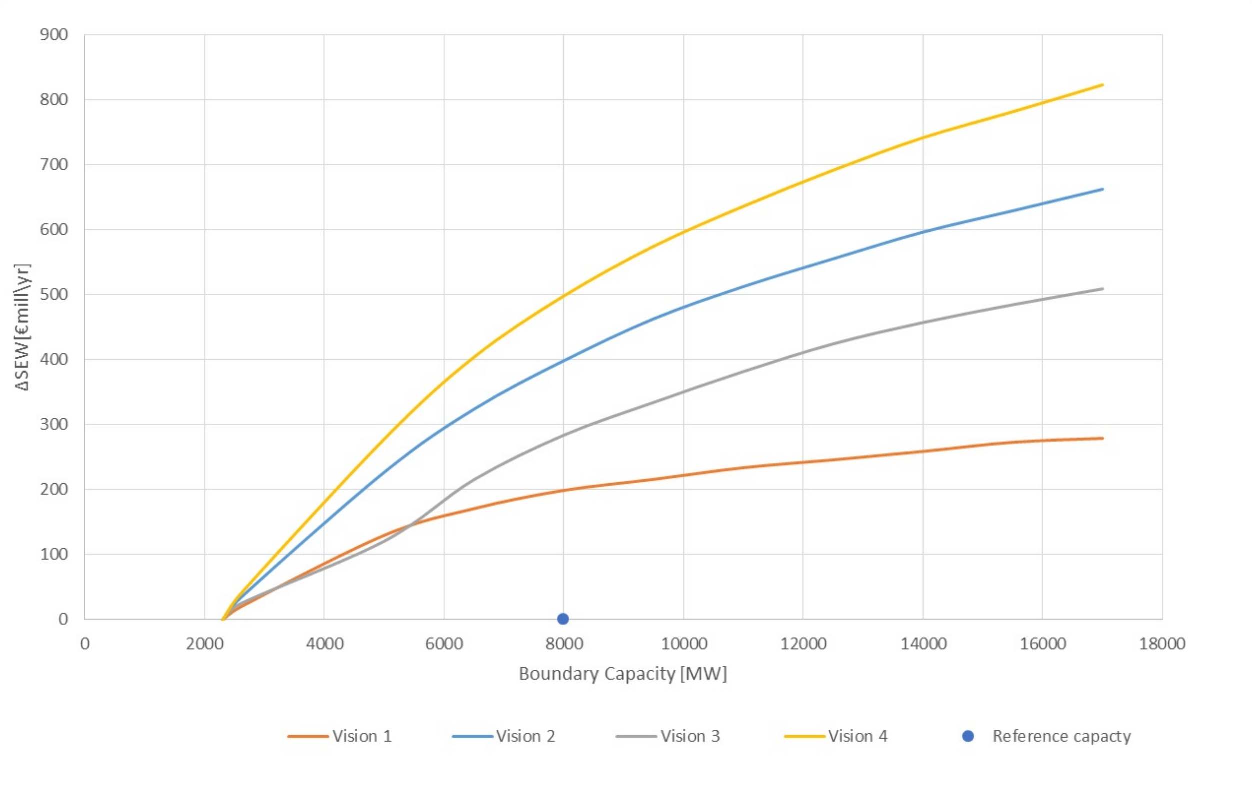


This boundary has appeared for many years as one of the most congested in Europe. Main drivers for grid development are i)the integration of MIBEL to European mainland market; ii) RES integration, especially in the Iberian Peninsula; and iii) the need for Spain to comply with the EU 10% interconnection rate target by 2020.

The Madrid Declaration signed in March 2015 by the EC and the French, Spanish and Portuguese Governments shows the strong political will to increase the capacity over this boundary by developing 4 projects (one PST, and three additional HVDC interconnections: one subsea and two terrestrial) on top of the HVDC already commissioned in 2015 on the eastern part of the border.

Three multi-terminal projects promoted by non-ENTSOE members are also assessed as future projects in TYNDP2016 although at the time of closure of the consultation phase these projects did not demonstrate compliance with the EC's draft guidelines for treatment of all promoters; two of them would connect Spain, France and Great Britain and one Spain, France and Italy

Welfare and Capacity



This figure shows how the SEW of Iberian Peninsula-Central Europe boundary evolves when exchange capacity increases (beyond 5 GW, boundary capacity is supposed to increase simultaneously by homothetic steps, 1/3 MIBEL-GB, 1/3 MIBEL-FR, 1/3 MIBEL-IT). Assessment per project are not used to calculate these values. This study should be considered as an additional analysis with respect to the CBA assessment.

Interconnection target for 2030

Grid development through this boundary is driven by the compliance with the target interconnection rate of 10% of installed generation capacity for every EU country by 2020, as current ratio for Spain is still far from the target. Depending on the scenarios, the required capacity for 2030 ranges from 9 GW in Vision 1 to 15 GW in Vision 4.

The four projects mentioned in the Madrid Declaration are expected to increase the capacity between France and Spain to 8 GW and therefore this boundary is still marked as inadequate in all scenarios. Nevertheless this huge investment effort from TSOs improves very much the interconnection ratio of Spain (reaching around 9% in Visions 1 and 2 and around 8% and 6% in Visions 3 and 4 respectively).

Notwithstanding, looking at the particular geographical position of the region, if the Iberian Peninsula is considered as a whole (Spain and Portugal), the interconnection ratio would be lower.

Project ID	Name	GTC Direction 1	GTC Direction 2
16	Biscay Gulf	2600	2200
184	PST Arkale	500	100
270	FR-ES project -Aragón-Atlantic Pyrenees	1500	1500
276	FR-ES project -Navarra-Landes	1500	1500
	The following projects do not comply with the selection guidelines		
281	ANAI: Abengoa Northern Atlantic Interconnection		
282	ASEI: Abengoa Southern Europe Interconnection		
296	Britib		

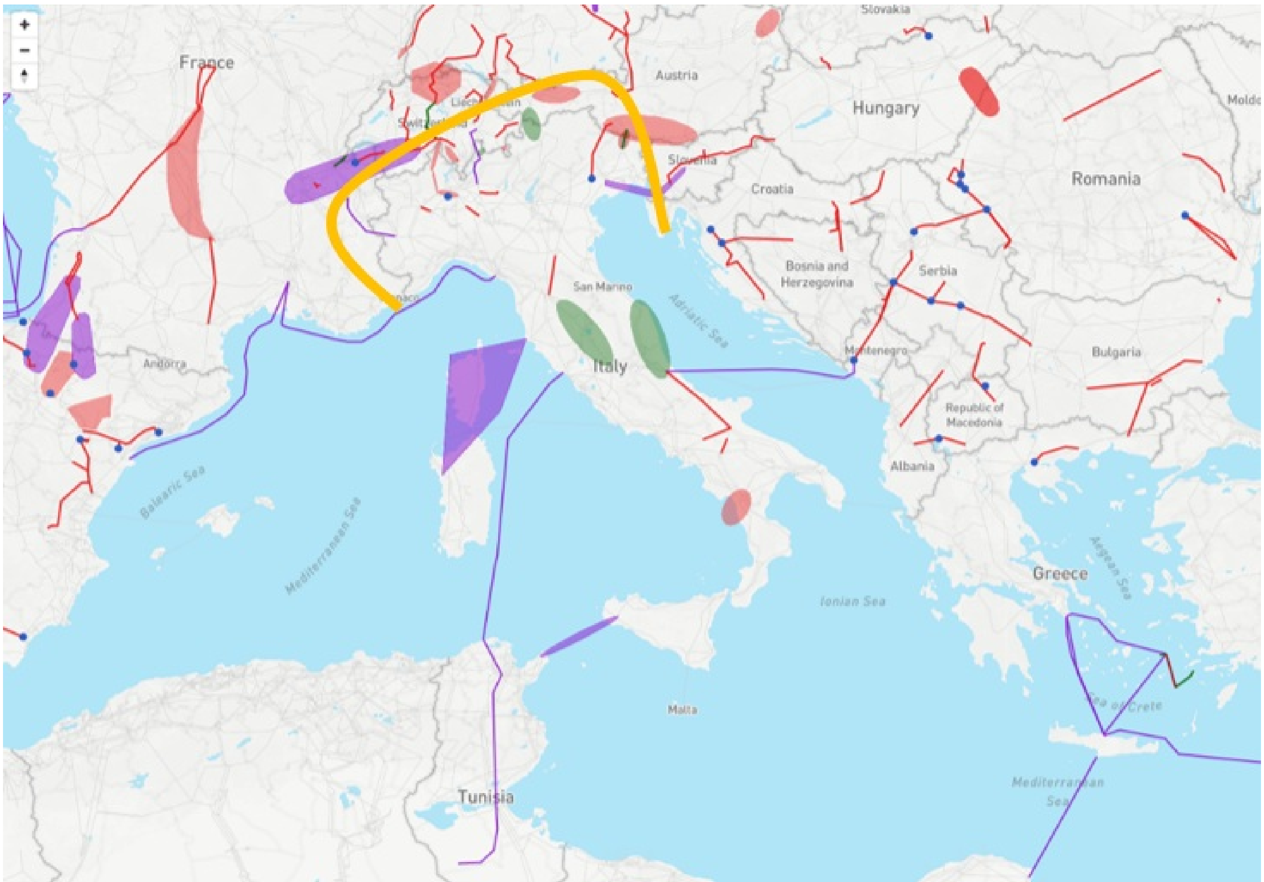
Italian peninsula integration

Overcoming partial isolation of the italian system

The main drivers behind the development of the transmission capacity at the North-Italian boundary concern the exploitation of new generation, mainly located in the North of Germany and France (wind) and in the South of Italy (wind and photovoltaic). The interconnection projects planned on this boundary will enable wider power exchanges, thus making possible the integration of new generation and pump storage capacity located in the Alps region.

Furthermore, additional links between Italy and North-Africa and between Italy and Montenegro, will contribute as well to the interconnection of the Italian peninsula, by increasing market integration, RES usage and system security.
In addition, the SA.CO.I 3 link connecting Italy and Corsica is of major relevance for the security of supply and market integration within the European system.

TYNDP findings



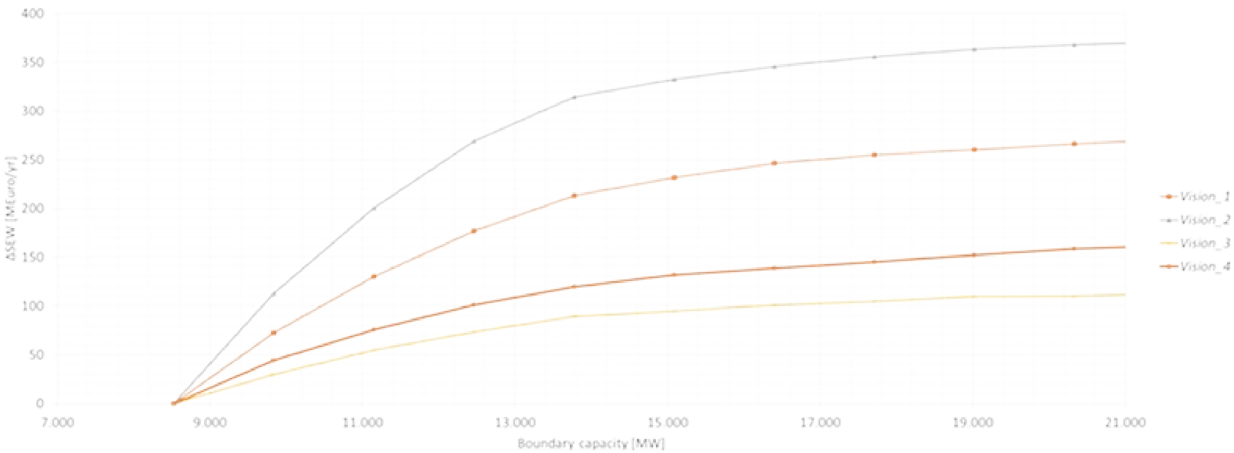
Referring to the North-Italian boundary, the analysis shows that highest SEW/GTC rate is achieved in Vision 2, while the lowest is in Vision 3.

The higher SEW/GTC values in V2 and V1 are substantially related to the low CO2 prices used in such scenarios, which lead to a relevant Italian import according mainly to the value of the demand (higher in V2 than in V1). Conversely, in V3 and V4, the higher CO2 prices and higher RES generation capacity lead to a different use of the Italian Northern boundary, characterised by a lower SEW, but higher RES integration indicators.

It is also relevant to highlight that, according to the curves described below, the 2030 reference capacity due to the projects planned on the Northern Italian boundary is quite close to the optimal transmission capacity in the examined scenarios, meaning that any further increase of GTC cannot provide an equivalent increase of SEW.

Detailed TYNDP project CBAs show that average SEW contributions per project in the perimeter of the Italian Norther boundary range from 35 to 50 MEuro/year, with higher benefits given by the projects that are commissioned first.

Welfare and Capacity



The SEW/GTC curve depicted refers to the impact of reinforcing the interconnection at the North-Italian boundary, the reference capacity reflects the capacity increase on the North Italian Border mainly due to the commissioning of PCI projects. Referring to Italy Tunisia interconnection promoted by Terna, the project is considered mature enough to be included in the reference year 2030 model (expected commissioning in 2022). In the same 2030 reference network interconnections with the Balkans (expected commissioning in 2019) and Corsica (expected commissioning in 2023) are included as well.

Interconnection target for 2030

Making the balance between societal welfare gain and infrastructure investment costs for increasing levels of interconnection, the optimal level of interconnection, regarding the Italian Norther boundary, is around 13.5 GW, which is what the TYNDP portfolio of mid-term and long-term projects aims to deliver.

The following table provides the list of mid and long-term projects on the Northern Boundry and on the other boundaries relevant to the integration of the Italian Peninsula.

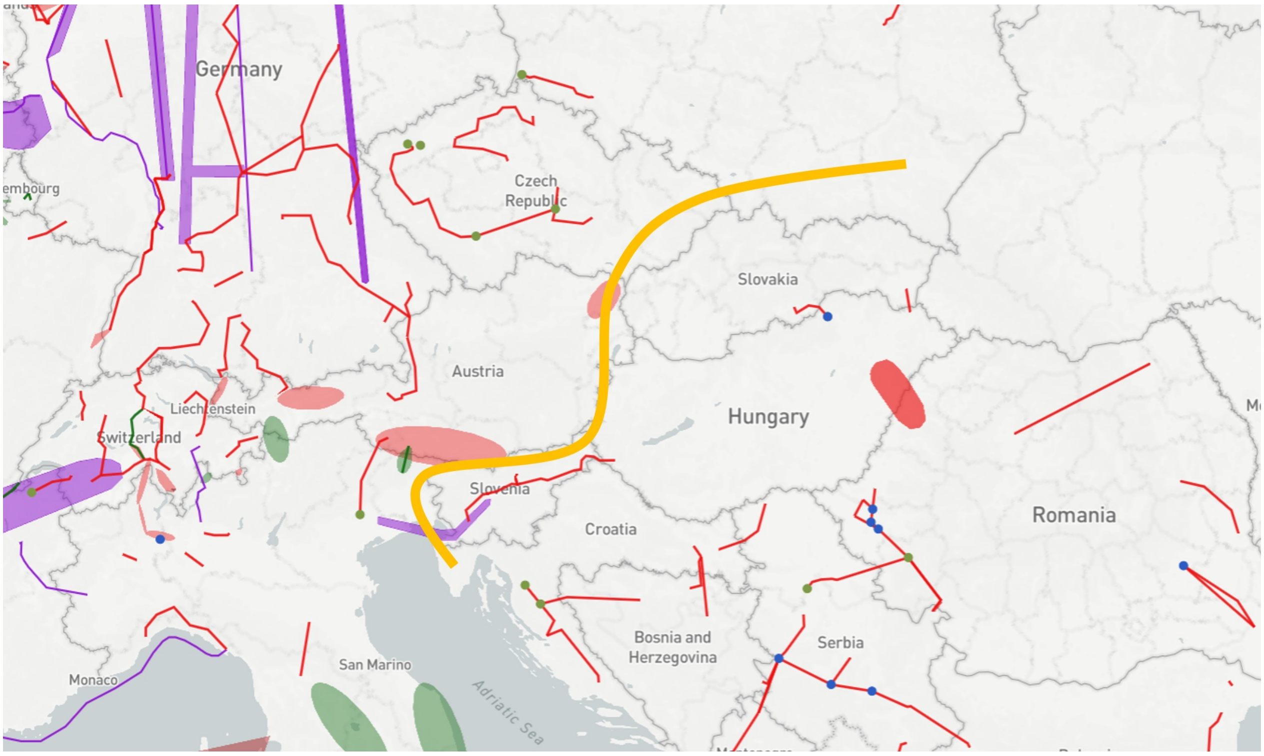
Project ID	Name	GTC Direction 1	GTC Direction 2
21	Italy-France	IT-FR : 1000	FR - IT: 1200
26	Austria - Italy	IT-AT: 1000	AT-IT: 1100
28	Italy-Montenegro	ME-IT : 1200	IT - ME: 1200
29	Italy-Tunisia	TU-IT: 600	IT-TU: 600
31	Italy-Switzerland	IT-CH: 750	CH-IT: 750
150	Italy-Slovenia	SI-IT: 950	IT-SI: 950
174	Greenconnector	IT-CH: 850	CH-IT: 850
210	Wurmlach (AT) - Somplago (IT) Interconnection	IT-AT: 150	AT-IT: 150
250	Merchant line "Castasegna (CH) - Mese (IT)"	IT-CH: 100	CH-IT: 100
299	SACOI3	IT-FR(CO): 100	

South East integration

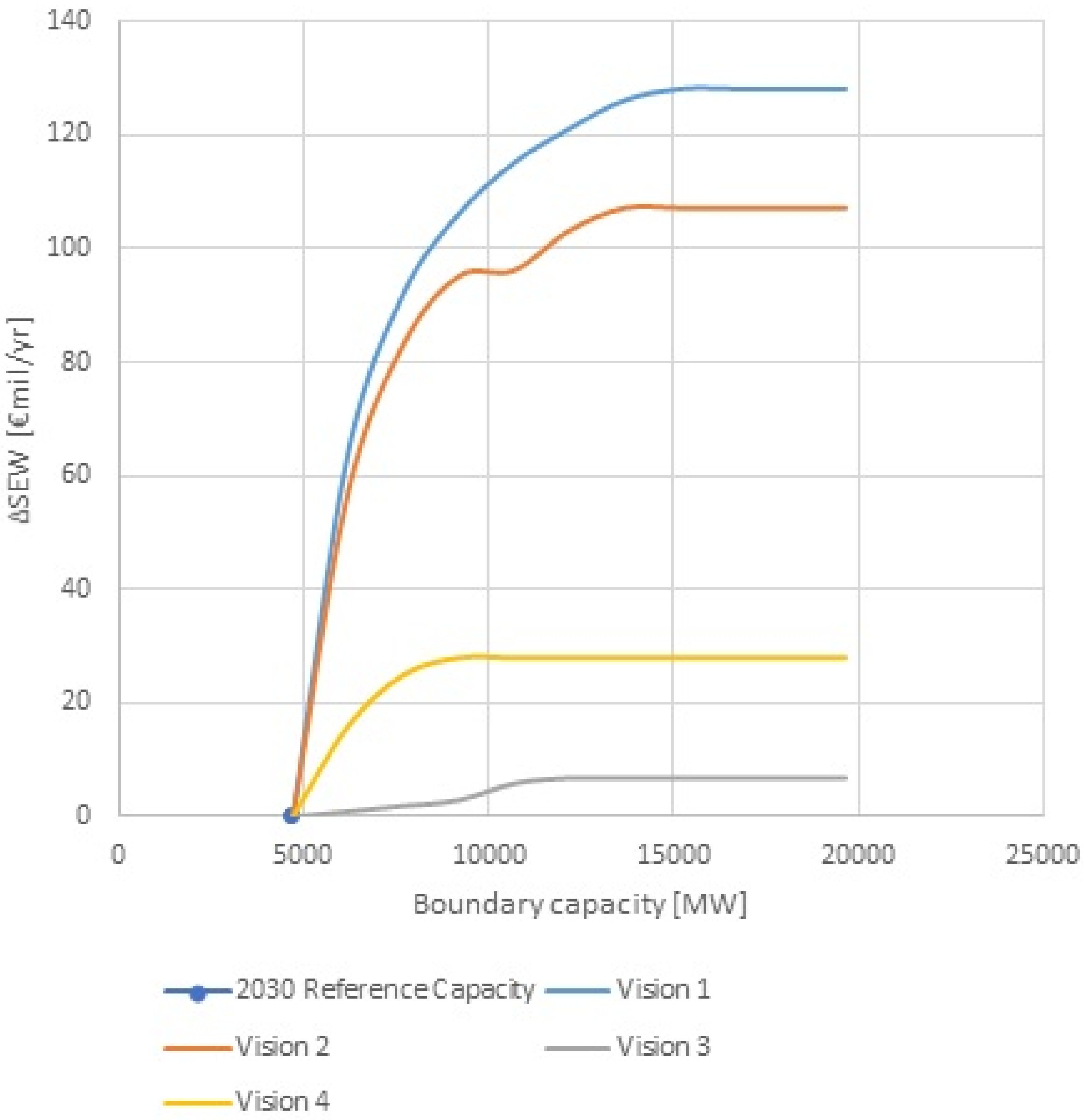
Strengthening the interconnection between IT/AT/SI/CZ and HR/HU/SK in South East Europe.

The drivers for investments in this region are integrating high potentials of renewables into a relatively sparse network.

TYNDP findings



The analyses show the relation between additional capacity increases across these borders and the overall welfare gains as a conservative estimates. Linked with presumed project costs in these areas, the earlier TYNDP studies did not identify relevant investment proposals. Hence, no TYNDP projects are proposed at this stage in the TYNDP.



Interconnection target for 2030

Making the balance between societal welfare gain and infrastructure investment costs for increasing levels of interconnection, the optimal level of interconnection is around 5 GW. This is in line with the present transmission capacities across this boundary.

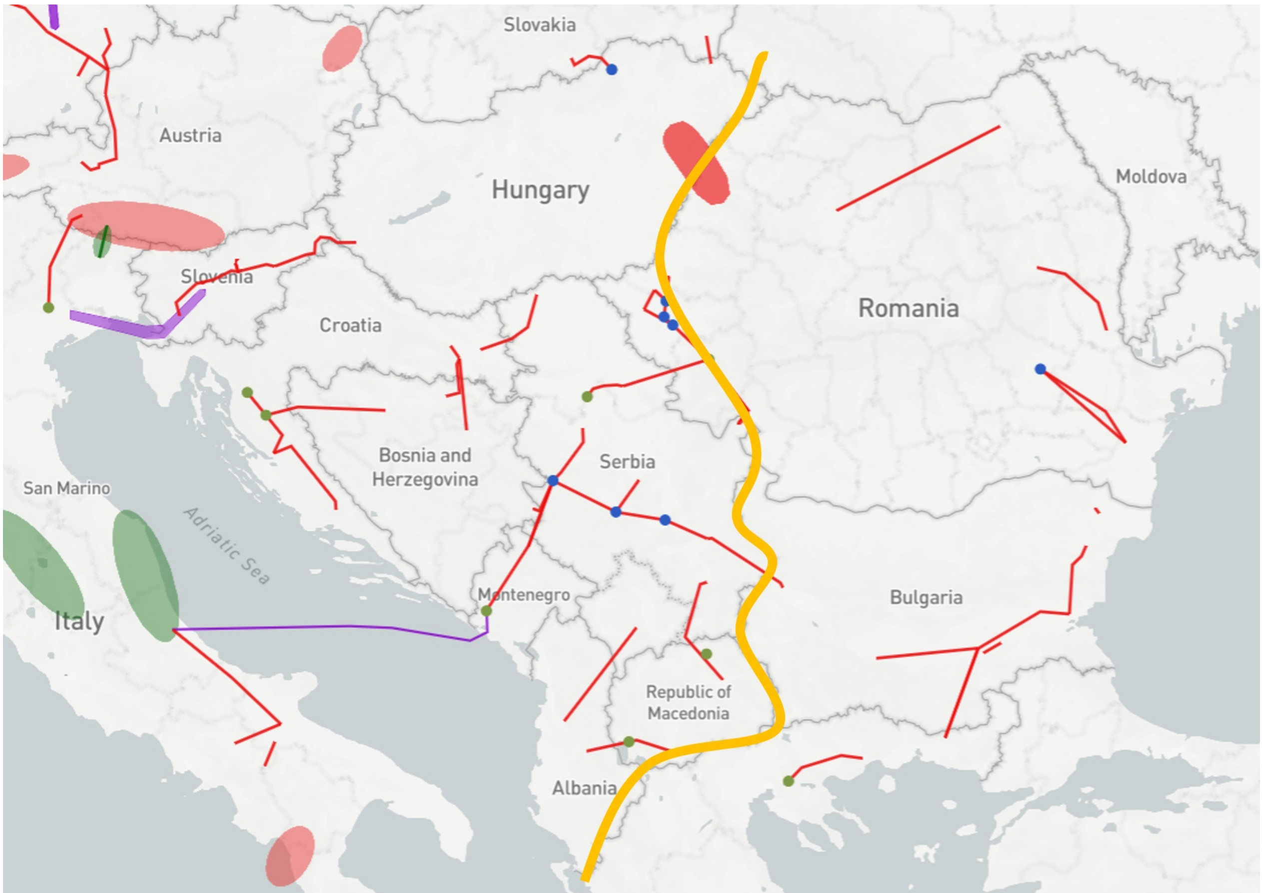
Project assessed in the TYNDP 2016 Project 141 -Slovenia-Hungary corridor GTC COntribution SI-HU: 1650 MW GTC COntribution HU-SI: 850 MW

Eastern Balkan

Strengthening the interconnection from BG, RO and GR to the rest of South-East Europe.

Strengthening the E→W and N→S corridors is a prerequisite for market integration and the exploitation of the high RES potential in the East part of South-East Europe. Increase of transfer capacity through the boundary at the West borders of Bulgaria and Romania and the North borders of Greece, will allow the increase of exports to West Europe and, through the Balkans, to Italy both from thermal low-cost generation in Bulgaria and Romania and from RES installed in Bulgaria, Romania and Greece, depending on the examined Vision.

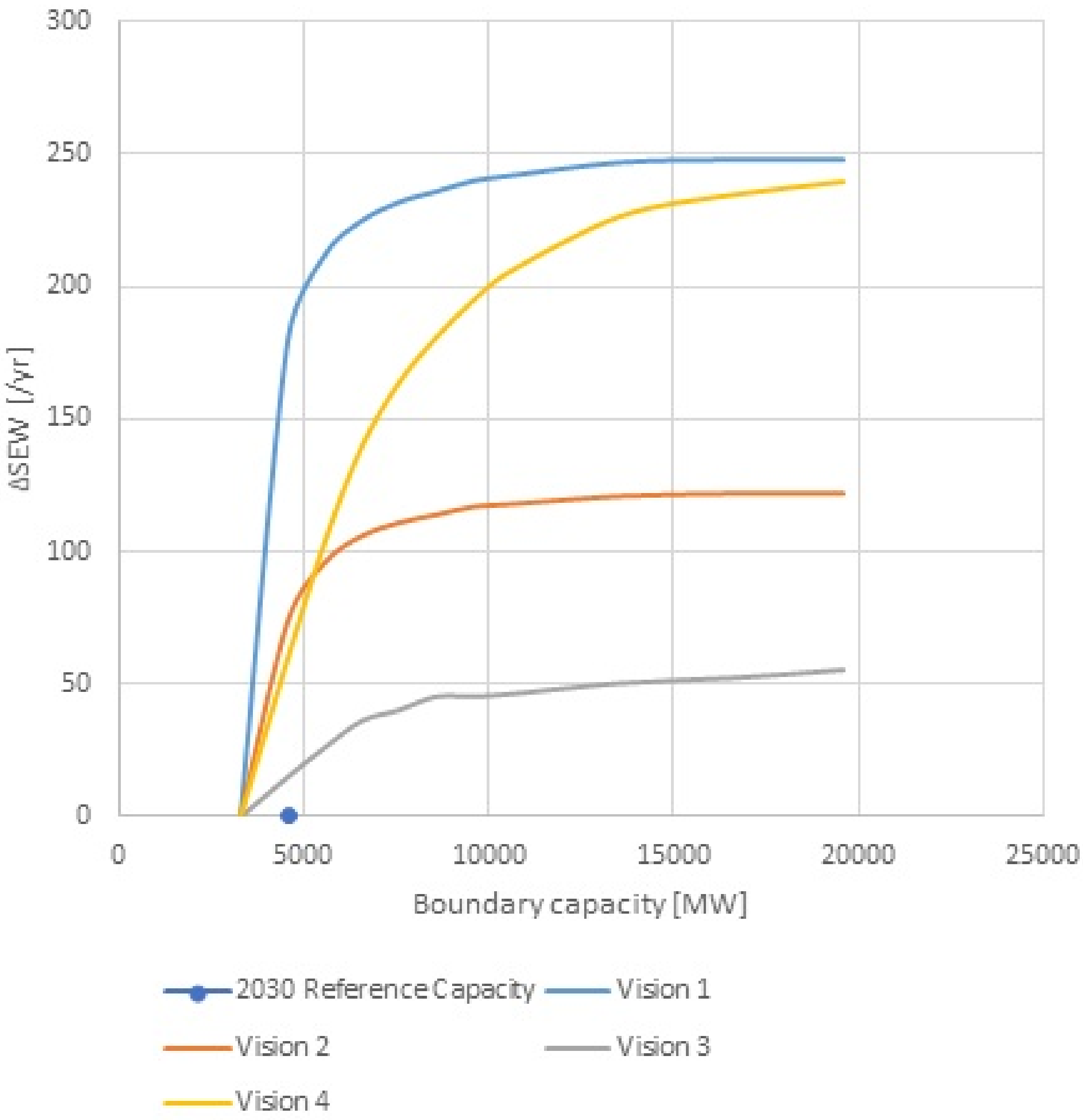
TYNDP findings



The analyses show that increase of transfer capacity over the examined boundary, results in an increase of societal welfare (ΔSEW) in all visions, up to a certain point where the respective variation curve reaches a saturation region. The highest saturation values for ΔSEW appear in Visions 1 and 4.

Detailed TYNDP project CBAs show that average SEW contributions per project in the perimeter of this boundary range from 20 to 50MEuro/year. This corresponds to about 62 MEuro/year per additional GW of transfer capacity.

Welfare and Capacity



Interconnection target for 2030

Making the balance between societal welfare gain and infrastructure investment costs for increasing levels of interconnection, the optimal level of interconnection ranges from 5 GW to 8.5 GW.

Compared with the present and planned investments this shows that in most of the Visions, their implementation will result in a transmission network that is adequate to cope with the expected power flows.

Projects assessed on this boundary:

Project ID	Name	GTC Direction 1	GTC Direction 2
144	Mid Continental East corridor	950	500
147	CSE9	750	200
259	HU-RO	800	200
268	Upgrading existing single 400 kV interconnection line between Romania and Serbia to double 400 kV line	550	500
277	New double 400 kV interconnection line between Bulgaria and Serbia	1500	400