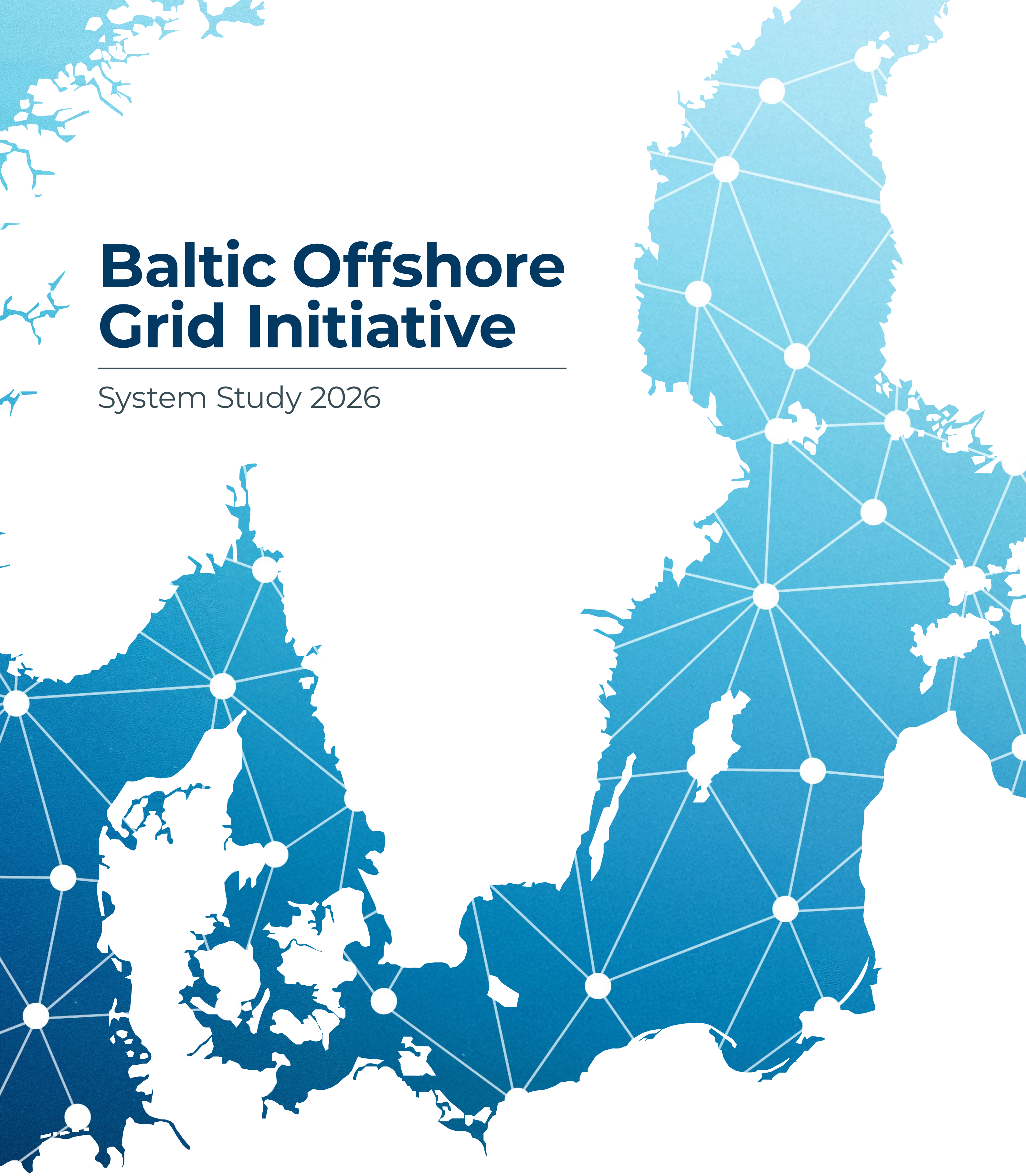

Baltic Offshore Grid Initiative

System Study 2026

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SVENSKA KRAFTNÄT

Content

Executive summary

The Baltic Sea region has the potential to play a pivotal role in Europe's transition to a clean, secure and resilient energy system. Building on its first offshore expert paper in May 2025, the Baltic Offshore Grid Initiative (BOGI) now takes a further step to promote regional sea basin planning. This offshore energy system optimization with a broad view on different sensitivities provides an analysis that translates transmission corridors to potential projects for the 2040 time horizon. Thereby, it supports a better understanding of how offshore cross-border projects can contribute to cover regional system needs. The findings highlight that a strengthened offshore interconnectivity is essential for unlocking the region's substantial offshore energy potential. At the same time, sensitivity analyses show that the scale of Baltic Sea offshore wind deployment and hydrogen production will ultimately depend on the level of future electricity and hydrogen demand as well as the overall cost trajectory of relevant technologies.

A sector-coupled linear expansion model was used to run an offshore system optimization for the Baltic Sea region for the 2040 time horizon, while keeping parameters in the rest of Europe constant. The input data builds on ENTSO-E's Ten-Year Network Development Plan 2024, updated with latest figures from national plans from the Baltic Sea Transmission System Operators (TSOs), related to national offshore wind ambitions, electricity and hydrogen demand, and infrastructure developments. By modelling electricity and hydrogen together, the study shows the interdependencies of a sector-coupled energy system.

The study identifies around 13 GW of new electricity interconnectors, mostly direct connections between countries. These links exhibit high utilization levels throughout the year and help smoothening out differences in weather conditions, production levels and consumption patterns. The Baltic Sea region becomes a net exporter of electricity, although all countries continue to import and export energy seasonally. Energy flows are increasingly moving from the Nordic countries, as well as through and from the Baltic States, toward the southwest and onward into continental Europe.

The Base Case analysis indicates that the Baltic Sea region could expand offshore wind capacity by up to 50 GW by 2040 on top of the 2030 values, with the largest growth occurring in Poland, Finland and Sweden. According to the results, the Baltic States could also develop significant offshore capacity, including for export, while Denmark and Germany would remain constrained by limited remaining offshore areas in the Baltic Sea. Based on input assumptions, most new offshore wind farms are connected radially directly to shore as distances are rather short. Some countries, however, provide offshore nodes that can serve as future hybrid hubs, with the Danish island of Bornholm emerging as a central linking point for Denmark, Sweden and Germany.

Results show that additional large scale renewable sources (RES), such as offshore wind, let the region contribute to Europe's clean energy needs, with an amount that varies dependent on external conditions, as investigated in the sensitivities. Part of the wind generation is used to cover electricity demand directly, while a growing share is used for hydrogen production via electrolysis. This strengthens the regional energy system by allowing flexible use of wind power and reducing reliance on global hydrogen imports.

The study also explores four sensitivities reflecting key uncertainties: lower electricity demand, lower hydrogen demand, higher onshore renewable energy potential and higher investment costs. The sensitivities help assess how modelling results for grid and generation capacities respond to changing assumptions and indicate the robustness of conclusions when critical parameters shift. Across all sensitivities, offshore wind remains part of the regional energy mix, although the scale varies significantly with underlying assumptions. Lower electricity demand reduces offshore wind buildout strongly, particularly in Finland and Sweden. Changes in hydrogen demand directly influence electrolyzer deployment and hydrogen flows. When more onshore renewables become available, they replace part of the offshore generation because of lower installation costs. Higher infrastructure costs on the other side reduce the buildout of both offshore wind and hydrogen production in the region. Despite these differences, the need for electricity interconnectors remains robust in all sensitivities, underlining their strategic value for a future energy system dominated by variable renewable energy sources.

Comparing the Base Case to a situation without additional interconnectors highlights the importance of regional cooperation. With the proposed interconnectors in place, extreme price spikes are substantially reduced, CO_2 emissions decrease, and overall system costs fall by an estimated €2 billion per year in 2040.

Overall, the study demonstrates that the Baltic Sea region can provide a major contribution to Europe's clean energy transition if offshore wind, electricity interconnection and hydrogen infrastructure are developed in a coordinated manner. The results show clear advantages of regional cooperation: lower system costs, higher energy security, and better integration of renewable generation. The identified infrastructure would require long lead times, thus stable frameworks, early investment decisions, continued collaboration among governments, TSOs and developers would be essential to fully capture the region's potential.

Study background

The Baltic Sea region holds significant potential to contribute to Europe's clean-energy transition towards 2050. Its countries share the ambition to accelerate large-scale RES deployment and strengthen energy security and energy independence, yet the region's diversity also calls for tailored cooperation. The Baltic Sea region comprises large and small power systems, varying degrees of interconnection, and different shares of onshore RES and offshore wind ambitions, technical potential as well as electricity demand. These differences create complementarities that can be best harnessed through gradual and coordinated regional engagement. A sea-basin perspective can unlock this potential by allowing the identification of synergies between national plans, supports coherent development of offshore infrastructure, and helps ensure that new assets deliver benefits beyond individual borders. Early coordination across countries towards the 2040 time horizon can improve the efficiency of investments, speed up implementation and make the most of the region's diverse wind and demand characteristics.

Having published its first offshore expert paper in May 2025, the Baltic Offshore Grid Initiative (BOGI) now takes a next step. Building on the European Network of Transmission System Operators (ENTSO-E) Pan-European Ten-Year Network Development Plan 2024 (TYNDP24), this offshore system optimization study provides a close-up of the energy system of the Baltic Sea region with a broad view on different sensitivities. National assumptions and potential for offshore wind development are updated. Thereby, the data used in this study establishes a new mid-point between TYNDP24 and TYNDP26 for the Baltic Sea region. The study moves from corridors (as identified in the TYNDP24 process) to potential projects for the 2040 time horizon, supporting a better understanding of how offshore cross-border projects can contribute to the regional system needs. Furthermore, the study analyses the interdependencies of a sector coupled (electricity and hydrogen) Baltic Sea energy system and how they impact regional planning of offshore infrastructure.

Today, Europe faces significant economic, financial and political uncertainties, which can alter framework conditions and affect the feasibility of grid development and offshore wind projects. In 2024 and 2025, some of the region's offshore wind auctions failed, demonstrating the impact of fast-changing external conditions. To address these uncertainties, sensitivity analyses are a key component of this system study. The sensitivities help assess how modelling results for grid and generation capacities respond to changing assumptions and indicate the robustness of conclusions when critical parameters shift.

All in all, the study aims to create a coordinated basis for discussions with and between policy makers, offering a plausible point of departure to promote regional basin planning in the Baltic Sea. It can align national ambitions with European objectives and provide a sound scenario for long-term infrastructure planning. While approaches and starting points differ, exploring regional coordination in the Baltic Sea represents an important opportunity: to strengthen system resilience, efficiently exploit offshore RES, and ensure that the region realizes its full contribution to Europe's decarbonization goals.

Modelling approach

To minimize system costs and plan the offshore system of the Baltic Sea region, a sector-coupled linear investment optimization model was used, with 2040 chosen as the target year. This year is widely used as it remains closely linked to upcoming investment decisions. For an identified project to be operational by 2040, preparations would have to start in the very near future.

Model and input data updates

As a basis, the TYNDP24 NT2040 model was used. It has been modified to allow for investments into generation and transmission assets according to trajectories provided by the Transmission System Operators (TSOs). For the **Baltic Sea region,** the model was able to invest in:

- Offshore wind farms (Radial or hub-ready)
- Offshore interconnectors
- Hydrogen pipelines
- Electrolyzers (on- and offshore)
- Onshore transmission capacity fine-tuning (up to 1 GW per border)

The onshore electricity generation capacities, both renewable and thermal, as well as the electricity and hydrogen demand, were updated with latest figures from national plans and kept constant throughout the study. The offshore interconnection potentials for each country were provided by the respective TSOs to reflect the current political realities and strategies. In cases where a maximum offshore interconnection buildout was not specified (Sweden, Germany and Denmark), the optimizer was allowed to invest into up to 6 GW of new offshore interconnection capacity per country. However, to avoid excessive offshore interconnection between two markets, the buildout was limited to a maximum of one project per country pair.

For the **rest of Europe,** the RES generation capacities as well as the demands were brought to TYNDP26 levels and kept stable. The hydrogen storage capacities in Europe were also updated according to recent studies.[1] Other input parameters such as investment costs, commodity, fuel prices and CO_2 emission costs were harmonized with the latest numbers from the TYNDP26.

Reference grid

An important modelling aspect is the reference grid that is used as a basis for further expansion and the topology of the potential investment candidates. The reference grid for each region and type can be seen in the following table.

Table 1: Reference grid for electricity and hydrogen

	Baltic Sea	Rest of Europe
Onshore electricity grid	TYNDP24 – 2035 + updates	TYNDP24 – 2035 + updates
Offshore electricity grid	TYNDP24 – 2030	TYNDP24 – 2035
Onshore hydrogen grid	TYNDP24 – 2035	TYNDP24 – 2035
Offshore hydrogen grid	TYNDP24 – 2030	TYNDP24 – 2035

For the Baltic Sea region in particular, the reference electricity and hydrogen grids can be seen in the following map.

1 EWI – Institute of Energy Economics at the University of Cologne (2024): Hydrogen storage in German and Europe – Model-based analysis up to 2050, report commissioned by RWE Gas Storage West GmbH.

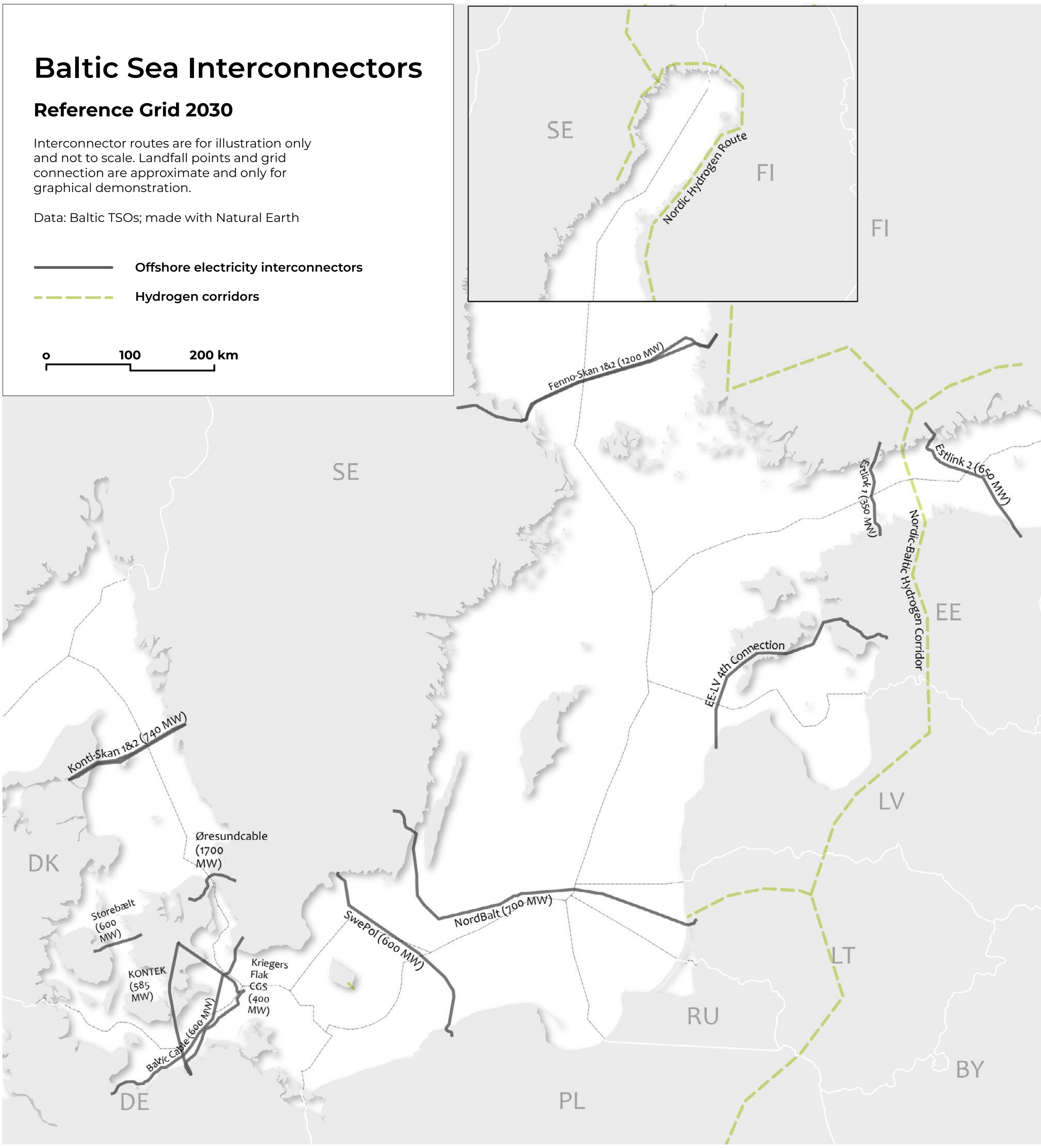

Figure 1: Electricity and hydrogen reference grids in the Baltic Sea region for 2030

As the focus of this study was the development of the offshore network infrastructure in the Baltic Sea region, particular consideration was given to the designated offshore wind areas and the topology of the offshore transmission system. The TSOs, referring to the region's national maritime spatial plans, specified whether areas that potentially host offshore wind capacities could either be connected radially only or might eventually be part of an offshore hub, i.e. are "hub-ready" in the study. Most capacities were specified by TSOs as candidates to be radially connected due to their short distance to shore.

The model topology allows for investment in point-to-point interconnections as well as in offshore hybrid interconnectors[2] between two zones. In addition, the islands of Bornholm (DK) and Saaremaa (EE) were modeled as offshore hubs facilitating links between multiple zones. The connection limits based on dimensioning faults for each country were also respected.

Investment optimization method

A linear modelling approach was applied. The optimization model was allowed to invest in offshore generation and offshore transmission assets to cover the electricity and hydrogen demands at the lowest possible cost. On the electricity side, the starting capacities for offshore wind, and offshore transmission in the Baltic Sea countries were based on projections from 2030 onwards. The optimizer was allowed to expand up to potentials defined by the TSOs. Thermal generation and onshore capacities were pre-set to 2040 levels. In the rest of Europe, the generation capacities were updated to 2040 levels as well, but no further investment was allowed. To avoid inconsistencies and forced offshore interconnections, a 1 GW onshore interconnector fine-tuning per border in Baltic Sea region was allowed in the optimization.

A similar set-up was implemented for the hydrogen sector. The demand in the entire Pan-European system can be covered by local production from electrolyzers (which couple the two sectors), by pipeline imports from Africa or by shipped ammonia imports, with the latter being the most expensive option. Prices for pipeline and ammonia imports as well as electrolyzers (onshore and offshore), were based on the TYNDP26 assumptions. To avoid bottlenecks in the hydrogen grid, some expansion in the rest of Europe was also allowed, based on TYNDP24 projects.

In other words, all input data were already at 2040 levels except for the Baltic Sea offshore infrastructure, which starts with 2030 values and is then optimized in this system study.

Since the optimizer uses a linear approach, all investment costs scale in a linear manner. This can result in small buildout proposals for interconnector projects. In order to avoid the computationally intensive process of solving a mixed-integer problem, an iterative "rounded relaxation" method was implemented. During these iterations, the small buildouts are removed, and the model is informed of the higher costs of partial buildouts. The resulting project portfolio is therefore more robust and more realistic in terms of asset sizes and cost. A more detailed explanation of the offshore topology and rounded relaxation methodology can be found in the Appendix.

2 A 'hybrid interconnector' or 'offshore hybrid project' has dual functionalities: i) connect two or more countries or market zones via subsea connections with each other and ii) connect offshore RES to the onshore energy system.

Base Case results

As described in the previous chapter, the study optimized the offshore system for the Baltic Sea in 2040 identifying the cost-optimal solution under the defined scenario assumptions. Further aspects such as system stability, energy system resilience and security of supply were not considered. The economic optimization revealed several potential electricity interconnector projects in the Baltic Sea. In Figure 2, projects throughout the entire basin are shown, spanning north-south and east-west, totaling approximately 13 GW of interconnection capacity. The island of Bornholm emerges as a strategic hub, linking Denmark, Germany and Sweden. For the Baltic States, the model suggests a connection to Germany, an additional Estonia-Finland link, and a potential Finland-Latvia line. Other projects include a potential Sweden (SE4)-Germany connection and a Finland-Sweden (SE3) link. The capacities of the lines range from 600 MW to larger 2000 MW projects.

In this scenario, we see significant electricity export potential in Finland. This leads to the interconnection buildout towards the south (via Sweden and the Baltics). The interconnection between Germany and the Baltics seems to serve a dual role. Although the main purpose is the transmission of electricity from Finland and the Baltics to the rest of Europe via Germany, we also see notable flows in the opposite direction, mainly in the summer when Germany has an excess of PV generation. Bornholm, with its strategic geographical position emerges as an important hub both for additional offshore wind integration and for facilitating of flows between different countries without the need for additional expensive offshore infrastructure. All of the identified interconnectors show at least some bidirectionality in their flows, helping smooth price peaks throughout the region.

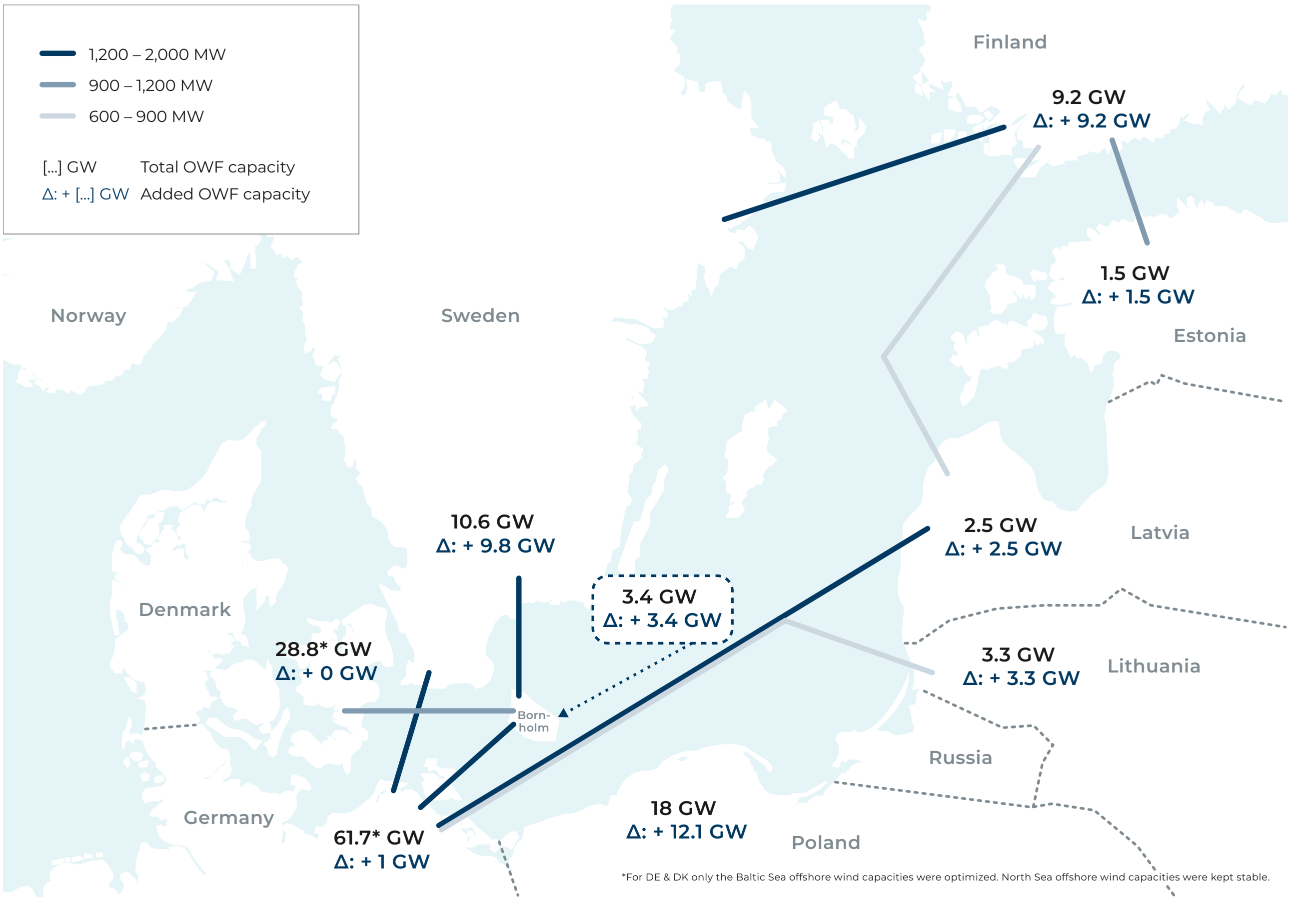

Figure 2: Interconnector and offshore buildout in the Base Case

Most proposed connections are point-to-point interconnectors between mainland countries rather than hybrid interconnectors that also integrate links to offshore wind farms. This reflects the fact that most offshore wind potential in the Baltic Sea is located close to shore, making direct mainland connections cost-effective. Four countries offered expandable offshore nodes to the model that would allow for offshore hybrid projects. These nodes are the Danish island of Bornholm, Estonia's Saaremaa Island, the Latvian hub and the Lithuanian hub.

On the onshore side, the available transmission fine-tuning of up to 1 GW per border is fully invested on all borders in the Baltic Sea except between Estonia and Latvia. All proposed lines (both on- and offshore) show very high utilization rates (80-90 %) indicating efficient use of the additional infrastructure.

Next to offshore transmission lines, offshore wind and electrolyzer capacities were also optimized. Starting capacities for 2030 and trajectories for 2040 were provided by the Baltic Sea TSOs. For 2030, the region shows a diverse picture: while the Baltic States and Finland have no offshore wind farms, Poland, Denmark and Germany are more advanced, with a similar picture for electrolyzers. The assumed offshore wind starting capacity for 2030 is 13 GW (excluding DE North Sea and Denmark West (DKW)) with electrolyzers at around 7.2GW (excluding DE and DKW – see Table 2 for details).

In the Base Case, the additional offshore wind capacity reaches 51 GW. Most countries approach their 2040 threshold, which represents the reported trajectories and not necessarily the technical potential. Poland sees the largest expansion with around 15 GW, followed by Finland and Sweden with around 10 GW each. The Baltic States add 10.5 GW. Bornholm becomes an energy hub with 3 GW, while Germany adds only 1 GW as its Baltic Sea offshore wind potential is nearly exhausted by 2030. Denmark's and Germany's North Sea offshore development was kept constant as the optimization focuses solely on the Baltic Sea.

The produced offshore wind energy is used for direct electrification and also for hydrogen production via electrolysis (which couples the two sectors). European hydrogen production is expected to mainly appear onshore, but offshore hydrogen production from dedicated wind farms (DRES) could play a role in the future as well. In this case, offshore wind feeds directly into electrolyzers at sea, with hydrogen transported to shore via pipeline. This could become a more attractive alternative for offshore RES located far off the coast, where the cost of connection is higher. From the total offshore RES buildout of 51 GW, about 9 GW is dedicated to offshore hydrogen production, particularly in Poland (≈ 3 GW), Estonia (≈ 2 GW), Denmark (≈ 1.4 GW), Lithuania (≈ 1.2 GW) and Finland (≈ 1.1 GW). However, grid-connected onshore electrolyzers remain the main source for hydrogen production with an additionally built capacity of 40 GW across the Baltic Sea region. A large part of this capacity is built in Finland with 16 GW and Poland with 9 GW. This is driven by the high-RES potential in Finland and a strong local hydrogen demand in Poland. Nevertheless, expansions between 1 and 6 GW are found in the rest of the Baltic Sea countries. DKW electrolyzer capacity was not optimized as the study focuses on the Baltic Sea Region only. On the hydrogen transmission side, the model invested only into a small amount of offshore pipelines, indicating no bottlenecks for hydrogen transport in Baltic Sea region.

Offshore wind, and to a large extent electrolyzer buildout, reach their maximum values for 2040 in all countries. This shows, that energy security is improved as the region can cover large parts of the necessary needs for the energy transition through intra-regional production of both electricity and hydrogen in a cost-effective way. However, it is important to note that these outcomes reflect the input of the projected hydrogen demand as well as the assumptions regarding hydrogen import prices and the constraints on import volumes via pipelines and ammonia into Europe, which remain uncertain.

As expected in an energy system powered almost entirely by variable renewable energy sources, electricity prices show increased volatility both in the short term (across days and weeks) and over the course of the full year. The additional offshore interconnectors help smooth out price swings across the region by allowing electricity to flow towards areas where it is needed most. The flexibility provided by linking the electricity and hydrogen sectors via electrolyzers supports stabilizing electricity prices. However, hydrogen prices and electricity prices mutually influence each other to some extent. A balanced development of production and demand of both sectors would be beneficial for the region.

Price duration curves in the Baltic Sea countries appear as expected with seasonal peak prices on winter days with low wind infeed and lowest prices on summer days, with high PV infeed. Market results show that average electricity prices in the region are highest in Germany. In the rest of the Baltic Sea region, prices are generally lower and more aligned with each other, with Finland and Sweden showing the lowest electricity prices benefitting from the Swedish hydro-based electricity production. Hydrogen prices converge across the Baltic Sea region, indicating sufficient pipeline infrastructure and no issues with system congestion.

When considering electricity flows, the Baltic Sea region serves as a net exporter to the rest of Europe, as the solver activated renewable generation potentials in many countries of the region that surpass their national consumption needs (see Figure 2). This translates into a positive net position where the region's total annual electricity exports exceed its imports by 75 TWh. Among the Nordic countries (DK, FI, SE), each country maintains a net export position of 15–30 TWh per year, either by exporting electricity directly to Germany or via interconnections with the Baltic States. The Baltic States in turn export and import seasonally, while also facilitating flows from the North to the South, thus ending up with a more balanced net position. Germany and Poland are modest net exporters, though both experience significantly higher trade volumes of imports and exports, with Germany also acting as a transit hub for electricity flows from the Baltic region towards Central and Southern Europe.

On the hydrogen side, the Baltic Sea shows a more diversified picture. While some countries have a strong exporting profile, other countries are net importers. Among the net exporting countries, Finland and Denmark account for a large share of exports. Lithuania is the main hydrogen exporter among the Baltic States, but both Estonia and Latvia have net exporting positions. Germany is the largest importer of hydrogen in this scenario stemming both from domestic needs but also from transit flows to the rest of the continent. Also, Poland is a net importer of hydrogen. While the Baltic Sea region contributes to the European hydrogen production, a significant share of hydrogen (almost 50 % of total hydrogen demand) is imported to Europe from world markets.

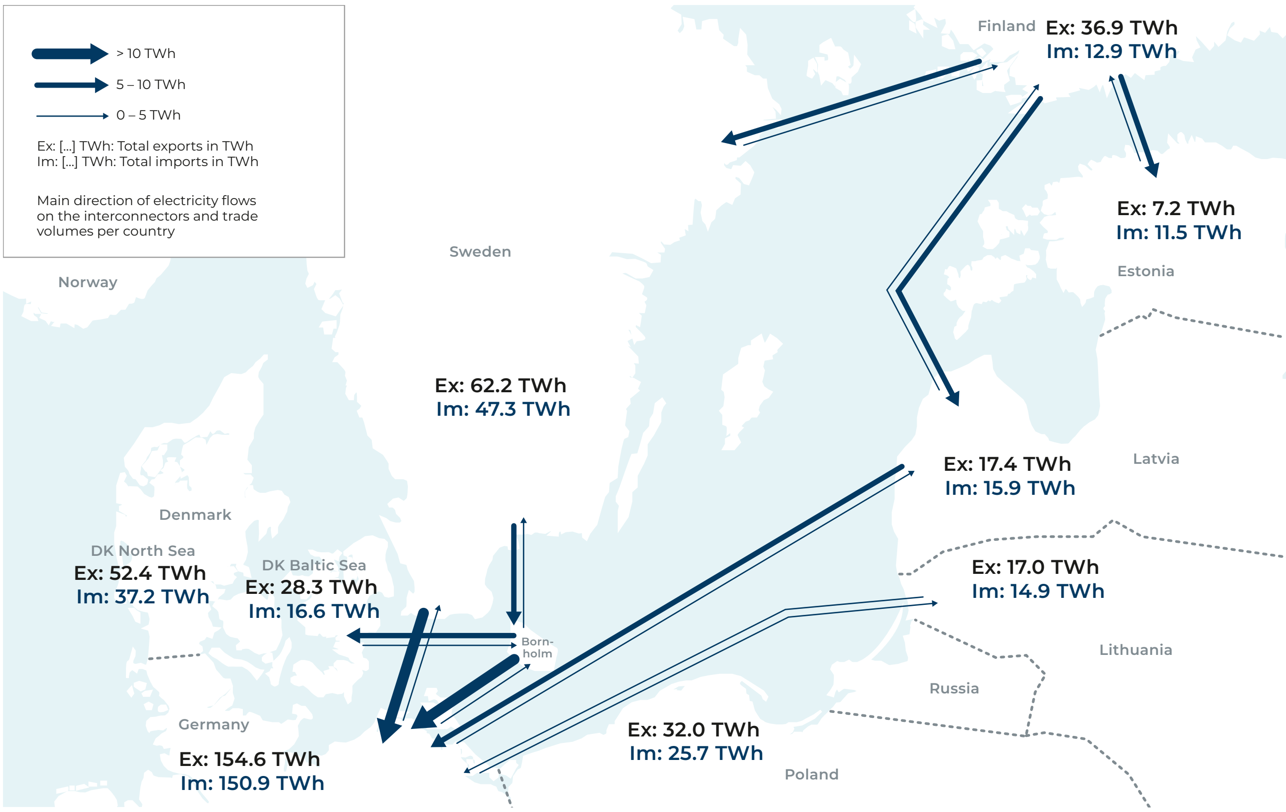

Figure 3: Directions and volume of the expected electricity flows on the interconnectors

These results indicate the potential and the European need to utilize the Baltic Sea region's renewable energy resources to secure a green and cost-efficient energy transformation for the continent as a whole. Offshore wind remains a key resource that can be utilized to achieve that goal with radial connections to the mainland still emerging as the preferred solution to connect these generation assets to the grid in the Baltic Sea.

Benefits of identified interconnections

Interconnectors form an essential component of a stable and secure European energy system. The findings of the Base Case clearly show that increasing interconnection capacities between countries in the Baltic Sea region is important, not just for a stronger system by connecting countries with each other, but also for fully tapping into the benefits of expanded renewable generation capacities. It then becomes important to assess which additional advantages can be realized through greater interconnection, beyond what is achieved by adding more offshore wind power.

To achieve this goal, the results of the Base Case were compared to a situation where the same system was optimized without the option to add interconnectors in the region between 2030 and 2040, thus reflecting a more national focused approach to grid planning. All other investments were allowed in a similar way as in the Base Case. By looking at the results of this comparison, the additional benefits of new interconnectors in the region can be assessed.

As in the previous analysis, the model aimed to meet electricity and hydrogen demand at the lowest possible cost. The results show that the base case incorporating interconnectors buildout leads to a more cost-effective future power system than the comparison case without interconnections. This highlights how cross-border collaboration delivers greater benefits to the region than a purely national approach.

In particular, compared to a case without the additional interconnectors…

— **Results showed that peak prices (>500 EUR per MWh) are reduced significantly in the Baltic Sea region.** Interconnectors help lower peak prices by enabling imports from countries with different load and generation profiles, reducing dependence on costly local peaking plants. They also reduce the need for expensive demand-side response measures by providing additional generation capacity from neighboring systems, ensuring reliable supply without forcing sensitive consumers – such as large scale industrial facilities – to adjust their usage. Moreover, as household electricity contracts become increasingly flexible, interconnections act as a crucial safeguard against market volatility, offering protection against extreme price fluctuations.

— **CO_2 emissions are reduced by 2.2 million tons across Europe** for the modelled year 2040. It is a consequence of changes in generation dispatch and the unlocking of renewable generation potential.

— **System costs savings of 2 billion EUR per year in 2040 are realized.** This cost reduction stems from savings in operational costs, such as those linked to fuel for thermal power generation and the reduction of expensive hydrogen imports. ETS costs reduction for CO_2 are already included. However, in case of considering additionally the societal costs of CO_2 according to the ENTSO-E CBA guidelines[3] this would lead to even higher system costs savings.

Taking all these effects into account highlights that interconnectors (especially point-to-point) are a cornerstone of tapping into the export potential of green energy from the Baltic Sea region. They enable the cost-efficient sharing of renewable energy, be it offshore wind or onshore RES, reduce system costs, CO_2 emissions and price peaks. This also strengthens the region's energy security as the need for long-distance imports even from outside Europe is reduced.

3 CBA 4 Guideline_entso-e

Sensitivities results

Europe faces significant economic and political uncertainties, which can alter framework conditions and affect the feasibility of grid development projects. To address these uncertainties, sensitivity analyses are a key component of this system study. They help assess how modelling results for grid and generation capacities respond to changing assumptions and indicate the robustness of conclusions when critical parameters shift.

Four sensitivities were deemed most relevant for this study (see Figure 4)

1. Lower electricity demand across Europe
2. Lower hydrogen demand across Europe
3. Higher potential for onshore renewable energy sources (RES) in the Baltic Sea region
4. Higher investment costs for all assets across Europe

Electricity demand highly depends on the speed of direct electrification. The development in this area can be impacted by many factors, including costs, industry development and the existence of supporting governmental subsidy schemes or regulatory frameworks. The same is valid for the development of hydrogen demand across Europe, which acts as a critical lever of both the size and the flexibility in overall electricity demand.

In most cases, onshore RES provide a cheaper alternative to offshore wind. However, their potential, especially the buildout of onshore wind, is often capped by land use limitations and/or local resistance.

Substantial cost increases, both of materials and interest rates, have had a dramatic impact on the speed of offshore wind development in the last couple of years. This study is based on the standard cost levels of TYNDP26 and assumes thus costs that do not reflect the latest cost increases that have recently materialized due to too few suppliers and production capacity constraints. While TYNDP cost levels reflect reasonable assumptions for 2040, sensitivity 4 brings cost levels closer to current price hikes, thus showing the effect high-cost scenarios would have on the offshore infrastructure buildout.

Each parameter was evaluated independently through separate sensitivity model runs. By methodically adjusting these factors, it is possible to determine the extent of their impact on the model outcome, providing deeper insight into related risks, opportunities and the general trends that influence the results of the Base Case. In reality, several of the modelled sensitivities might occur simultaneously and thus have cumulative impact.

As outlined in the modelling chapter, the parameters being optimized in the study only focus on the Baltic Sea region while keeping parameters in the rest of Europe constant .The same approach applies to the sensitivities. In sensitivities 1, 2 and 4 electricity demand, hydrogen demand and costs are adjusted for the whole system, while only the impact on offshore wind, hydrogen, and interconnector development in Baltic Sea countries is analyzed.[4] In sensitivity 3 only the onshore RES potential for the Baltic Sea countries (excluding Germany and Denmark West) is increased, while the onshore RES potentials for the rest of Europe are kept at the same levels as in the Base Case. Consequently, results should be interpreted in terms of directional trends rather than absolute figures.

4 In order to dampen this “All Europe” effect, capacities of RES and electrolysers have also been reduced – although to a minor extend.

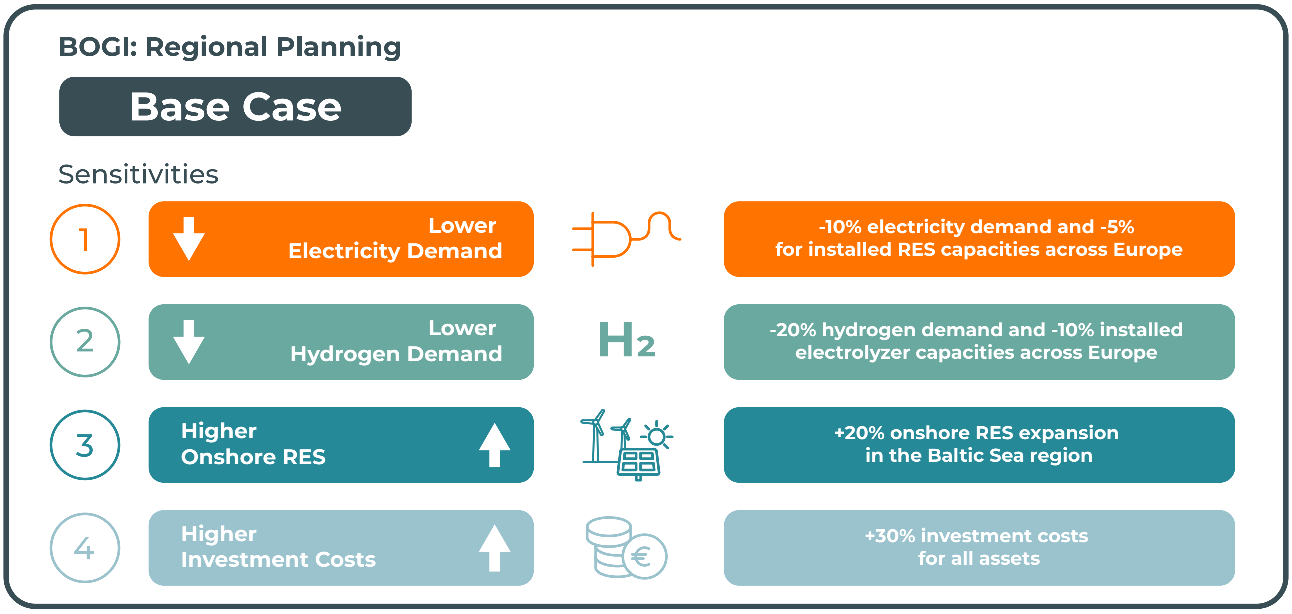

Figure 4: Sensitivity overview

Key insights from the sensitivity analyses include the following:

Lower electricity demand (-10%) and reduced installed RES capacities (-5%) in all of Europe

reduces offshore wind development in the Baltic Sea region significantly. With a total buildout of offshore wind of 18 GW (- 33 GW) in the Baltic Sea Region, this represents more than 60 % regional reduction compared to the base case. In Finland, offshore wind buildout is stopped completely, while it is severely reduced in Sweden and Poland. With more RES available elsewhere in Europe to cover remaining demand, export opportunities from the Baltic Sea region decline, electricity prices fall, and offshore wind becomes less attractive.

This limits electrolyzer deployment and hydrogen production in the region. Offshore produced hydrogen (DRES) in particular is almost fully removed as it is no longer cost competitive. As hydrogen production capacity was kept constant in the rest of Europe, lower electricity prices increase hydrogen production elsewhere in Europe thereby reducing the hydrogen price substantially which in turn not only reduces the hydrogen production in the Baltic Sea region but also global imports to Europe.

With less offshore wind energy production in the region the economic rationale for some interconnectors changes. The interconnector Finland-Latvia is no longer viable. On the other hand, we still see a need for interconnectivity between Germany and the Baltic States.

As explained before, the model setup keeps the rest of Europe constant and only allows adjustment in the Baltic Sea region. Thus, the trends observed here, i.e. a reduction of offshore wind capacity and hydrogen production (especially DRES) would likely be felt all over Europe. Still results seem to confirm that the export opportunities of the Baltic Sea region, both for electricity and hydrogen, depend on the need for offshore wind to fuel the energy transition in Europe.

Lower hydrogen demand (-20%) and reduced installed electrolyzer capacities (-10%) in all of Europe

results in more generation capacities being available to be used in the electricity sector where before they were utilized to cover the hydrogen demand. This strongly affects offshore wind buildout, mainly in Finland and Sweden where a reduction of 10.3 GW and 6.7 GW respectively is observed. In Finland this additional offshore wind was used almost evenly between the electrolyzers and for exports. In Sweden´s case, the previously built offshore capacity was being built in large to cover the hydrogen demand, which in this case does not exist anymore. Also, in this scenario DRES dedicated to hydrogen production built in the Baltic Region is almost fully removed since it is no longer economically viable to generate electricity solely for hydrogen production. Subsequently electrolyzer capacity buildout in all Baltic Sea countries also decreases (nearly 30 percent in total). Hydrogen exports from the Baltic Sea drop by 50 %, combined with lower imports of hydrogen from the rest of the world. The electricity export from the Baltic Sea region is only moderately reduced. Prices for electricity and hydrogen fall across Europe.

With no additional offshore wind in Finland and lower hydrogen production in the region the interconnector between Finland and Latvia becomes economically less attractive. The interconnector between Finland and Estonia is enough to transport the excess electricity towards the Baltics. Interconnectivity needs between Germany and the Baltic States remain in place however, with reduced net flows to Germany.

Higher onshore RES potential (+20%)[5] in the Baltic Sea region

replaces part of the offshore wind buildout in the region with cheaper onshore generation. Of the 11.5 GW reduced offshore wind, 9 GW alone come from complete buildout stop in Finland. Instead of offshore wind about 9 GW onshore wind are built additionally in Finland. Sweden experiences an increase of 7.6 GW of onshore wind while the Swedish offshore wind buildout remains largely unchanged.

Lower electricity prices enable greater electrolyzer deployment in the Baltic Sea region, boosting both electricity and hydrogen exports to the rest of Europe and reducing global hydrogen imports. Germany still facilitates exports to the rest of Europe since the price difference remains significant.

On the interconnector side, interconnection capacities remain similar to the base case. We see, however, a shift of interconnection need between Finland and Latvia to Sweden and Latvia, driven by higher (and cheaper) onshore wind production in Sweden. Onshore RES production in Finland reaches the same levels as earlier offshore wind production. However, production happens at different time periods and is primarily used for national consumption (e.g. hydrogen production) rather than electricity exports.

Higher investment costs for all assets (+30%)

dampen offshore wind and electrolyzer buildout in the Baltic Sea region. Additional offshore wind buildout in Finland is stopped completely and reduced by one third in Sweden (- 3.2 GW). Hydrogen imports from outside Europe become more competitive, reducing electrolyzer capacity in Sweden, Finland, and the Baltic States.

Offshore wind for direct electrification remains viable, so electricity exports from the region in general decline only slightly, while hydrogen exports from the Baltic Sea region fall sharply. Prices for electricity and hydrogen rise slightly across Europe.

As the study builds on cost assumptions of TYNDP26, these do not reflect the actual price peaks. Modelling a cost increase of 30% as done in this sensitivity reflects current high-cost levels and shows that offshore wind buildout in such a cost setting becomes economically less attractive.

Looking at the interconnector buildout, it becomes again clear that some interconnections primarily serve the export of cheaper renewable electricity from Nordic countries (SE and FI) to the rest of Europe through the Baltic States to Germany. In this high-cost scenario, shorter distances are favored by the model, so the interconnection between Finland and Latvia is removed and the overall interconnector capacity between the Baltic States and Germany is reduced (-0.7 GW). It can be anticipated that under sensitivities with even higher cost increases, a larger share of the identified offshore interconnector buildout would be significantly reduced, as we approach a point where these projects are no longer economically viable.

5 Onshore RES potential in German was kept constant as a 20% increase in German RES potential would have had a huge impact on the results due to Germany´s size. Furthermore, DK West also was not part of the increase as we just focused on the Baltic Sea side.

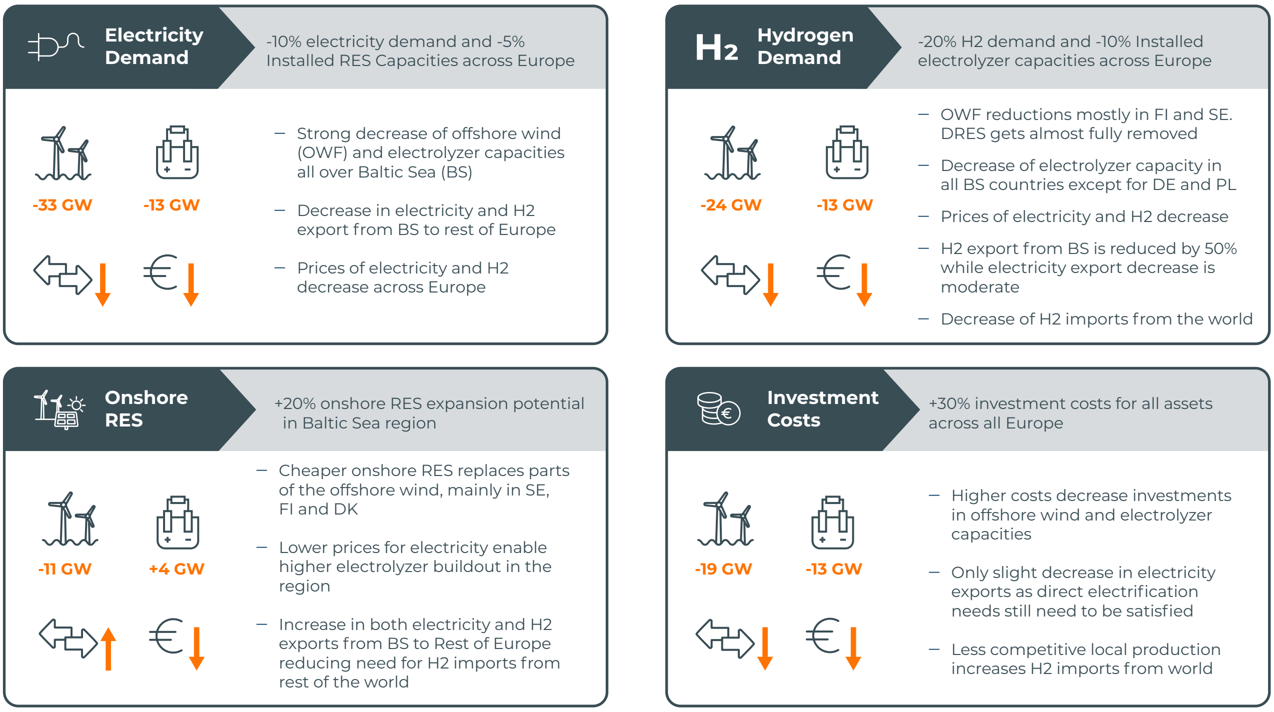

Figure 5: Main findings of the sensitivities

Despite these variations, interconnector development remains relatively stable across all sensitivities (see Figure 6). In carbon-free based systems with high RES, interconnectors are essential to balance price differences and leverage the low correlation in generation across the Baltic Sea region.

The sensitivity analyses demonstrate how results for the Baltic Sea region change when key input parameters are varied. The study confirms that offshore wind development in the region is strongly influenced by demand levels, cost assumptions, and the availability of alternative renewable sources. Nevertheless, offshore wind remains a component of the system in all scenarios.

Reduced electricity and hydrogen demand lowers the need for offshore wind expansion, particularly in countries with abundant RES potential and long transport corridors for electricity or hydrogen (e.g., Finland and Sweden). Similarly, assuming greater onshore RES potential in the Baltic States, Poland, Finland, and Sweden makes offshore wind less attractive, as onshore development is generally more cost-effective. Despite these shifts, the Baltic Sea region continues to act as a net energy exporter to Germany and the rest of Europe.

In contrast, interconnector projects – including hybrid solutions – remain robust under all sensitivities. This reflects a core assumption: Europe and the Baltic Sea region are transitioning from fossil-based systems to a diversified mix of renewable energy sources. In such a future, enhanced interconnectivity is essential for cost-efficient and reliable integration of variable renewable generation, enabling price convergence and resource sharing across borders. This strengthens energy security for both the Baltic Sea region and the entire Pan-European electricity system.

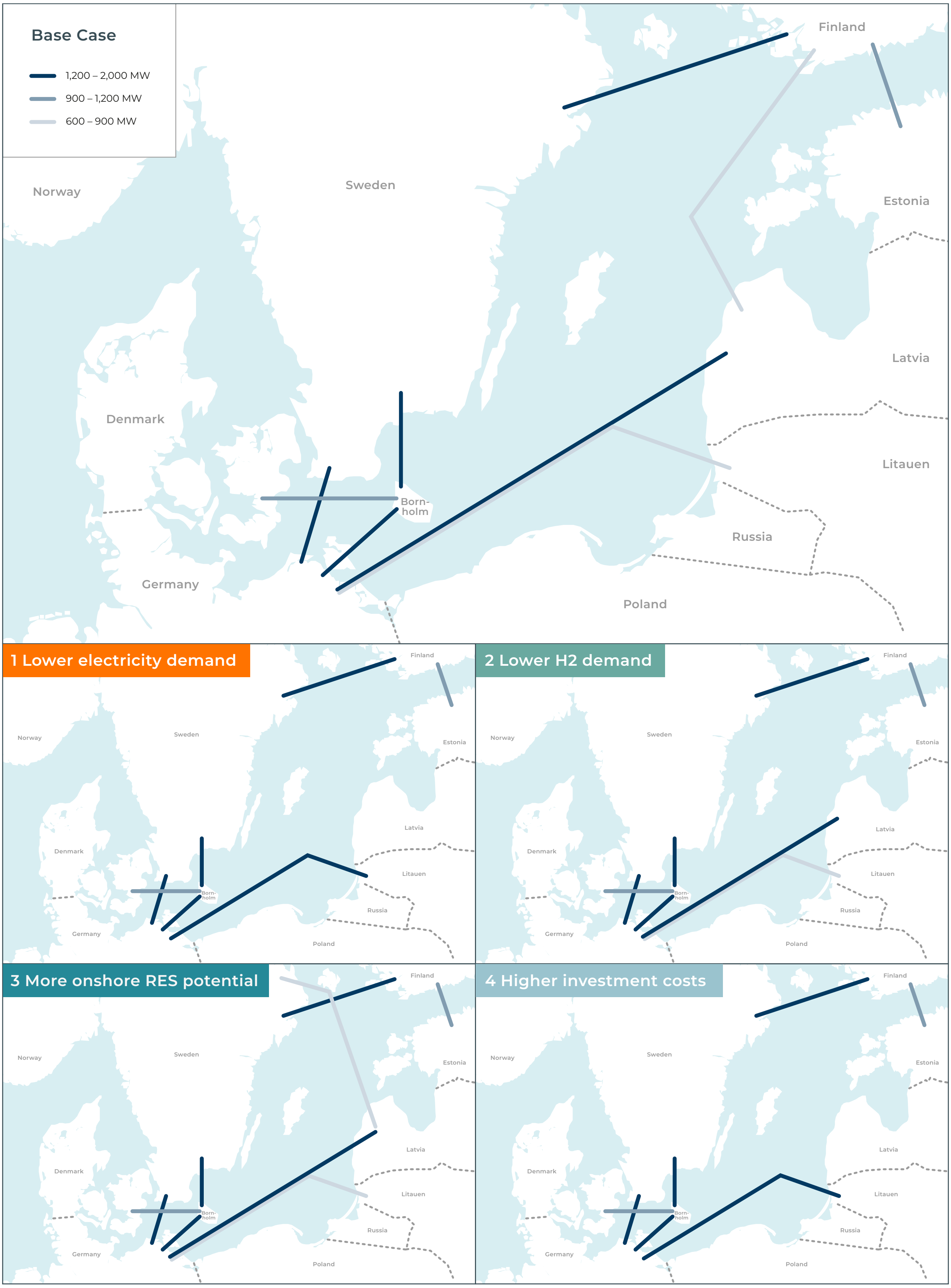

Figure 6: Interconnector buildout throughout the Sensitivities

Next steps

Regional sea-basin planning creates a basis for coordinated discussions with and between policy and decision makers. It takes the identification of corridors for interconnection a step further towards potential projects, while also showing the impact of different sensitivities for the region. The Baltic Sea TSOs will continue to jointly engage in the development of the power system, work closely with governments and project developers, to further advance the offshore ambition in the Baltic Sea region.

Appendix

The appendix provides additional details on the modelling approach and the key input data used in this study. Here, we explain the methods, assumptions, and data sources behind our analyses to ensure transparency and reproducibility. This section supports a deeper understanding of the results and allows stakeholders to evaluate the robustness of our findings.

Input Data

In this section, we provide additional details regarding the input data and their sources. The analysis is based on the TYNDP24 2040 NT model. To align the model with the objectives of this study, several adjustments were made to both the input data and the overall setup. Given that the study focuses on the Baltic Sea region, these modifications were applied differently for countries within the region compared to the rest of Europe.

For countries outside the region, the primary aim was to harmonize the data with TYNDP26 as closely as possible and to prevent artificial bottlenecks that could distort the results. Accordingly, renewable generation capacities, electrolyzer capacities, and electricity and hydrogen demand across the rest of Europe were updated to TYNDP26 levels. To ensure consistency in the transmission network between TYNDP versions and between the reference grid of the TYNDP24 model (2035 grid) and the anticipated 2040 grid, additional cross-border capacity was incorporated based on projects submitted in TYNDP24 and their expected commissioning dates. Similarly, for the hydrogen pipeline network, expansion of onshore corridors was allowed in line with TYNDP24 projections. Hydrogen storage capacities were also increased to more realistic levels, informed by an EWI[1] study. These adjustments ensure that the system outside the Baltic Sea region reflects conditions as close as possible to the projected 2040 scenario.

For the Baltic Sea region, a tailored approach was adopted. The TSOs in the region provided their projections for onshore renewable and thermal generation capacities for 2040, along with demand data. For offshore wind, electrolyzers, and batteries, the TSOs supplied planned capacities for 2030 as well as the maximum potential capacities per zone up to 2040. Regarding the onshore transmission network, capacities were updated similarly as in the rest of Europe, by including projects of sufficient maturity for 2035. Additionally, a 1 GW fine-tuning capacity limit was introduced for investments between onshore borders to prevent "forced" offshore interconnections between neighboring zones. For the offshore electricity network, TSOs specified buildout limits for offshore interconnection capacity based on their plans and strategies – ranging from a 400 MW cap for Poland to unrestricted optimization for Germany, Denmark, and Sweden. To avoid unrealistic interconnection levels, a 2 GW investment cap was applied between each country pair.

Economic data also played a critical role in updating the model. Commodity prices for hydrogen and ammonia imports, natural gas, and other fuels, as well as ETS costs for CO_2, were harmonized with TYNDP26 scenario assumptions. Investment costs for the various technologies were also sourced from the same dataset. These costs are particularly significant as they strongly influence the analysis.

For offshore transmission expansion, costs were calculated based on inter-zone distances and a routing factor of 1.3, with additional consideration for DC converter costs. For radially connected offshore wind farms, investment costs depend on the technology (AC or DC) and the distance to shore, with 80 km set as the AC limit. For hybrid offshore wind farms, platform costs are included in generation costs, while transmission leg costs are calculated separately. The detailed offshore topology will be presented in the following section of the appendix.

Offshore Topology and Setup

A key objective of the BOGI System Study is to assess the development of the offshore electricity transmission network in the Baltic Sea. Consequently, particular attention was given to the configuration of the offshore topology within the model.

As previously noted, TSOs provided offshore wind potential for the various offshore areas and indicated in

1 EWI – Institute of Energy Economics at the University of Cologne (2024): Hydrogen storage in German and Europe – Model-based analysis up to 2050, report commissioned by RWE Gas Storage West GmbH.

the PEMMDB whether these areas should be considered hub-ready. Purely radial capacities were therefore restricted to connections with their respective onshore home markets. For hub-ready capacities, a different modeling approach was applied.

For the 2040 target year, we assume that hybrid HVDC interconnectors integrating one or two offshore wind farms are technically feasible without requiring an additional platform beyond the one hosting the converter (see Figure 7 for an example). Further offshore network meshing beyond these hubs was not considered, except for hubs located on physical islands such as Bornholm (Denmark) and Saaremaa (Estonia).

In PLEXOS, the model setup was designed to allow different types of offshore interconnections between nodes. The simplest configuration is a point-to-point line between countries; therefore, investment candidates of this type were introduced for all country pairs.

For hybrid interconnections, a more detailed setup was implemented. For each potential wind farm designated as hub-ready, multiple nodes were generated. Each node can connect to its home market and to one additional area (not belonging to the same wind farm). This approach enables the model to generate all feasible hybrid interconnector configurations

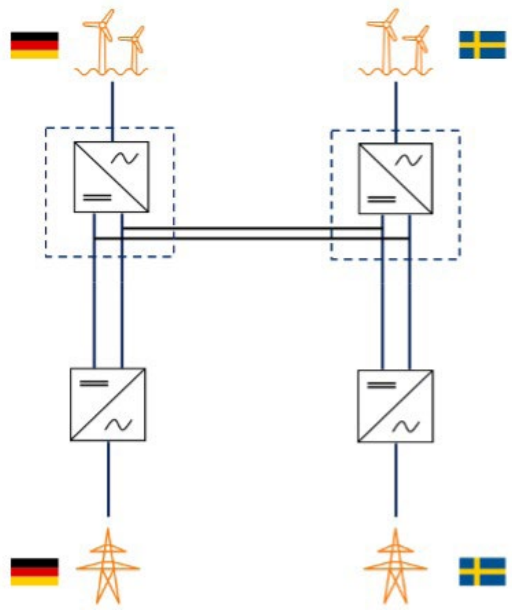

Figure 7: Example of a hybrid interconnector integrating offshore wind

while preventing undesired meshing. A schematic example is shown in Figure 8. The generation potential investment limit applies to all nodes of a wind farm, ensuring that the total buildout does not exceed the specified maximum. As a result, the model can produce either a cross-border radial connection or a hybrid interconnector involving one or two wind farms, depending on the countries involved.

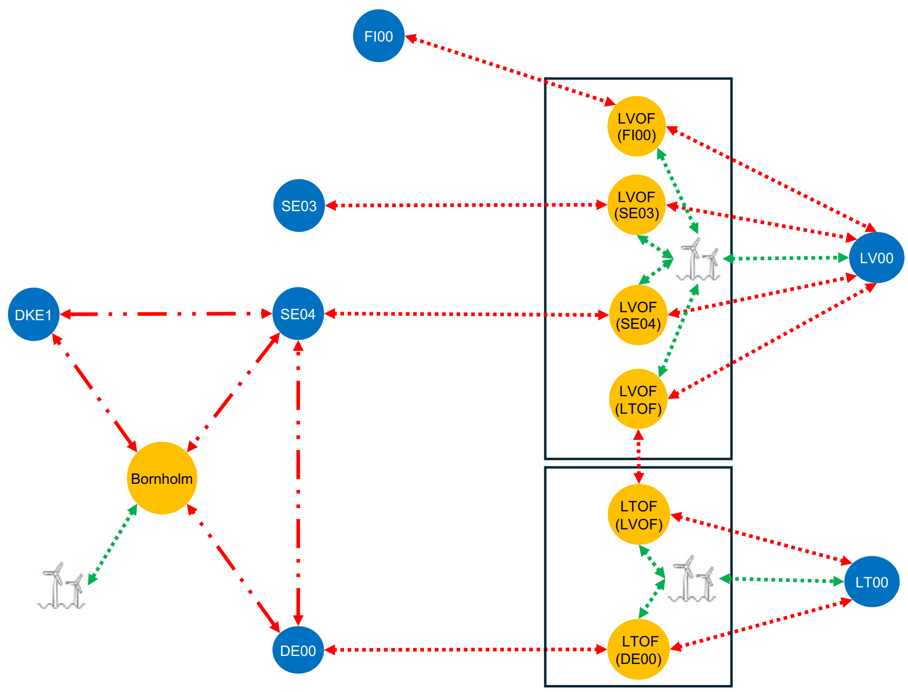

Figure 8: Schematic example for hybrid interconnector setup (blue circles are home markets, yellow are offshore hubs)

Rounded Relaxation

Linear optimization models frequently generate solutions with numerous small, fractional interconnector buildouts. Such outcomes are not realistic, as transmission investment costs are inherently non linear: for example, a 1 GW interconnector does not cost half as much as a 2 GW asset. One solution is to employ a Mixed Integer Programming (MIP) formulation to enforce binary or discrete project level decisions. However, MIP models are computationally intensive and often impractical for large-scale system studies.

To approximate the effect of discrete investment decisions while keeping solution times computationally manageable, we implement an iterative post processing method inspired by the concept of Rounded Relaxation, adapted specifically for interconnector sizing decisions.

The procedure operates according to the following iterative strategy:

Baseline Run

All interconnector candidates are initially represented using the cost structure of a standard 2 GW transmission line. This establishes a uniform reference for evaluating relative cost-effectiveness.

Iterative Adjustment Steps

After each model run, capacity expansion results are reviewed, and constraints for the subsequent iteration are updated as follows:

- **Elimination of Unrealistically Small Buildouts**
  Interconnectors with marginal or no deployment (< 300 MW) are considered non viable; their maximum capacity is therefore constrained to 0 MW in the next iteration.
- **Enforcement of High Capacity Projects**
  Interconnectors showing substantial deployment (> 1700 MW) are treated as cost effective, large scale investments. These assets are enforced as fully built in the subsequent iteration.
- **Progressive Expansion of Threshold Range**
  The lower and upper thresholds are gradually relaxed across iterations to guide the solution toward a stable and economically meaningful buildout configuration.

This process leads to a classification of remaining projects into two categories: fully built or medium sized. For medium sized projects, intermediate iterations adjust investment costs to reflect the increased unit cost associated with partial buildouts. Both thresholds and cost multipliers are user configurable.

An example of the logic is shown below:

Capacity Built [MW]	Action
0-300	Max Units Built → 0
300-700	Investment Cost*1.5
700-1,200	Investment Cost*1.25
1,200-1,500	Investment Cost*1.125
1,500-1,600	No action
1,700-2,000	Min Units Built → 1

By iteratively adjusting project constraints and cost assumptions, the method converges toward a set of interconnector investments that remain economically robust even when subjected to higher cost assumptions for partial buildouts. This yields a more realistic and implementable portfolio of transmission projects without requiring computationally intensive MIP formulations.

Table 2: Overview final capacities and results (*all DE and all DK) for the base case

		Baltic Sea	DE (BS)	DK	EE	FI	LT	LV	PL	SE
Grid-connected Offshore Wind	2030 Capacity [MW]	13,273	4,031	2,478	0	0	0	0	5,927	837
	Buildout [MW]	42,713	1,000	3,400	1,500	9,236	3,256	2,500	12,073	9,748
	2040 Capacity [MW]	55,987	5,031	5,878	1,500	9,236	3,256	2,500	18,000	10,585
Off-grid Off-shore Wind (DRES)	2030 Capacity [MW]	0	0	0	0	0	0	0	0	0
	Buildout [MW]	8,657	0	1,400	2,000	1,130	1,244	0	2,883	0
	2040 Capacity [MW]	8,657	0	1,400	2,000	1,130	1,244	0	2,883	0
Grid-connected Electrolyzers onshore	2030 Capacity [MW]	66,665	43,375*	16,334* (295.5 DKE)	0	1,400	1,300	0	400	3,856
	Buildout [MW]	40,476	1,012 (DE BS only)	1,196 (DKE only)	1,000	16,474	3,593	2,000	9,100	6,102
	2040 Capacity [MW]	107,141	44,387*	17,530*	1,000	17,874	4,893	2,000	9,500	9,958

Table 3: OWF buildout in all cases in MW

Radial OWF [MW]	**Base Case**	**Cost +30%**	**Elec -10%**	**hydrogen -20%**	**Onshore RES**
Denmark	0	0	0	0	0
Estonia	1,500	1,500	1,500	1,500	1,500
Finland	9,236	0	0	0	0
Germany	1,000	1,000	1,000	1,000	1,000
Latvia	2,500	1,320	738	2,500	2,500
Lithuania	1,856	3,800	740	1,923	700
Poland	12,073	10,726	7,857	12,917	11,210
Sweden	9,748	6,524	1,949	3,090	9,702
Sum	**37,913**	**24,869**	**13,785**	**22,930**	**26,611**

Hub OWF [MW]	**Base Case**	**Cost +30%**	**Elec -10%**	**hydrogen -20%**	**Onshore RES**
Denmark	3,400	2,925	2,878	3,400	3,400
Estonia	0	0	0	0	0
Finland	0	0	0	0	0
Germany	0	0	0	0	0
Latvia	0	0	0	0	0
Lithuania	1,400	0	1,400	1,400	1,400
Poland	0	0	0	0	0
Sweden	0	0	0	0	0
Sum	**4,800**	**2,925**	**4,278**	**4,800**	**4,800**

DRES Wind [MW]	**Base Case**	**Cost +30%**	**Elec -10%**	**hydrogen -20%**	**Onshore RES**
Denmark	1,400	475	522	0	1,400
Estonia	2,000	0	0	0	2,000
Finland	1,130	0	0	0	0
Germany	0	0	0	0	0
Latvia	0	0	0	0	0
Lithuania	1,244	700	0	0	2,400
Poland	2,883	3,000	0	0	3,000
Sweden	0	0	0	0	0
Sum	**8,657**	**4,175**	**522**	**0**	**8,800**

Table 4: Electrolyzer buildout in all cases in MW

Grid-connected Electrolyzers onshore [MW]	**Base Case**	**Cost +30%**	**Elec -10%**	**Hydrogen -20%**	**Onshore RES**
Denmark	1,196	796	796	1,196	1,196
Estonia	1,000	541	756	706	1,000
Finland	16,474	15,677	14,565	14,400	17,200
Germany	1,012	0	4,500	2,300	2,674
Latvia	2,000	825	513	1,020	2,000
Lithuania	3,593	2,752	1,746	4,023	3,629
Poland	9,100	9,100	9,100	9,100	9,100
Sweden	6,102	1,105	2,043	2,043	7,653
Sum	**40,476**	**30,796**	**34,019**	**34,789**	**44,453**
Off-grid offshore Electrolyzers [MW]	**Base Case**	**Cost +30%**	**Elec -10%**	**Hydrogen -20%**	**Onshore RES**
Denmark	1,144	400	400	0	1,121
Estonia	1,697	0	0	0	1,673
Finland	726	0	0	0	0
Germany	0	0	0	0	0
Latvia	0	0	0	0	0
Lithuania	1,087	565	0	0	2,061
Poland	2,400	2,400	0	0	2,400
Sweden	0	0	0	0	0
Sum	**7,054**	**3,365**	**400**	**0**	**7,256**

Table 5: Baltic Sea region import/export of electricity and hydrogen in GWh for sensitivities

Base	Electricity Exports [GWh]	Electricity Imports [GWh]	Net [GWh]
Denmark BS	28,280	16,589	11,692
Denmark NS	52,391	37,150	15,241
Estonia	7,250	11,454	-4,205
Finland	36,939	12,846	24,092
Germany	154,642	150,945	3,697
Latvia	17,427	15,908	1,519
Lithuania	16,965	14,858	2,107
Poland	31,951	25,723	6,229
Sweden	62,202	47,252	14,950

Base	Hydrogen Exports [GWh]	Hydrogen Imports [GWh]	Net [GWh]
Denmark	63,464	28,966	34,497
Estonia	27,848	21,526	6,322
Finland	44,343	2,435	41,908
Germany	45,642	196,485	-150,843
Latvia	28,808	26,713	2,095
Lithuania	43,909	28,198	15,711
Poland	29,209	52,963	-23,753
Sweden	24,156	26,789	-2,633

Cost +30%	Electricity Exports [GWh]	Electricity Imports [GWh]	Net [GWh]
Denmark BS	28,212	16,777	11,435
Denmark NS	51,870	37,372	14,498
Estonia	9,548	12,067	-2,519
Finland	24,344	17,845	6,499
Germany	154,464	149,840	4,624
Latvia	9,544	9,121	423
Lithuania	23,796	17,858	5,938
Poland	30,769	25,957	4,812
Sweden	65,644	41,379	24,265

Cost +30%	Hydrogen Exports [GWh]	Hydrogen Imports [GWh]	Net [GWh]
Denmark	38,041	6,462	31,579
Estonia	22,733	22,971	-239
Finland	36,563	4,285	32,278
Germany	57,836	184,824	-126,989
Latvia	23,122	23,587	-465
Lithuania	34,175	21,412	12,763
Poland	18,702	43,240	-24,538
Sweden	298	18,020	-17,722

Elec -10%	Electricity Exports [GWh]	Electricity Imports [GWh]	Net [GWh]
Denmark BS	26,955	15,837	11,118
Denmark NS	40,100	38,077	2,022
Estonia	9,354	12,145	-2,791
Finland	24,892	16,685	8,208
Germany	138,445	147,098	-8,654
Latvia	8,843	9,218	-375
Lithuania	21,696	17,457	4,238
Poland	23,833	29,381	-5,548
Sweden	61,672	43,907	17,765

Elec -10%	Hydrogen Exports [GWh]	Hydrogen Imports [GWh]	Net [GWh]
Denmark	44,310	4,330	39,980
Estonia	25,229	24,730	499
Finland	34,609	1,922	32,687
Germany	48,193	191,434	-143,240
Latvia	23,863	25,158	-1,295
Lithuania	30,352	23,299	7,053
Poland	9,660	44,101	-34,441
Sweden	162	12,280	-12,118

Hydrogen -20%	Electricity Exports [GWh]	Electricity Imports [GWh]	Net [GWh]
Denmark BS	27,856	16,345	11,511
Denmark NS	54,007	35,144	18,863
Estonia	9,362	12,551	-3,190
Finland	27,457	15,965	11,492
Germany	157,690	146,607	11,083
Latvia	15,701	11,505	4,196
Lithuania	15,319	13,828	1,491
Poland	30,937	25,708	5,228
Sweden	61,539	46,463	15,076

Hydrogen -20%	Hydrogen Exports [GWh]	Hydrogen Imports [GWh]	Net [GWh]
Denmark	36,133	4,544	31,589
Estonia	25,976	25,656	320
Finland	34,269	4,218	30,051
Germany	31,871	201,169	-169,298
Latvia	26,639	26,071	569
Lithuania	37,579	25,628	11,951
Poland	23,440	44,764	-21,324
Sweden	1,277	12,923	-11,646

Onshore RES	**Electricity Exports [GWh]**	**Electricity Imports [GWh]**	**Net [GWh]**
Denmark BS	29,273	16,298	12,975
Denmark NS	52,467	37,683	14,784
Estonia	8,639	11,632	-2,993
Finland	31,207	13,450	17,757
Germany	152,759	153,465	-706
Latvia	18,317	16,855	1,462
Lithuania	16,531	15,301	1,229
Poland	34,256	22,950	11,306
Sweden	71,165	46,064	25,101

Onshore RES	**Hydrogen Exports [GWh]**	**Hydrogen Imports [GWh]**	**Net [GWh]**
Denmark	75,040	40,100	34,940
Estonia	25,167	18,841	6,327
Finland	45,038	2,472	42,566
Germany	43,533	207,564	-164,031
Latvia	26,078	23,540	2,538
Lithuania	45,091	25,121	19,970
Poland	32,245	52,958	-20,713
Sweden	35,157	30,329	4,828

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