Offshore renewable energy and grids

An analysis of visions towards 2050 for the Northern Seas region and recommendations for upcoming scenario-building exercises

Final Report
July 2021

Authors

Christopher Andrey (Artelys)

Paul Barberi (Artelys)

Ekaterina Florez (DVN)

Wim van der Veen (DNV)

João Gorenstein Dedecca (Trinomics)

EUROPEAN COMMISSION

Directorate-General for Energy
Directorate C— Green Transition and Energy System Integration
Unit C4 — Infrastructure & Regional Cooperation

Contact: Thomas Brégeon

E-mail: Thomas.Bregeon@ec.europa.eu

European Commission
B-1049 Brussels

EUROPEAN COMMISSION

Offshore renewable energy and grids

An analysis of visions towards 2050 for the Northern Seas region and recommendations for upcoming scenario-building exercises

2021

EN

LEGAL NOTICE

Luxembourg: Publications Office of the European Union, 2022

ISBN 978-92-76-47244-5
doi: 10.2833/693330

Table of Content

GLOSSARY

ACER	European Union Agency for the Cooperation of Energy Regulators
ATR	Autothermal Reforming
BEMIP	Baltic Energy Market Interconnection Plan
CCfD	Carbon Contract for Difference
CCS	Carbon Capture and Storage
CTP	Climate Target Plan
EC	European Commission
ENTSO-E	European Network of Transmission System Operators for Electricity
ENTSOG	European Network of Transmission System Operators for Gas
EU	European Union
EU ETS	EU Emissions Trading System
EV	Electric Vehicle
GHG	Greenhouse gas
GW	Gigawatt
HVDC	High-Voltage Direct Current
JRC	Joint Research Centre
LTS	Long-Term Strategy
METIS	Markets and Energy Technologies Integrated Software
MS	Member State
MSP	Maritime Spatial Planning
NDC	Nationally Determined Contribution
NSCOGI	North Seas Countries' Offshore Grid Initiative
NSEC	North Seas Energy Cooperation
NUTS	Nomenclature of Territorial Units for Statistics
PCI	Project of Common Interest
PEM	Polymer Electrolyte Membrane
REFM	Renewable Energy Financing Mechanism
RES	Renewable Energy Source
SG	Support Group
SMR	Steam Methane Reforming
TEN-E	Trans-European Networks for Energy
TSO	Transmission System Operator
TWh	Terawatt-hour
TYNDP	Ten-Year Network Development Plan

EXECUTIVE SUMMARY

The region of the North Sea is foreseen to play a pivotal role in the decarbonisation of the European economy. This is due to several unique characteristics that the region possesses. First, the North Sea is recognised as having an excellent potential for offshore electricity generation technologies, and offshore wind in particular, thanks to the relative shallowness of its waters, allowing bottom-fixed wind turbines and other technologies to be deployed even far from shore. Second, the offshore wind regimes are very steady compared to other technologies such as onshore wind, ensuring that offshore assets have very high full load hours, some projects regularly running the equivalent of more than 4000 hours at full capacity. Third, the onshore region around the North Sea presents significant decarbonisation opportunities as it hosts large industrial clusters, which are good candidates to transition to the use of electrolytic hydrogen to decarbonise their processes, as they are hard to decarbonise through other means such as electrification. Fourth, the region also hosts considerable gas infrastructure (with dual networks dedicated to gases with different calorific contents, L-gas and H-gas) covering part of the countries surrounding the North Sea), which could turn out to be key assets to kick-start local hydrogen clusters via the repurposing part of the existing gas infrastructure. Finally, due to its coastal nature, the region hosts a number of large ports (for example Rotterdam, Antwerp and Hamburg), providing opportunities to import hydrogen and derivatives (e.g. e-methane, e-ammonia, e-methanol, etc.) from other regions, including from extra-EU suppliers.

In this context, one of the essential requirements to support investment decisions in renewable energy technologies, flexibility solutions, electrolysis, repurposing of gas assets, etc. is the establishment of consistent scenarios on how offshore renewable energy and grids in the region could evolve between today and 2050. Such scenarios can be the basis on which different stakeholders assess the market potential for their technologies, evaluate the associated risks and design strategies, and on which public authorities can draft mechanisms to incentivise the emergence of a well-adapted portfolio of projects at particular locations, etc.

Objectives of this study

The key objective of this study is to provide an overview of existing national and regional long-term analyses, assumptions and plans on offshore renewable energy and grids in the North Seas Energy Cooperation (NSEC) countries.

The study aims at identifying the common grounds and diverging aspects of transition pathways and their underlying assumptions, while also providing a qualitative discussion of the way the scenario-building and planning methodologies may differ.

Finally, while the objective of this study is not to establish a pathway or a scenario for the evolution of the energy system around the North Sea basin, we provide recommendations on aspects that we think are important to take into account in upcoming scenario-building exercises that aim at shedding light on potential plausible futures of the North Sea region. These aspects include for example renewable energy sources (RES) potentials assessment, maritime spatial planning, multi-energy considerations, and risk assessment.

The approach we have used in this study employs:

- A **literature review,** covering circa 40 relevant publications that provide scenarios or key insights into potential developments of the energy system in the North Sea region.

- A **stakeholder engagement process**, with bilateral interviews of circa 35 entities involved in various aspects of the development of the electricity, gas and hydrogen systems in the North Sea region (public authorities, project developers, TSOs, etc.)

Overview of key results and recommendations

A number of common grounds across scenarios have been identified, leading to a robust basis on which upcoming exercises will be able to build. The key common grounds are:

- **Ambitious decarbonisation levels** – The vast majority of the considered scenarios are in line with the climate neutrality objective at the 2050 time horizon, which is at the heart of the European Green Deal. Only a very limited number of scenarios are not on a pathway to reach that target, but, most often than not, this aims to test the robustness of the analysis. Therefore, while it is of crucial importance to continue building scenarios that are compatible with the 2050 net zero target, especially if they are underpinning infrastructure investment choices, it seems that this dimension is already well integrated by modellers and that no further recommendations on the decarbonisation levels to be imposed at that time horizon is required, according to our analysis.

- **Final electricity demand in 2030 is quite consistent across scenarios** – There is a good level of agreement on the level of electricity demand at the 2030 time horizon, especially when compared to the 2050 time horizon. Indeed, in many of the analysed scenarios, the trade-offs between direct and indirect electrification routes mostly appear in the 2030-2050 period, when heating, transport and industry undergo structural changes to fully decarbonise. Therefore, the uncertainties associated to these choices are not yet materialising in terms of electricity demand in 2030.

- **Electrolytic hydrogen will be a key contributor to the decarbonisation and will drive investments in RES capacities** – All the scenarios that have been considered include hydrogen as one of the options to decarbonise hard-to-abate sectors, and in some scenarios, hydrogen technologies are also considered as competitors to direct electrification routes (e.g. for mobility applications such as buses and trucks). Some scenarios foresee a role for alternatives to electrolytic hydrogen production in the EU (e.g. SMR/ATR with CCS, hydrogen imports, etc.). While it is positive that hydrogen is explicitly considered in most scenarios, as its production has a strong impact on the need for RES capacities and energy infrastructure, there are numerous uncertainties (see below).

- **The ambition in terms of deployment of offshore wind is in line with the European Commission Offshore Renewable Energy Strategy at the 2030 time horizon** – The scenarios that cover the countries in the North Sea region are compatible with the deployment levels targeted by the offshore strategy for the offshore wind technologies at the 2030 time horizon.

On the other hand, a number of uncertainties or diverging aspects between studies have been identified, especially at the 2050 time horizon (but also for previous time horizons to some extent). For each of the key uncertainties we have identified, we attach a recommendation on how it can be tackled in upcoming scenario-building exercises.

The key uncertainties and associated recommendations are:

- **Pace of decarbonisation** – The reviewed scenarios diverge in the speed at which they converge towards climate neutrality at the 2050 time horizon. The EU increased ambition 2030 GHG emissions reduction target is not integrated in the majority of scenarios, since most scenario-building exercises pre-date its proposal and adoption.

  Recommendation #1 - Ensure alignment with the 2030 55% GHG reduction target in upcoming scenario-building exercises.

- **2030 hydrogen demand** – The reviewed scenarios show a high level of convergence in terms of 2030 hydrogen demand levels. However, in our assessment, they are below the expected levels foreseen in national hydrogen strategies. As with the previous point, this is mostly due to existing scenarios pre-dating the EU hydrogen strategy, which has acted as a catalyst of national hydrogen strategies.

  Recommendation #2 - Ensure alignment of at least one of the scenarios with the most recently published hydrogen strategies, and consider variations on imports/exports, demand levels (see other recommendations)

- **Trade-off between decarbonisation routes and resulting hydrogen demand in 2050** – While there is a good level of agreement on electricity and hydrogen demand levels at the 2030 time horizon (although not always aligned with national hydrogen strategies, see previous point), there are important uncertainties related to the choices in 2050 between direct electrification, indirect electrification and use of biomethane to decarbonise end-uses in the industry, buildings and mobility sectors.

  Recommendation #3 – Build multiple contrasted scenarios of the demand for electricity, hydrogen and methane, with different depths of electrification, in order to allow for a no-regret analysis of infrastructure and RES capacities.

- **Hydrogen supply options and provision of flexibility** – While the volume of hydrogen required to meet end-use sectoral demand is uncertain (see previous point), the way to supply this volume is equally uncertain. According to publications and consulted stakeholders, the most promising option is electrolytic hydrogen, with potential roles for hydrogen imports and production of hydrogen via SMR combined with CCS (Carbon Capture and Storage). The hydrogen production methods have profound impacts on the interaction with the electricity sector, and hence on the flexibility services that have to be provided by other technologies.

  Recommendation #4 – Consider multiple import routes and optimise the deployment of renewables and flexibility solutions (interconnectors, batteries, pumped-hydro storage, CAES (compressed-air energy storage), hydrogen pipelines, hydrogen storage, repurposing of existing assets, hydrogen-fired turbines, etc.) to assess trade-offs on the location of electrolysers (offshore, close to landing points, close to industrial clusters), the additional deployment of renewables to meet the demand, etc.

- **Compatibility between scenarios and maritime spatial plans is difficult to assess** – The practices used by coastal Member States to establish their respective maritime spatial plans are found to diverge considerably, and the reporting of areas dedicated to renewable energy deployment and/or energy infrastructure is heterogeneous. This leads to uncertainties in terms of plausibility of RES deployment scenarios.

Recommendation #5 – Establish best practices in terms of maritime spatial planning, and assess the possibility of conducting a comparison between the latest set of MSPs and the potentials for offshore wind published in the ENSPRESO database developed by the Directorate General Joint Research Centre of the European Commission (JRC).

Furthermore, publications and stakeholders have identified regulatory and market design aspects that may, in their opinion, prevent some ambitious scenarios from materialising. These uncertainties could be addressed in scenario-building exercises by performing sensitivity analyses. The three key uncertainties are related to:

- The incentives to ensure the hydrogen demand emerges, given the current price differentials between fossil-based hydrogen and electrolytic hydrogen,
- The definition of an efficient offshore market design, especially for hybrid projects, with questions related to offshore bidding zones and the allocation of congestion incomes,
- The potential bottlenecks that could materialise due to permitting, especially for joint or hybrid project due to their international nature.

Finally, the study provides a set of recommendations related to the modelling approaches and datasets that underpin the definition of scenarios. The main recommendations are:

- Adoption of a **holistic approach**, recognising the flexibility that can be provided by all sectors of the economy, from smart electric vehicle charging to cross-sectoral seasonal flexibility via e.g. hydrogen storage,
- Representation of **flexibility needs on all timescales**, from infra-hourly to seasonal (potentially multi-annual), requiring models with an hourly time resolution (or finer) over the entire year to capture the challenges brought by RES integration and the solutions that can be proposed by sector integration,
- Evolution of the nature of scenario-building, **from visions to pathways**. We are now in an era of implementation of the transition, during which it becomes crucial to understand what to do next, and not only what we are aiming for in several decades. Building pathways also allows for the identification of no-regret options, which are required given some of the uncertainties discussed herein. This transition from visions to pathways should be accompanied by a more detailed spatial granularity, in order to better represent local specificities and links with the existing infrastructure.
- Finally, the last recommendation relates to **datasets**. First, there is a need to harmonise the outputs of maritime spatial plans so as to enable the benchmarking of scenarios against potential restrictions emerging from such plans. Second, efforts should be considered to increase the spatial resolution of offshore wind generation profiles, to enable the assessment of several offshore hub locations.

1. INTRODUCTION

General context – EU climate and energy targets

At the Paris climate conference (UNFCCC COP21) in December 2015, 197 Parties adopted the first-ever global, legally binding global climate deal. The deal has been ratified by over 180 countries, and has entered into force in November 2016. The EU has been a key player in reaching this agreement, which aims at limiting global warming to well below 2°C above pre-industrial levels and pursue efforts to keep it to 1.5°C. The nationally determined contribution (NDC) of the EU and its Member States reflects their objective to reduce greenhouse gas emissions by 40% by 2030 compared to 1990, and is consistent with the initially objective to reduce emissions by 80 to 95% by 2050.

As a response to its commitments under the Paris Agreement, and in order to pursue its objectives of updating its energy policy framework to facilitate the transition away from fossil fuels towards cleaner energy, the European Commission has published a number of policy proposals in November 2016, the so-called Clean Energy for All Europeans Package (CEP). The political compromise that has been reached at the time, which included updated objectives for 2030 (32% renewable energy target, 32.5% energy efficiency target) and governance mechanisms to plan, report and monitor as well as coordinate how the efforts shall be distributed amongst Member States (through e.g. National Energy and Climate Plans, Long-Term Strategies and the associated progress reports), results in new rules that resulted in actions by Member States and the Commission from 2019 on.

In early 2020, the European Climate Law proposed by the Commission[1] further endorsed the net zero greenhouse gas emission objective for 2050. With this new regulation, a legal binding target of **net zero greenhouse gas emission by 2050** is proposed and the EU institutions and Member States would be bound to take the necessary measures to meet this target. After having conducted an impact assessment of potential targets for 2030, the Commission has amended its proposal[2] to include a binding Union-level **target of reducing net greenhouse gas emissions by at least 55% by 2030,** compared to 1990 levels.

The assessment of the impacts of both the 2030 and the 2050 targets was based on extensive modelling exercises carried out by the European Commission:

- The pathways of the *Long-Term Strategy* (LTS) have informed the setting of the net-zero objective by 2050. In its analysis[3], the Commission has compared different ambition levels for 2050, and different ways of reaching them. The two scenarios that reach net zero emission by 2050 are the 1.5TECH and 1.5LIFE scenarios.

- The pathways of the *Climate Target Plan* (CTP) have informed the setting of the 2030 target (55% reduction compared to 1990). In its analysis[4], the Commission has examined several 2030 targets, and how they compare in terms of preparing the transition towards a net-zero emission economy.

All credible pathways toward climate neutrality at the 2050 time horizon imply a drastic acceleration of the deployment of renewable energies in order to support direct and indirect electrification in the mobility, industry and buildings sectors.

---

[1] COM(2020) 80 final

[2] COM(2020) 563 final

[3] In-depth analysis in support of the Commission Communication COM(2018) 773

[4] SWD(2020) 176 final

It should be noted that the scenarios developed in the LTS and in the CTP have been built using a Member States spatial granularity, but that only the aggregated results have been made publicly available. Therefore, all MS-level figures shown in this report have been obtained by using specific disaggregation keys such as third-party scenarios. Assumptions related to the disaggregation of LTS pathways are provided in the following sections of this document.

EU Strategies – Key tools to reaching ambitious climate and energy targets

Reaching a net zero carbon economy at the 2050 horizon and meeting the proposed 55% GHG reduction target by 2030 will require extraordinary efforts all across Europe in order to phase-out carbon-intensive technologies and to scale up alternatives in a cost-effective manner. The European Commission has published a number of strategies aiming at supporting key transformations and at providing objectives for the deployment of technologies that have a key role in the decarbonisation of the European economy.

For a transformational change of the magnitude envisaged above to materialise in a timely and cost-effective manner, synergies between sectors and vectors have to be identified and properly taken into account, both when planning the evolution of the energy systems and of its components, and when designing frameworks and structures (e.g. markets) enabling citizens and businesses to interact with the energy system. In an effort to encourage the emergence of this vision, the European Commission has published the *Energy System Integration Strategy*[5] in July 2020. This strategy focuses on applying the energy efficiency first principle, on a greater direct electrification of end-uses, on the indirect electrification of end-uses that cannot be electrified (due to technical, efficiency or cost drivers), and on a greater active participation of consumers in the operations of the energy system.

Furthermore, recognising the role that hydrogen plays in all the transition pathways explored in the assessment of the LTS and CTP, the European Commission has published a *Hydrogen Strategy*[6], with proposed targets for the production of renewable hydrogen[7] in Europe (1 MtH_2/y by 2024, 10 MtH_2/y by 2030) and for the deployment of electrolysers in Europe (6 GW by 2024, 40 GW by 2030). Since then, a number of Member States have also followed suit and published their own hydrogen strategies, some of which include electrolysis deployment targets for 2030 (e.g. 6.5 GW in France, 5 GW in Germany, 3 to 4 GW in the Netherlands, 4 GW in Spain, 2 to 2.5 GW in Portugal[8], 2 GW in Poland).

Despite the expected evolution of the level of energy efficiency (in particular, incentivised by the Renovation Wave strategy[9]), the combination of an increased direct electrification and the development of indirect electrification in mostly hard-to-abate sectors via the use of hydrogen (or derived gases and liquids) produced in Europe will result in the need for a sharp upscaling of the deployment of renewable electricity generation technologies in order to implement the principle of additionality[10]. For example, in the 55% pathways explored in the CTP, shown below on Figure 1, the electricity production in Europe more than doubles between today and 2050.

---

[5] COM(2020) 299 final

[6] COM(2020) 301 final

[7] Renewable hydrogen is defined as hydrogen being produced by electrolysis with renewable electricity, by reforming of biogas or by biochemical conversion of biomass.

[8] Hydrogen Europe, *Clean Hydrogen Monitor 2020*, 2021

[9] COM(2020) 662 final

[10] Broadly, the additionality principle corresponds to the requirement that the additional electricity consumption triggered by the decarbonisation of (mostly) hard-to-abate end-uses via electrolysis should be provided by sources that would not have been used otherwise. As foreseen by RED II, the European Commission is expected to publish a Delegated Act in 2021 to provide an explicit definition of the additionality principle.

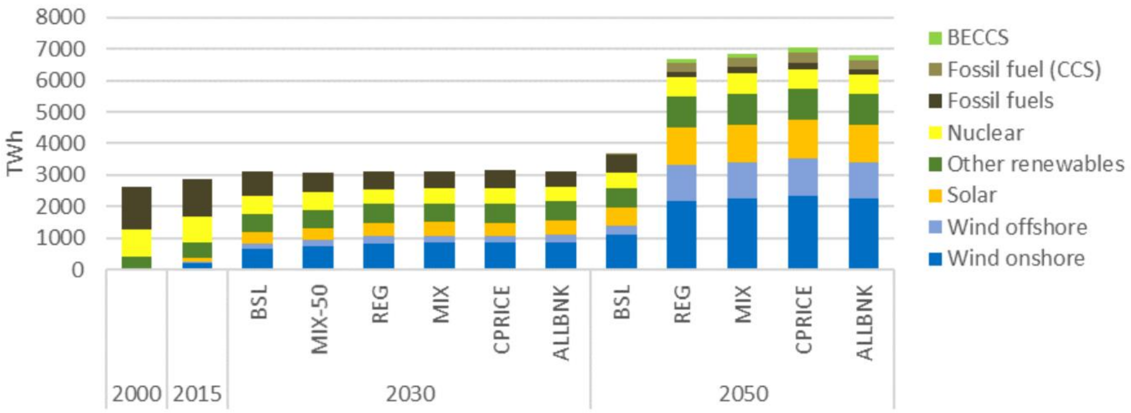


Figure 1 - Electricity production in CTP pathways. Source: EC.

This figure also provides an illustration of the magnitude of the structural transformation of the electricity generation mix that has to materialise between today and 2030, involving, among others, an ambitious evolution of the deployment of solar PV and onshore wind, and a particularly important effort to scale up the uptake of offshore wind technologies, which will be the fastest growing electricity generation technologies in the EU according to these scenarios.

The Strategy on Offshore Renewable Energy

A successful deployment of offshore renewables, and offshore wind in particular, is key to cost-efficiently reaching a net-zero carbon emission energy system. Furthermore, as the electricity infrastructure becomes the backbone of the energy system, it is very likely that the need for electricity interconnections will increase significantly too. Projects based on offshore RES technologies (e.g. large wind farms) have the advantage that they can be combined with interconnection projects in so-called hybrid projects, leading to a cost-efficient way to increase RES generation and the interconnectivity of the European energy system. Developing hybrid projects requires a strong coordination between countries for e.g. maritime spatial planning, tendering of offshore wind farms and planning of the offshore and onshore transmission systems.

In its *Strategy on Offshore Renewable Energy*[11], the European Commission proposes to significantly boost the deployment of Europe’s offshore wind capacity from its current level of 12 GW to at least 60 GW by 2030 and to 300 GW by 2050, building on the global leadership position of the European offshore wind industry.

---

[11] COM(2020) 741 final

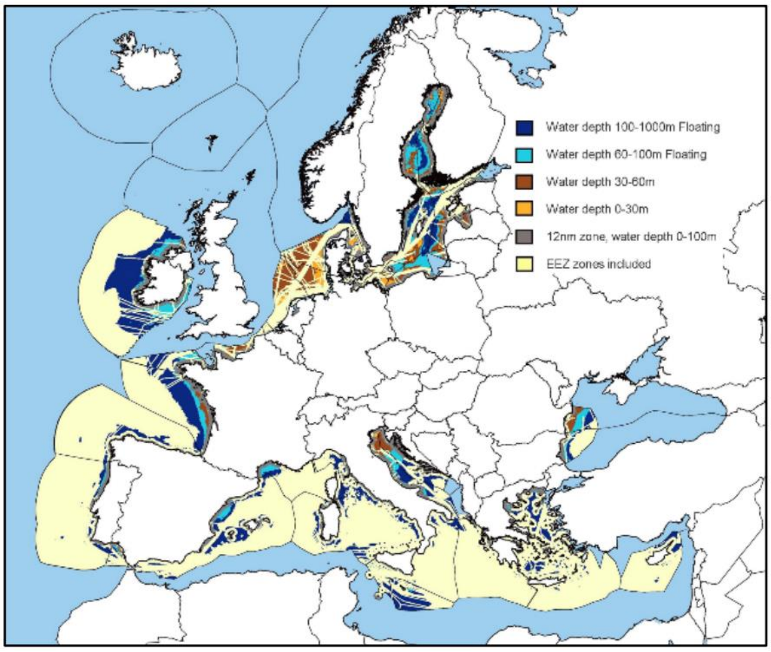


Figure 2 - Offshore potentials in European sea basins. Source: EC based on JRC ENSPRESO potential assessment

Ocean energy technologies (e.g. tidal, wave, solar floating) are expected to complement offshore wind and reach at least 1 GW by 2030 and 40 GW by 2050. In its recent publication[12], IRENA has assessed that although interest in ocean energy is global, Europe is a clear frontrunner as it has three-quarters of the currently globally installed capacity and more than half of the pipeline of projects.

The Offshore Strategy identifies a number of actions and measures aiming at ensuring that offshore technologies can play their role in the decarbonisation of the European economy. In particular, actions to facilitate the cooperation between Member States to better integrate offshore energy plans in their respective National Energy and Climate Plans and in their national Maritime Spatial Plans (MSPs)[13] are proposed. Potential cooperation aiming at establishing MSPs at sea basin level should also be explored according to the proposals of the Commission. Furthermore, the offshore strategy proposes that the revised TEN-E Regulation[14] includes aspects related to the planning of offshore grids by TSOs at sea basin level, including hybrid projects.

Finally, the offshore strategy proposes to address key market design issues, in particular related to the structure of bidding zones, the use of congestion incomes (in particular the allocation of congestion rents between the transmission and the generation assets

---

[12] IRENA, "*Innovation Outlook, Ocean Energy Technologies*", 2020. See also IRENA, "*Fostering a blue economy: Offshore renewable energy*", 2020

[13] Maritime Spatial Plans are to be produced and updated by Member States in accordance with Directive 2014/89/EU. The following website provides a summary of the status quo: https://www.msp-platform.eu/msp-practice/countries (accessed April 2021).

[14] Regulation (EU) No 347/2013, commonly known as TEN-E, is being revised in the context of the Green Deal. The proposed revision, its impact assessment and the opinion of the Regulatory Scrutiny Board can be accessed on the Commission's website: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12382-Revision-of-the-guidelines-for-trans-European-Energy-infrastructure (accessed April 2021)

in hybrid projects, in a way that is compliant with e.g. the Electricity Regulation), and the sharing of benefits between countries[15]. Technical considerations that may represent bottlenecks for a large-scale deployment of offshore assets are also to be addressed, in particular on the topic of standardisation and interoperability amongst converters from different manufacturers.

The European Commission has launched a series of sea-basin level studies addressing the assessment of RES potentials, the optimal configuration of grids (radial, hub or hybrid approaches), and an evaluation of the role offshore assets can play in the decarbonisation of coastal Member States and landlocked Member States which do not have a direct access to offshore wind potentials[16] (potentially via financing schemes such as the Renewable Energy Financing Mechanism, which links contributing countries that voluntarily pay into the mechanism with hosting countries that agree to have new projects built on their soil[17]).

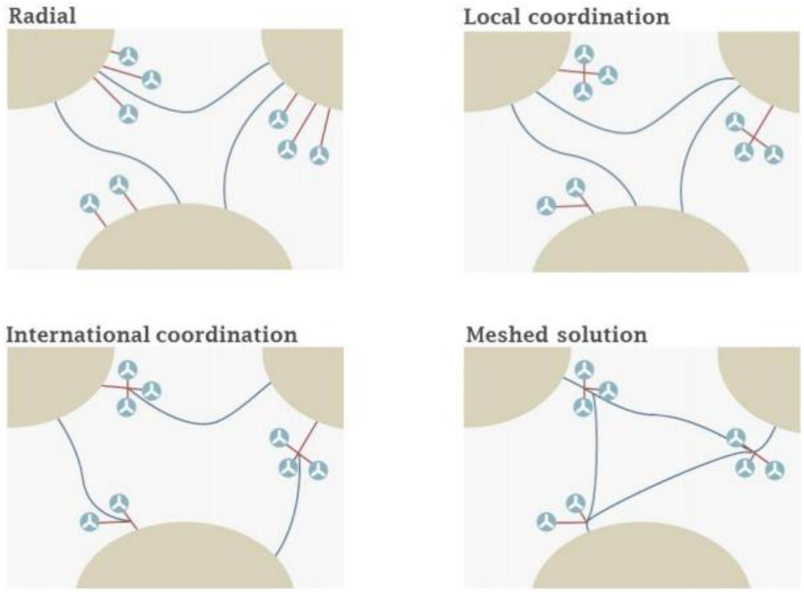


Figure 3 – Configurations of grid connection of offshore wind farms. Source: North Seas Countries' Offshore Grid Initiative, Working Group 1 – Grid Configuration, 2012. The "International coordination" and "Meshed solution" are examples of hybrid projects. The local coordination approach is often referred to as the "hub configuration"

These studies include:

- Study on the offshore grid potential in the Mediterranean region[18]
- Study on Baltic offshore wind energy cooperation under BEMIP[19]

---

[15] See the Staff Working Document accompanying the offshore strategy (SWD(2020) 273 final)

[16] See e.g. the recently announced cooperation between Luxembourg and Denmark to build an offshore energy island.

[17] Commission Implementing Regulation (EU) 2020/1294 of 15 September 2020 on the Union renewable energy financing mechanism

[18] https://op.europa.eu/en/publication-detail/-/publication/91d2091a-27bf-11eb-9d7e-01aa75ed71a1/language-en/format-PDF/source-218059400

[19] https://op.europa.eu/en/publication-detail/-/publication/9590cdee-cd30-11e9-992f-01aa75ed71a1/language-en?WT.mc_id=Searchresult&WT.ria_c=37085&WT.ria_f=3608&WT.ria_ev=search

- Study on the offshore energy potential in the Atlantic Ocean[20]

Collectively, these studies provide evidence of the important role offshore technologies can play in the decarbonisation of the European economy, with the right regulatory conditions in place for a large-scale roll-out of offshore wind (and other offshore technologies).

The roll-out of offshore wind in Europe not only has implications for the decarbonisation of the European economy, but could also be an opportunity for European businesses to remain at the forefront of offshore wind technologies, to support the decarbonisation of other areas, for example in the US where the Biden administration has recently announced[21] a 30 GW objective for offshore wind by 2030.

The role of the North Seas Energy Cooperation as a facilitator of the delivery of the 2050 vision for the North Sea basin

As discussed in the paragraphs above, offshore technologies are identified as key technologies in the transition towards a decarbonised European economy, as they enable to produce large volumes of electricity with a rather steady generation profile (compared to other variable renewable technologies) and can, on top of decarbonising the existing electricity mix, participate in powering the direct and indirect electrification of end-uses currently relying on fossil fuels.

The North Sea basin is attracting significant levels of attention given its large-scale potential for offshore wind deployment in particular, the ability to combine interconnection projects and offshore generation assets (into so-called hybrid assets), its proximity to large consumption centres (notably industrial clusters), the experience of neighbouring countries with the deployment of large offshore infrastructure (electricity and gas), etc.

Created in 2016, the **North Seas Energy Cooperation** (NSEC), into which the NSCOGI – the North Seas Countries' Offshore Grid Initiative was a regional cooperation of 10 countries to facilitate the coordinated development of a possible offshore electricity grid in the greater North Sea area – has been integrated, aims at facilitating the cost-effective deployment of offshore renewable energies, in particular wind, and promoting interconnections between the countries in the region. The NSEC is a voluntary cooperation with the aim of securing a sustainable, secure and affordable energy supply for the North Seas countries. Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway, Sweden and the European Commission are the current members of the NSEC (due to the departure of the UK from the EU on 31 January 2020, the UK is not a member of the NSEC anymore).

The NSEC includes four support groups (SGs) that focus on specific areas:

- **SG1** – Hybrid and joint projects
- **SG2** – Maritime spatial planning
- **SG3** – Support framework and finance
- **SG4** – Delivering 2050

A High-Level Group, consisting of high-level representatives of the participating North Seas countries and the European Commission, provides political guidance and support

---

[20] The results of the procurement procedure have not been announced, as far as the authors are aware.

[21] https://www.whitehouse.gov/briefing-room/statements-releases/2021/03/29/fact-sheet-biden-administration-jumpstarts-offshore-wind-energy-projects-to-create-jobs/

to coordinators and to support groups. Finally, the NSEC also includes a ministerial body, meeting at least once a year[22].

The fourth support group "Delivering 2050" aims at looking at the challenges ahead on the way to 2050, and to analyse opportunities that can emerge via projects based on a sector integration approach (e.g. hub-and-spoke model, where electricity generated by large-scale offshore wind farms can be either delivered directly via electricity cables or via pipelines after transformation into hydrogen by electrolysers). Furthermore, the second support group "Maritime spatial planning" is in the process of undertaking a study aiming at building scenarios of the long-term evolution of the North Sea region towards 2050 that recognises the potential competition between the various uses of maritime areas, thereby providing important insights into environmental and spatial issues related to offshore wind energy deployment.

In its 2019 political declaration the Ministers of the countries in the North Seas Energy Cooperation and the European Commission confirmed their commitment to working towards a net-zero carbon emission European economy by 2050 and underlined the role that offshore RES can play in reaching this ambition.

On the 6th of July 2020, the North Seas Countries and the European Commission issued a joint statement calling for a European enabling framework for offshore wind energy[23]. This statement puts an emphasis on the cooperation between countries and the indispensable role of offshore wind energy to reach common European targets. The support group "Delivering 2050" reaffirm its will to work towards "*a shared long-term vision for the role of offshore renewable energy to deliver ambitious 2050 energy and climate objectives in the North Seas region and a joint understanding of the future energy system in the region*". In order to support that effort, the NSEC recognises the need for a "*study that compiles existing national and regional long-term scenarios for offshore wind energy and grids in a systematic way, with a view to facilitating comparisons between the North Seas countries. The study will examine technical aspects of the analyses, assumptions on policy and market development and establish common ground among national long-term scenarios*".

On 14 December 2020, the NSEC has published a press statement underlying the importance of such fora for upscaling offshore renewable energy by facilitating the multi-use planning of sea space, cost-efficient development of offshore and onshore grids and joint renewable offshore projects between countries.

Scenarios for the North Sea region

The complete decarbonisation of the European economy at the 2050 time horizon can be achieved by following a large variety of routes. A large number of scenarios and pathways have been built with the objective to shed light on some of the key aspects of the transition. The implications for the deployment of offshore wind in the North Sea region can be important, as different routes may lead to different needs for renewable energy deployment in Europe and different strategies on the way to transport energy across Europe.

Without anticipating the discussions in the following sections of this document, let us try to structure the key elements use to characterise scenarios on the evolution of the energy system, and identify the key drivers influencing these elements. The following

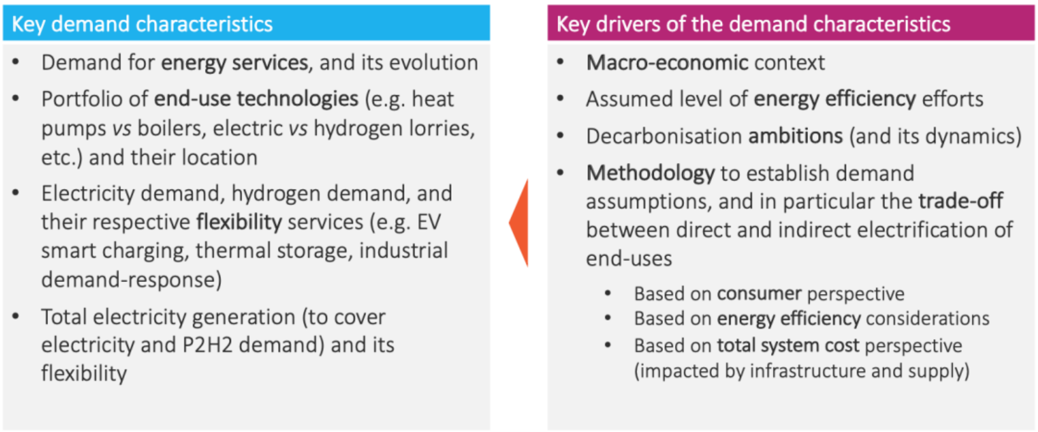
---

[22] See https://ec.europa.eu/energy/sites/default/files/governance-and-support-structure.pdf for more details on the structure and governance of the NSEC.

[23] https://www.benelux.int/files/2715/9411/1327/NSCOGI_3.1_Joint_Statement_2020.pdf

figures provide an overview of the demand, supply and infrastructure dimensions of such a scenario.

Scenarios describing the evolution of the energy system rely on various **demand-side assumptions**, with some publications starting from demand for energy services (e.g. demand to maintain heat at a given temperature), other from final energy demands (that depend on the technologies supplying these services). The level of flexibility of the demand is becoming one of the central assumptions of scenario-building exercises as, via sector integration, more and more sectors interact, enabling cross-sectoral flexibility services to be exchanged[24].



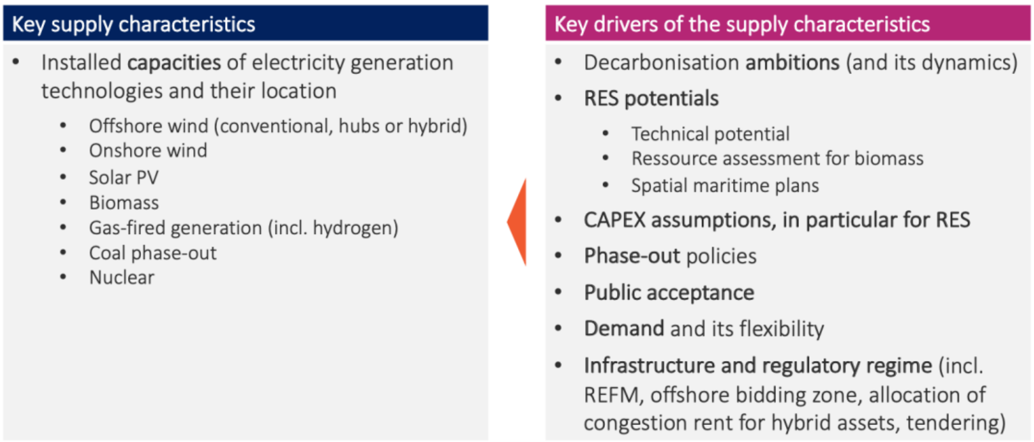
Key demand characteristics

- Demand for **energy services**, and its evolution
- Portfolio of **end-use technologies** (e.g. heat pumps *vs* boilers, electric *vs* hydrogen lorries, etc.) and their location
- Electricity demand, hydrogen demand, and their respective **flexibility** services (e.g. EV smart charging, thermal storage, industrial demand-response)
- Total electricity generation (to cover electricity and P2H2 demand) and its flexibility

Key drivers of the demand characteristics

- **Macro-economic** context
- Assumed level of **energy efficiency** efforts
- Decarbonisation **ambitions** (and its dynamics)
- **Methodology** to establish demand assumptions, and in particular the **trade-off** between direct and indirect electrification of end-uses
    - Based on **consumer** perspective
    - Based on **energy efficiency** considerations
    - Based on **total system cost** perspective (impacted by infrastructure and supply)

The second type of assumptions are linked with the **supply side**. If we concentrate on the electricity sector, these assumptions mainly relate to the installed capacity of electricity generation technologies. On the gas side, they refer to the different sources of gas (electrolysis is considered as a conversion process, see below). The objective of most prospective studies is to project plausible evolutions of supply technologies to meet the demand for services (or final energy demands). How to combine supply-side technologies strongly depends on costs, potentials, demand level and flexibility, and decarbonisation objectives.



Key supply characteristics

- Installed **capacities** of electricity generation technologies and their location
    - Offshore wind (conventional, hubs or hybrid)
    - Onshore wind
    - Solar PV
    - Biomass
    - Gas-fired generation (incl. hydrogen)
    - Coal phase-out
    - Nuclear

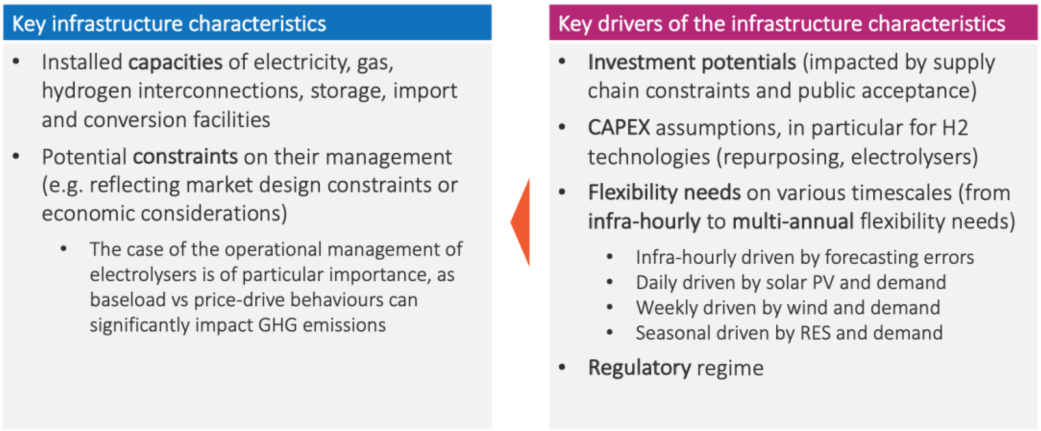
Key drivers of the supply characteristics

- Decarbonisation **ambitions** (and its dynamics)
- **RES potentials**
    - Technical potential
    - Ressource assessment for biomass
    - Spatial maritime plans
- **CAPEX assumptions, in particular for RES**
- **Phase-out** policies
- **Public acceptance**
- **Demand** and its flexibility
- **Infrastructure and regulatory regime** (incl. REFM, offshore bidding zone, allocation of congestion rent for hybrid assets, tendering)

---

[24] See e.g. https://op.europa.eu/en/publication-detail/-/publication/a6eba083-932e-11ea-aac4-01aa75ed71a1 where the impact of the level of short-term flexibility that can be delivered by electric vehicles on the role of alternative flexibility solutions has been examined.

Finally, the third component relates to **infrastructure**, i.e. all the technologies that link demand and supply. These include import transmission, storage and conversion capacities. One key aspect to consider is the way the infrastructure links all these components (e.g. if electrolysers are linked with dedicated assets and/or to the grid) and if there are operational constraints put on some of the infrastructure components (e.g. price-responsive charging of EVs enabled or tariff-based charging, price-responsive operations of electrolysers or baseload behaviour, etc.).



Key infrastructure characteristics

- Installed **capacities** of electricity, gas, hydrogen interconnections, storage, import and conversion facilities
- Potential **constraints** on their management (e.g. reflecting market design constraints or economic considerations)
    - The case of the operational management of electrolysers is of particular importance, as baseload vs price-drive behaviours can significantly impact GHG emissions

Key drivers of the infrastructure characteristics

- **Investment potentials** (impacted by supply chain constraints and public acceptance)
- **CAPEX** assumptions, in particular for H2 technologies (repurposing, electrolysers)
- **Flexibility needs** on various timescales (from **infra-hourly** to **multi-annual** flexibility needs)
    - Infra-hourly driven by forecasting errors
    - Daily driven by solar PV and demand
    - Weekly driven by wind and demand
    - Seasonal driven by RES and demand
- **Regulatory** regime

This structure is not a strict one, as policy context and technological progress are evolving quickly, leading to novel approaches emerging, in particular at the interfaces between these building blocks (e.g. via sector integration, hybrid projects combining infrastructure and generation technologies, etc.). However, these building blocks help structuring the analysis of scenarios and to assess potential weaknesses or shortcomings in the underlying methodology.

Objectives of this study and overview of the approach

The key objective of this study is to provide an overview of existing national and regional long-term analyses, assumptions and plans on offshore renewable energy and grids in the North Seas Energy Cooperation (NSEC) countries[25].

The study aims at identifying the common grounds and diverging aspects of transition pathways and their underlying assumptions, while also providing a qualitative discussion of the way the scenario-building and planning methodologies may differ.

Finally, while the objective of this study is not to establish a pathway or a scenario for the evolution of the energy system around the North Sea basin, we provide recommendations on aspects that we think are important to take into account in upcoming scenario-building exercises that aim at shedding light on potential plausible futures of the North Sea region. These aspects include for example renewable energy sources (RES) potentials assessment, maritime spatial planning, multi-energy considerations, and risk assessment.

The approach we have used in this study employs:

- A **literature review,** covering circa 40 relevant publications that provide scenarios or key insights into potential developments of the energy system in the North Sea region.

---

[25] While the literature review and interviews of stakeholders has focused on the NSEC countries, with a particular emphasis on the role of offshore technologies in the North Sea, but also considering the Baltic Sea and the Atlantic Ocean, we expect many of the recommendations of this report to also apply to other regions.

- A **stakeholder engagement process**, with bilateral interviews of circa 35 entities involved in various aspects of the development of the electricity, gas and hydrogen systems in the North Sea region (public authorities, project developers, TSOs, etc.)

Our conclusions are of two different natures:

- First, we emphasise the **common grounds** and **uncertainties** related to the different visions of the evolution of the energy systems of the North Sea region, with a focus on providing actionable recommendations to handle the identified uncertainties in upcoming scenario-building exercises and the creation of robust datasets.

- Second, as a by-product of this investigation, we have collected the key **uncertainties** stakeholders and publications have identified on topics such as market design, interoperability, incentives, regulatory framework, which can lead to putting the roll-out of renewables in the North Sea region at risk if clarity is lacking.

We hope both conclusions will be useful, on one hand for upcoming scenario-building exercises such as the one that will be undertaken by NSEC’s SG2 support group, and, on the other hand for policy makers when addressing the general regulatory framework for the North Sea region.

2. ANALYSIS OF RECENT PUBLICATIONS RELATED TO THE EVOLUTION OF THE ENERGY SYSTEM OF THE NORTH SEA REGION

This section provides an overview of the key dimensions of interest that have to be explored when aiming at characterising energy transition pathways for the North Sea region. These elements cover the level of electricity demand for direct and indirect electrification, the generation and conversion technologies, with a focus on offshore wind and electrolysis, the deployment of flexibility solutions, and the infrastructure.

2.1. OBJECTIVES AND METHODOLOGY

Since the signature of the Paris Agreement in December 2015, an important number of studies have been conducted to analyse different decarbonisation pathways of the European Union. The scope and objectives greatly vary from one study to the other. Some analyse the décarbonisation of the full energy system of the European Union, while others focus on the decarbonisation of the power sector, with a more a less detailed approach regarding its integration with other energy sectors or vectors (hydrogen production, flexibility provided via sector coupling with heating systems, etc.).

In line with the European Commission *Strategy on Offshore Renewable Energy*, a growing number of studies are focusing on the development of wind offshore capacities and its integration with the neighbouring shores. With shallow waters and relatively strong and steady winds, the North Sea region (and to a lower extent the Baltic Sea region) is already the area where most of the projects are currently under construction, and where the potentials are the most important.

The objective of the literature review work was to identify among these different studies the common grounds and key uncertainties of offshore renewables and grids in the North Sea region. More generally, the literature was also a first step to identify the key themes to be included in the upcoming scenarios

The following methodology was used to conduct this analysis:

Step 1: Selection of relevant publications and identification of their general characteristics

The selection of the relevant publications was based on the analysis of the recent strategic visions and plans of different stakeholders active in the NSEC countries, along with European-level studies. This list was completed by other studies mentioned by stakeholders during the interviews we have organised, as explained in Subsection 2.2.

Based on this list of studies, the second objective of this first step was to collect general information about the different publications, the publishing entity, and the date of publication, the geographic scope of the study and the objective and general narrative of the study.

Step 2: Identification of the publications' key assumptions and results

In order to be able to compare the different studies, different metrics have been selected, based on the data available in the different studies and the topics identified as being of key importance for the development of offshore renewable energy projects in the North Sea region, and the provision of flexibility services.

In order to compare the ambitions and targets of the different energy scenarios, different quantitative indicators have been identified. The key quantitative indicators are the electricity demand, hydrogen demand (including the production of synthetic fuels such as e-gases or e-liquids) and installed power capacities, with a specific focus on offshore wind.

As some of the topics that are key to capture in order to describe offshore development are difficult to capture with quantitative indicators, such as the different approaches used in the scenario-building process or the level of representation of specific offshore infrastructures, we have added a set of qualitative indicators. Different insights have been extracted of the different publications, covering the following topics:

- Methodology used to build the scenarios (optimisation, expert judgment, based on technical potentials, based on pre-existing scenarios)
- Scenarios' storylines and narratives of the study
- Refinement of the representation of offshore infrastructure (hybrid projects, hydrogen infrastructure, etc.)

Structure of the analysis

The development of renewable energy in the North Sea relies on an important number of parameters, such as the evolution of the power and hydrogen demand, the RES potentials of the different countries, the existing infrastructure and the projects being considered, etc. In order to carry out a comparison of the quantitative information based on different studies, it is important to have a common framework of analysis, completed by qualitative analyses on some key topics of interest that cannot be covered by the sole quantitative analysis.

In order to provide a comprehensive vision of the development of renewable energy in the North Sea region in the different publications, we have decided to structure the analysis via a dedicated sub-section for the **common grounds**, and another covering the **key uncertainties**. This approach is well adapted to separate the points where convergence and divergence appear in the different scenarios we have analysed. One should note that this structure also means that comments related to a specific theme (e.g. the offshore infrastructure) can be found in the two subsections.

Where relevant, some topics are expanded upon in dedicated boxes, in order to provide the reader with the keys to understand the associated common grounds and uncertainties.

The different quantitative indicators presented in the report adopt the following convention: one point represent one scenario included in one publication. For readability reasons, the name of the different scenarios is not present in the graphs. This information can be found in “Annex C: Quantitative indicators data from the literature review”, where the figures associated to each graph are included.

2.2. LIST OF CONSIDERED PUBLICATIONS

The selection of publications considered in this literature review followed two main principles:

- Use only **recent studies** (2018-2021). During the last years, the political alignment towards aiming for full net decarbonisation of the European economy in 2050 has led to an important evolution of the different prospective scenarios. The (re)emergence of the indirect electrification route (green hydrogen, produced from renewable electricity) as a key decarbonisation option is one of the reasons why we have chosen to focus on the most recent energy scenarios, which have more ambitious deployment of renewable power generation (mainly solar PV and wind) and a more interlinked nature with the gas and/or hydrogen sectors.

- Cover a **representative spectrum** of the development of offshore renewable energy and energy grids in the North Sea region at different geographical levels (from EU-wide to regions), at different level of detail of the energy system (whole energy system decarbonisation to electricity-centric analyses) and from different actors (Member state ministries, TSOs, EU institutions, NGOs, consulting companies).

Most of the publications are including prospective scenarios of the evolution of the European electricity power system, or more generally the energy system. Some publications without quantitative descriptions of scenarios have also been included in our work to provide additional insights on topics of particular interest. These additional publications include European Commission strategies, meta-studies and maritime spatial plans.

The final list of publications can be structured in different groups:

NECPs

The National Energy and Climate Plans (NECPs) are strategic documents established by Member States describing the orientations they have designed to meet the EU's energy and climate targets for 2030, while keeping the 2050 targets in mind. The offshore development is not the key objective of these planning documents that are covering the whole energy sector, but they contain useful information for the development of the power demand and some targets for the development of wind offshore. The NECP of the NSEC countries were included in our analysis, along with the draft NECP of the United Kingdom.

Publications by TSOs

In order to plan their investments in the transmission grid, transmission system operators need to create different prospective scenarios for the evolution of the power system. Most of these planning documents are not specific to the development of offshore wind, and cover the whole power sector from demand to supply, with some information about the necessary infrastructure and interconnections with neighbouring countries. Two publications are however especially addressing the question of the development of offshore renewable in the North Sea:

- The "*Eurobar initiative*": a memorandum of Understanding between different TSOs to foster the integration of offshore wind into the European power grid, with the aim to create a "busbar alike system".

- The *"Winds of change" strategy of Energinet, completed by the prospective analysis "System perspectives for the 70% target and large-scale offshore wind"*. Both documents illustrate how Denmark could use its offshore wind potential to achieve its climate targets.

On top of the national TSO studies, the European association for the cooperation of transmission system operators (ENTSO-E) is also a key producer of prospective scenarios for the European power systems. The 2020 edition of the Ten-Year Network Development Plan (TYNDP 2020), along with strategic orientations for the storylines for the 2022 scenarios, have also been included in the analysis, along with some region-specific analyses focusing on the North Sea region.

Other studies

This category includes various publications from public authorities, NGO, consulting studies or research projects.

The Long-Term Strategy of the European Commission is a key strategic publication for the 2050 horizon since it provides different pathways of decarbonisation of the European Union's economy in order to achieve climate neutrality by 2050.

National-level energy planning documents produced by Member States have also been considered where relevant to the challenges related to offshore developments in the North Sea region.

Different NGO, consulting and research studies have also been included when they were specifically addressing questions related to the offshore development in the North Sea region. Additional publications at a more general level (geographical or not directly related to renewable offshore development) have fed into the analysis, allowing for a broader perspective of the possible evolution of key structural elements of the power system to be adopted.

Meta studies

Meta studies are analyses of the results of other studies. In our work here, we have analysed some of these publications comparing key elements of different prospective scenarios for the underlying included studies. These meta studies have been used as a way to collect some datasets from the underlying studies, and also to obtain some high-level insights of the differences between scenarios and how to compare them.

Additional ENTSO-E and EC publications

On top of the publications already covered by the "TSO" and "Other studies" categories above, additional publications from ENTSO-E have also been analysed, some having a direct connection to deployment levels of offshore renewable technologies in the North Sea region, other providing valuable insights into enabling mechanisms (e.g. studies covering interoperability, regional investment plan for the North Sea).

European Commission communications or proposals on key topics related to offshore development (hydrogen strategy, offshore strategy, Climate Target Plan, proposed TEN-E revision) have been reviewed. These documents have not directly been used as a source of quantitative information since they do not include prospective scenarios (except for the Climate Target Plan's impact assessment), but were instead used to provide qualitative information regarding targets, so as to compare the alignment of scenarios with EU targets.

The Maritime Spatial Plans (MSPs) of the countries considered in this analysis have been collected and analysed, with a focus on how these plans report offshore potentials, and useful insights for possible location of offshore wind farms.

Category	Author(s)	Title	Geographical scope	Year
NECP	National authorities	NECP (Draft NECP for UK)	NSEC + UK	2019
TSO	ENTSO-E & ENTSOG	TYNDP 2020 - Scenario Report TYNDP 2022 scenario storylines	Europe	2020
	ENTSO-E	TYNDP 2018 - Regional Insight Report - Northern Seas Offshore Grid	Europe/ North Seas	2019
	ELIA	Electricity scenarios for Belgium towards 2050	BE	2017
	Amprion	Eurobar for offshore integration	DE	2020
	Gasunie and TenneT	Pathways to 2050	DE, NL	2020
	Energinet.dk	Winds of Change	DK	2019
	Energinet.dk	System perspectives for the 70% target and largescale offshore wind	DK	2020
	RTE	Bilan Prévisionnel	FR	2019
	EirGrid	Tomorrow's Energy Scenario	IE	2019
	Creos	Scenario report 2040	LU	2020
	National Grid	Future energy scenarios	UK	2020
Other studies	Roland Berger for the European Commission	How to reduce costs and space of offshore development	North Sea	2019
	Navigant for North Sea Wind Power Hub	Integration routes North Sea offshore wind 2050	UK, NL, DE, DK, NO, SE, BE	2020
	Ea Energianalyse for Ørsted	Development in Europe towards 2050 and related challenges for power system infrastructure	Europe	2020
	Trinomics and LBST for FCH 2 JU	Opportunities for hydrogen Energy Technologies considering the National Energy & Climate Plans	Europe	2020
	PROMOTioN	Optimal Scenario for the Development of a Future European Offshore Grid	Europe	2020
	ETIPWind	ETIP Wind Roadmap	Europe	2019
	Eurelectric	Decarbonisation Pathways	Europe	2019
	CAN Europe	PAC Scenario	Europe	2020
	European Commission	Long-Term Strategy	Europe	2018
	Wind Europe	Our Energy, Our Future	Europe	2019
	DNV GL	North Sea Energy Outlook	NL	2020
	PBL NL Environmental Agency	The future of the North Sea	NL	2018
	Export Credit Norway	Offshore wind	NO	2020
	UK ministry - BEIS	Projections of greenhouse gas emissions and energy demand from 2019 to 2040	UK	2020
	IEA	World Energy Outlook 2019 (Offshore wind)	World	2019

Category	Author(s)	Title	Geographical scope	Year
Meta-studies	E3Modelling for ASSET project	Energy outlook analysis	Europe	2020
	IRENA	Scenarios for the Energy Transition: Global experience and best practices	World	2020
	Pentalateral Forum	Scenario comparison (R2B)[26]	PENTA countries	2020
	Joint Research Centre	Towards net-zero emissions in the EU energy system by 2050	Europe	2019
Other ENTSO-E and EC studies	European Commission	Offshore strategy, Hydrogen strategy, Climate Target Plan, Proposal for a revised TEN-E	Europe	2020
	ENTSO-E	Regional Investment Plan from Regional Group Northern Seas	Europe	2021
	ENTSO-E	NSOG corridor report on system needs	Europe	2021
	ENTSO-E	Position paper on Offshore Development - Interoperability[27]	Europe	2021
	ENTSO-E	Regional Investment Plan 2017	North Seas	2019

---

[26] This document is not publicly available and has kindly been shared by the Pentalateral Forum for the purpose of this study.

[27] See ENTSO-E's webpage dedicated to offshore development for more details on their views on interoperability, the planning processes, market design, etc. - https://www.entsoe.eu/outlooks/offshore-development/

2.3. COMMON GROUNDS

Power demand increase is driven by an electrification of the European economy

In order to decarbonise the European Union economy, all scenarios foresee an important direct electrification effort, accompanied by different strategies to tackle hard-to-abate sectors, amongst which indirect electrification, resulting in an increase of the electricity consumption at the 2030 and 2050 time horizons. Energy efficiency efforts and the electrification of the different end-uses in all sectors (buildings, mobility, and industry) impact the overall level of electricity generation.

It is important to underline that the decarbonisation of the different scenarios is mainly driven by decarbonisation targets and not by an optimisation of the supply and demand technologies triggered by the price of the different commodities. The projected price evolutions of the different fossil fuels and of CO_2 are not enough to drive the entirety of the required shift to renewable energy sources and the shift of end-uses towards low carbon solutions.

At the level of the European Union and the United Kingdom, the power demand ranges from 3300 TWh to 4400 TWh in the different scenarios we have analysed. In 2050, the total power demand ranges from 3400 TWh to 5500 TWh. For the 2050 horizon, most of the difference originates from the assumptions in terms of decarbonisation routes considered in the different pathways: reaching climate neutrality is often directly correlated to an increase of the power generation, in order to benefit from the carbon-free generation of the renewable energy production of wind and solar to drive electrification. For example, in the different scenarios of the *"Decarbonisation pathways"* of Eurelectric, the 80% reduction of CO_2 emissions by 2050 is achieved with an increase of the power demand to 4 200 TWh, while the 95% decarbonisation scenario implies a consumption of 4 900 TWh of electricity in 2050.

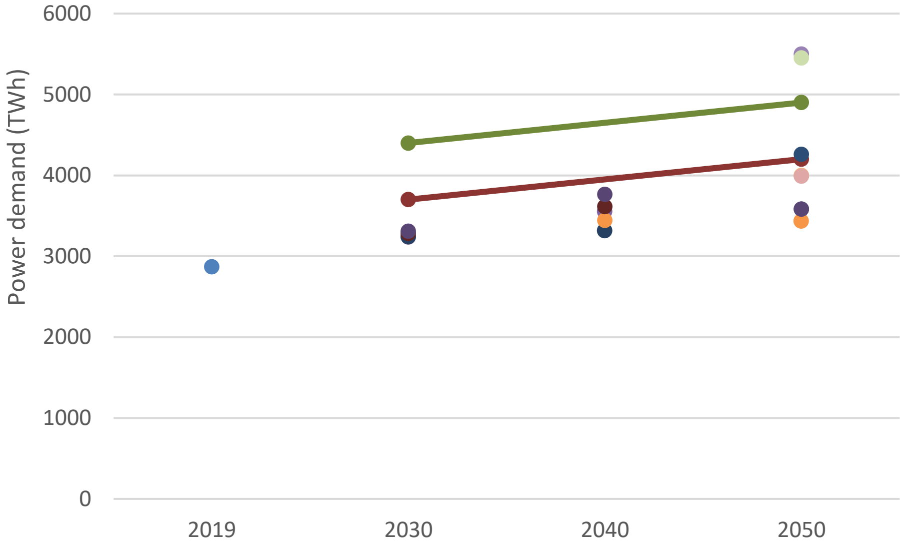


Figure 4 - Power demand evolution in EU27+UK across the different scenarios

At the country level, the power demand of the different NSEC countries and United Kingdom is also relatively similar across the different scenarios at the 2030 time horizon.

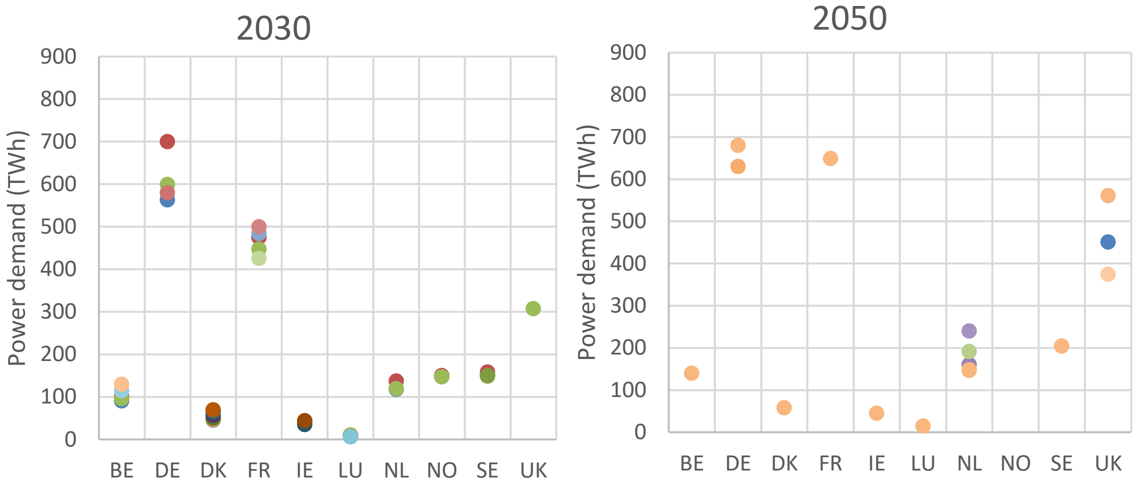


Figure 5 - Power demand across the different NSEC countries and UK

Green hydrogen demand is rising significantly after 2030

Currently, most of the energy demand of the European Union is covered by fossil fuel (natural gas and petroleum products). In order to decarbonise the end-uses currently dependent on fossil fuels, a switch to electricity (direct electrification) is one solution. However, for high-temperature industrial processes and heavy mobility, indirect electrification via electrolytic hydrogen is a promising decarbonisation route. Electrolytic hydrogen can also be further converted into synthetic gas or e-liquids via additional chemical transformation. This route limits the transformation of the processes of the different sectors (industry, mobility mainly) since they would still be using similar types of fuels, but this comes with a rather low overall efficiency, with a projected efficiency for PEM electrolyser of 75%-90% in 2050, requiring high RES capacities to be deployed.

In the different publications, there is a shared vision that the green hydrogen demand[28] in 2030 will remain relatively low, with negligible volumes compared to the power demand.

From 2030 onwards, most scenarios foresee an important increase of the hydrogen demand, mostly met by the production from electrolysers. For example, the scenario 1.5TECH of the EC's Long-Term Strategy estimates a hydrogen consumption[29] of 3260 TWh of hydrogen in 2050. Assuming an 85% efficiency for electrolyser, this is equivalent to a power demand for indirect electrification of 3840 TWh. This number is close to the total power demand of 4000 TWh.

---

[28] We are only referring here to the hydrogen generated by water electrolysis, without including here the hydrogen demand that is satisfied by conventional steam methane reforming.

[29] Hydrogen consumption includes here all P2X vectors, such as e-gas and e-liquids

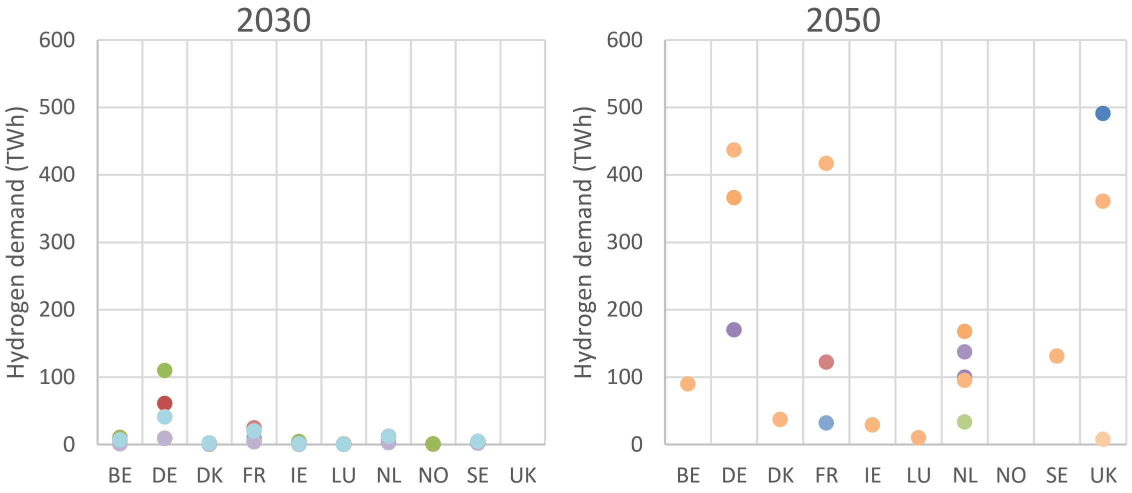


Figure 6 - Hydrogen demand across the different NSEC countries and UK

The ambition in terms of deployment of offshore wind is in line with the offshore strategy at the 2030 time horizon

The transformation of the power sector is key to achieve the decarbonisation objective of the European Union. The important increase of renewable energy, mainly from solar and wind, is common across all scenarios.

Methodology to determine the offshore capacity in the different publications

The process to establish the deployment level of the offshore wind capacity greatly varies from on publication to the next, and mainly depends on the objective of the study.

Some studies analyse the impact of a given target of offshore wind capacities on the European or North Sea power system. For these studies, the objective is to determine how the system would have to evolve to integrate this target of offshore renewable. For example, in the "Integration routes North Sea offshore wind 2050", the objective is to compare different integration routes for 180 GW of offshore wind, to quantify the necessary investments of onshore and offshore infrastructure, and to analyse the possible role of hydrogen to ensure adequacy of the system.

For other studies, the level of offshore capacity is based on storylines, taking into account different build-up constraints, technical potentials and acceptability to design different pathways of plausible offshore evolution. This is often an approach chosen by TSOs to create contrasted scenarios.

Using pre-existing scenarios is another approached used in some publications. The objective is often similar to the selection of a given target of offshore capacity: using existing scenarios create a framework of evolution for the offshore capacities in the North Sea region.

Finally, some studies are optimising the deployment of offshore capacities based on different technical constraints and potentials. These assessments are a way to determine the optimal combinations between the various available renewable sources to reach a given decarbonisation target.

Author	**Title**	**Modelling approach for offshore capacities**
North Sea Wind Power Hub	Integration routes North Sea offshore wind 2050	Objective 180 GW for the North Sea
Wind Europe	Our Energy, Our Future	Objective 212 GW for the North Sea
Energinet.dk	System perspectives for the 70% target and largescale offshore wind	Based on own storylines
ENTSO-E/ENTSOG	TYNDP 2020	Based on own storylines
RTE	Public consultation for the 2050 scenarios	Based on own storylines
Elia	Electricity scenarios for Belgium towards 2050	Based on own storylines
Roland Berger	How to reduce costs and space of offshore development	Based on each project characteristics
PROMOTioN	Optimal Scenario for the Development of a Future European Offshore Grid	Based on a literature review of other prospective scenarios
PBL NL Environmental Agency	The future of the North Sea	Scenario based (NL WLO Outlook)
Trinomics for FCH JU	Opportunities for Hydrogen considering the NECP	Scenario based (NECP)
CAN Europe	PAC Scenario	Scenario based (Fraction of LTS figures)
Ea Energianalyse for Ørsted	Offshore wind and infrastructure	Optimised (results closed to 1.5TECH results)
European Commission	Long-Term Strategy	Optimised
Gasunie and TenneT	Pathways to 2050	Optimised (based on potential from TenneT Infrastructure Outlook 2050)
Eurelectric	Decarbonisation Pathways	Optimised

In 2020, they are 25 GW of installed capacity of offshore wind across Europe[30]. For the 2030 horizon, most of the publications are in line with the Offshore Strategy's target of 60 GW, ranging from 57 GW to 150 GW. For the 2050 horizon however, while all the reviewed publications foresee an important increase of offshore capacity, with at least 150 GW installed capacities in EU27+UK, the objective of reaching 300 GW as targeted by the offshore strategy, is only met by around half of the scenarios.

---

[30] Wind Europe, *"Offshore Wind in Europe, Key trends and statistics 2020"*. This includes EU27+UK.

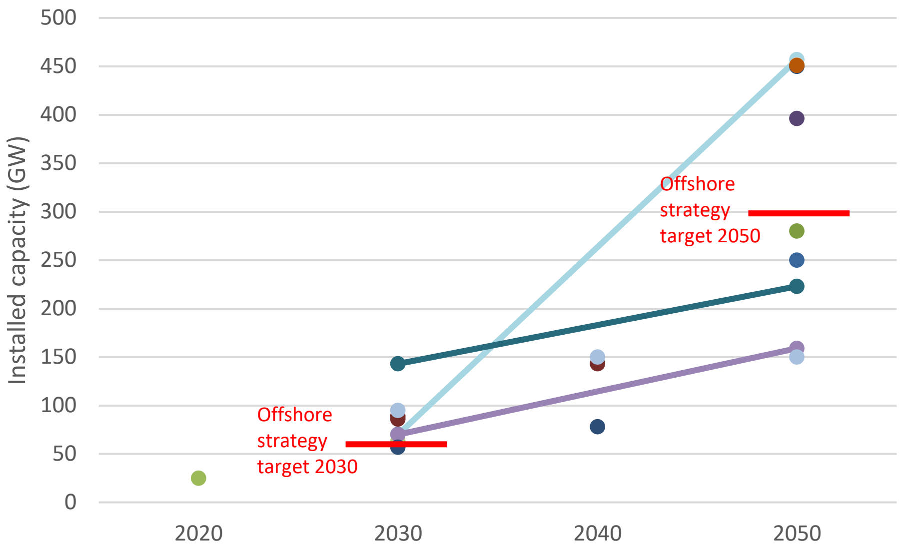


Figure 7 - Installed capacity of offshore wind in EU27+UK

The development of offshore wind will require substantial investments in energy infrastructure in the North Sea region

As illustrated in the previous paragraphs, the different scenarios foresee an important development of offshore wind capacities in the coming years. In order to cope with the additional renewable generation coming from these sources, an important evolution of the power system infrastructure, and potentially of the hydrogen infrastructure, will be required in the future.

The need to develop energy infrastructure to integrate offshore wind capacities and link them to end-uses was not covered by all publications: studies covering the decarbonisation of the entire European energy system are not providing detailed information regarding this topic. All studies from TSOs consider the development of offshore interconnections between Member States and within countries, but without explicitly addressing the question of the link between offshore wind farms and the shore.

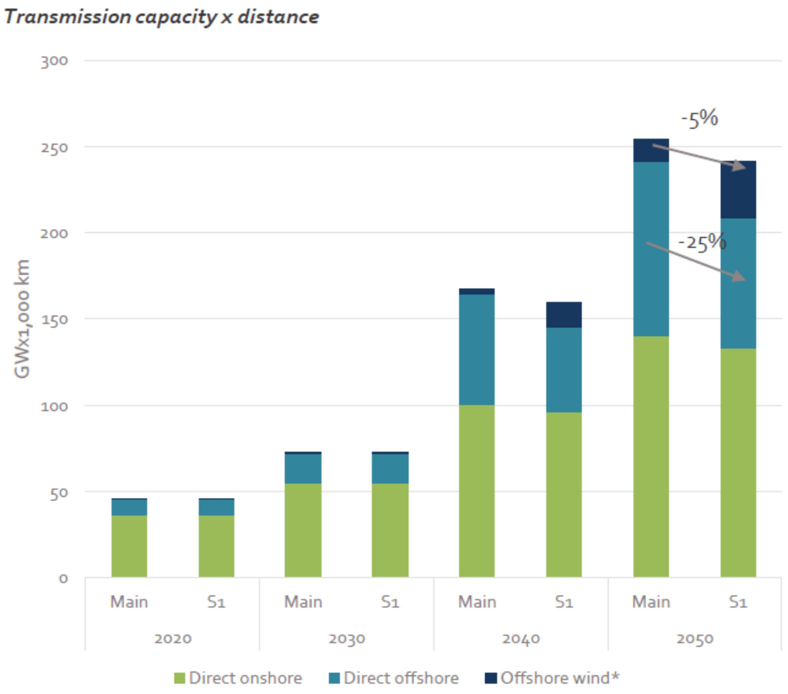
However, all publications modelling onshore and offshore infrastructure in their scenarios show that substantial investments in both onshore and offshore electricity grids will be required. The *"Integration routes North Sea offshore wind 2050"* by Navigant emphasises that congestions in onshore transmission grid can represent a major barrier to a large-scale deployment of offshore wind after 2030. The *"Offshore wind and infrastructure"* study by Ea Energianalyse shows that important investments in onshore and offshore capacities will be necessary: the total transmission capacity has to increase by a factor of 5 by 2050[31].

To limit the investments in offshore infrastructure, combining offshore wind farms connection to shore with electricity market interconnection between different countries appears to be a promising solution in various situations. In the *"Offshore wind and infrastructure"* study by Ea Energianalyse, a comparison has been carried out between a reference case where all wind farms are only connected to the nearest shore to a situation where multiple connections between the offshore hubs and countries are possible. Compared to the reference case, direct offshore connections (measured in GW-km) were found to be reduced by 25% in 2050, and despite an increase in hub

---

[31] The total onshore and offshore transmissions include onshore connections between the different modelled bidding zones, offshore connections between wind farms and the shores, and offshore connections between different wind farms.

transmission capacity (between different hubs or from on hub to another country), the total infrastructure size was reduced by 5%.



* Offshore wind includes all connections to offshore windfarms which are not "near-shore". In the S1 Multi-linked hubs sensitivity, this category includes all shore-to-wind site and wind site-to-wind site connections

Figure 8 - Benefits in term of installed capacities of transmissions between a situation where investments in hybrid projects are possible (S1) and a reference situation where wind farms can only be connected to the nearest shore (Main)
Source: Ea Energianalyse, "Offshore wind and infrastructure"

Offshore hybrid projects

Traditionally, offshore wind projects are connected to a single country. The electricity generated by the wind turbine is only feeding into a single bidding zone, like any power plant located onshore. But, thanks to their specific location at the crossroads of different countries, different kind of connections linking one wind farm to several countries are emerging. These different kinds of connection are often referred to as "hybrid projects".

These hybrid projects can have several benefits for the integration of offshore wind capacities in the North Sea region. By mutualising interconnections, for example linking countries via a HVDC connexion via wind farms, hybrid projects are often an import source of cost reduction for the different projects. The diminution of the length of cable is the main origin of the cost reduction, and avoided investments in offshore transformers or converters can provide additional cost reductions. In the study *"Hybrid projects: How to reduce costs and space of offshore development",* Roland Berger has analysed the benefits of 18 potential hybrid projects in the North Sea. They have shown than the 5 most promising projects offered a reduction of total project cost between 5 to 10% compared to the reference situation. These avoided costs were mainly coming from reduction in investment costs, and to a lower extend to avoided operational costs.

By linking multiple wind farms projects, and involving multiple countries, hybrid projects are more complex to develop than conventional projects with a radial connection to the shore. With a transnational approach, the current bidding zone configuration is not totally adapted for hybrid projects, and the introduction of offshore bidding zones for different wind power hubs is identified as a promising way to maximise the value brought by hybrid assets.

Even if hybrid projects appear to be an interesting solution in general, a project-by-project analysis is still required since, in specific situations, hybrid projects could be associated with higher costs than alternative configurations. In the study "Hybrid projects: How to reduce costs and space of offshore development", Roland Berger shows that among the 10 hybrid projects analysed in detail, 4 are found not to be generating savings over their lifetime. In particular, the Nautilus project interconnecting on offshore wind farm with Belgium and the UK appears to be less interesting in its hybrid configuration than in the counterfactual reference case. This is mainly due to the rerouting of the interconnection cable between the UK and Belgium in the hybrid projects, leading to higher investment costs for the different cables.

2.4. KEY UNCERTAINTIES

At the 2050 time horizon, the level of electrification, and the trade-off between direct and indirect electrification routes have an impact on the renewable capacities that are required in the North Sea region

Most of the scenarios included in the different publications aim to reach climate neutrality at the 2050 horizon, in line with the objectives set by the European Union. However, the route to achieve this climate neutrality greatly varies from one scenario to the next.

The first level of uncertainty is the importance of electrification (including direct and indirect electrification). A more important use of the biomass and biogas potentials can lead to a decrease of the required renewable generation to drive electrification. The emissions associated to the use of fossil fuels can also be mitigated by carbon capture and storage technologies in scenarios relying importantly on technological solutions, such as the 1.5TECH scenario of the EC's Long-Term Strategy.

Second, even with a similar electrification depth, the choice between direct and indirect electrification can lead to important differences in term of necessary power production. With an average efficiency of 75%-90%, converting electricity into hydrogen comes with an increase of the overall energy losses. With further transformation, such as the production of synthetic fuels or ammonia, the overall process efficiency process can decrease to below 50%. As illustrated in Figure 9, the importance of indirect electrification (referred in the figure as hydrogen demand) greatly varies between the different scenarios. At the 2050 horizon, the electricity demand for P2X can be at the same order of magnitude than the final electricity demand (see e.g. LTS-1.5TECH scenario), or about a third of the total power demand (EU PAC scenario).

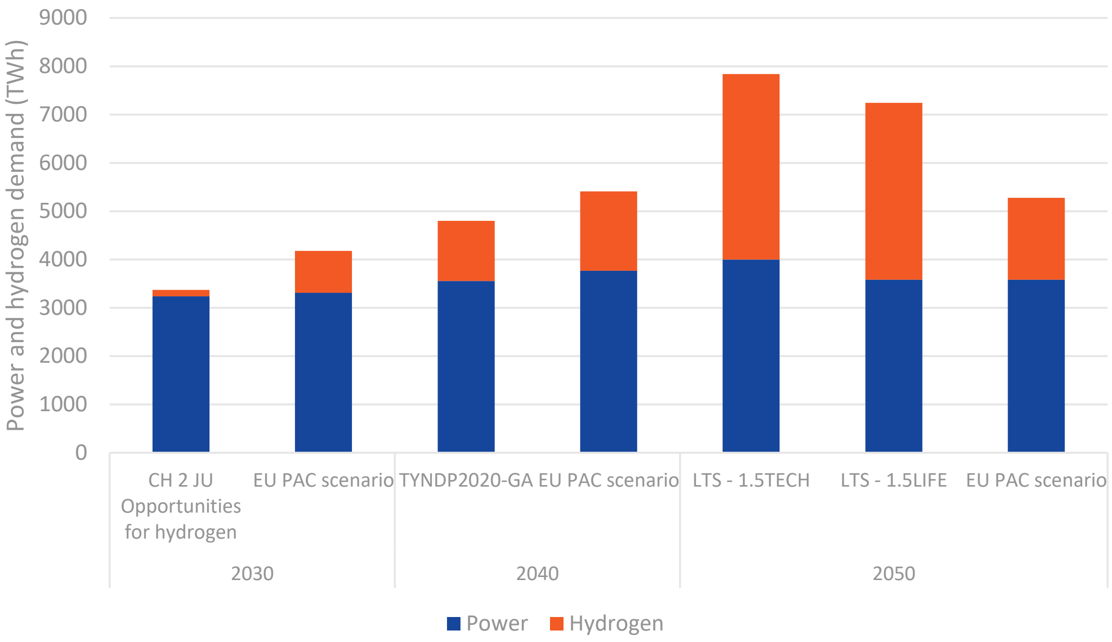


Figure 9 - Development of power and hydrogen[32] demand for EU27+UK (TWh) in a selection of scenarios

The last uncertainty regarding the decarbonisation pathways is the evolution of the energy exchanges with third countries. Currently, the European Union strongly relies on the import of fossil fuels, and see the development of renewable energy sources as a way to decrease its dependence on imports. In contrast, different studies and stakeholders are evaluating the economics of imports of decarbonised energy vectors, such as hydrogen, e-methane and e-ammonia, from neighbouring countries via pipelines or from further away via ships. For example, in the ENTSOs' TYNDP 2020 Global Ambition scenario, almost half of the overall gas consumption (included hydrogen and methane) is covered by imports.

The main sources considered in the set of reviewed scenarios for the imports of decarbonised gases are:

- Biomethane (CH_4): European countries with important biogas potentials
- Hydrogen (H_2) and derivatives such as e-methane (CH_4), e-ammonia (NH_3), e-methanol (CH_3OH): countries with important RES potentials associated with electrolysis facilities and subsequent conversion processes (e.g. methanation for the production of e-CH_4, Haber-Bosch for the production of e-ammonia, Fisher-Tropsch and Sabatier processes for the production of e-methanol), with hydrogen production from SMR/ATR with CCS.

As a consequence of the uncertainties related to the level that the total electricity demand will reach (including direct and indirect electrification), there is an important variability of the renewable capacities in the scenarios that have been considered, and in particular the offshore wind capacities. In Figure 10, we illustrate the large range of offshore capacities at the 2050 horizon in the different scenarios over the EU27+UK scope, varying from 150 GW to 450 GW in 2050. This should be compared with the target of the offshore strategy, which is to reach 300 GW by 2050.

---

[32] Hydrogen demand is converted in equivalent electricity demand based on an electrolyser efficiency of 85% (PEM electrolyser typical value)

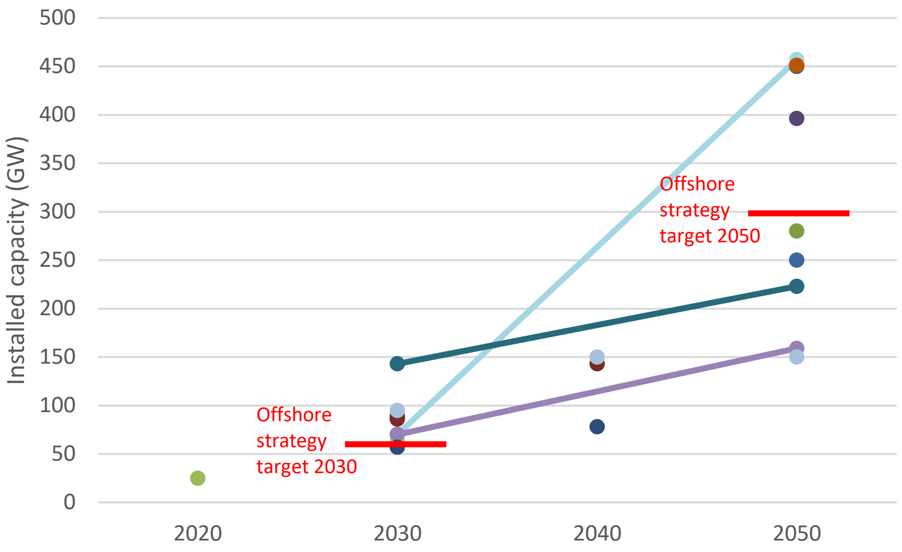
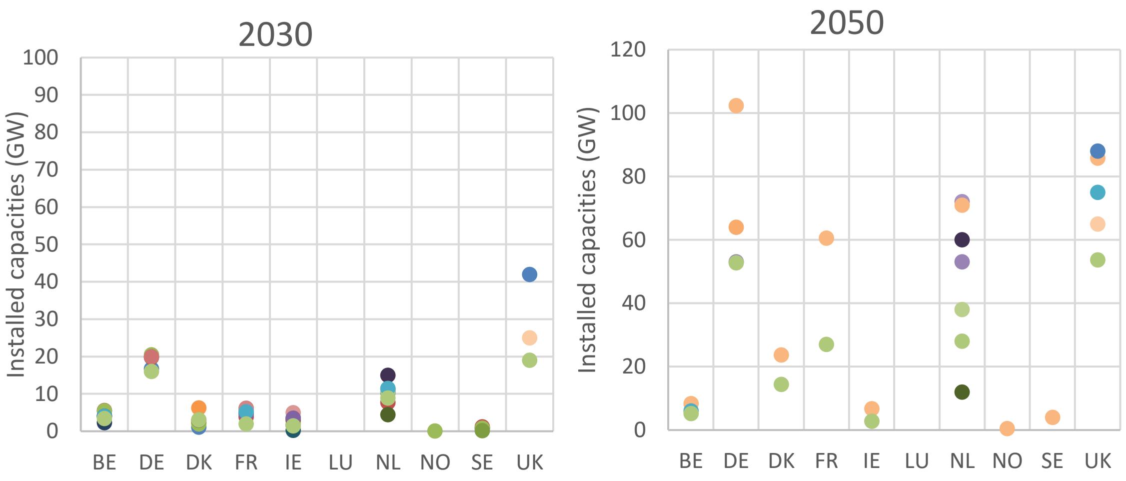


Figure 10 - Installed capacity of offshore wind in EU27+UK

When analysing the installed capacities at the 2050 horizon at the country level for the NSEC countries and UK, an important variability is found to emerge between scenarios. For Germany and the United Kingdom, all scenarios foresee an important increase of the offshore capacities, but with an important range between the lowest and highest values (from 50 GW to 100 GW for Germany, and between 55 GW and 90 GW for UK). For the Netherlands, the range is even higher, with lowest value close to what is expected for the 2030 horizon (12 GW), and highest values close to the ambition of Germany and UK (70 GW).



The evolution of the onshore and offshore infrastructure accompanying the development of offshore wind is highly complex and not consistently considered across scenarios

As mentioned in the sub-section covering common grounds, the important development of offshore wind capacities will require substantial investments in onshore and offshore infrastructure. However, the level of investments strongly depends on different assumptions on key structural evolutions of the energy system. Based on the analysis of the different publications, several ways to mitigate the necessary investments are identified, ranging from a better usage of existing networks, to the combination between interconnections and offshore assets via hybrid projects, via leveraging the flexibility offered by sector coupling, notably with a production of hydrogen with electrolysers and an injection into the gas network (via the repurposing of gas assets).

These topics are not treated with the same level of sophistication in the different studies that have been analysed. While the hybrid projects are addressed in all the publications relying on an explicit modelling of wind offshore infrastructure, the modelling of the impacts of the production of hydrogen and more generally of the impacts of sector coupling are only investigated in a limited number of studies.

Author	Title	Modelling of the connections between offshore wind farms and shores	Explicit modelling of hybrid projects	Representation of hydrogen	Sector coupling (gas-power)
Navigant for NSWPH	Integration routes North Sea offshore wind 2050	✓	✓	✓	✓
Energinet.dk	System perspectives for the 70% target and largescale offshore wind	✓	✓	✓	✓
Ea Energianalyse for Ørsted	Offshore wind and infrastructure	✓	✓	✓	✓
Roland Berger for the European Commission	How to reduce costs and space of offshore development	✓	✓	✗	✗
PROMOTioN	Optimal Scenario for the Development of a Future European Offshore Grid	✓	✓	✗	✗
Wind Europe	Our Energy, Our Future	✓	✓	✗	✗
PBL NL Environmental Agency	The future of the North Sea	✓	✓	✗	✗
ENTSO-E	TYNDP 2020	✗	✗	✓	✓
European Commission	Long-Term Strategy	✗	✗	✓	✓
Gasunie and TenneT	Pathways to 2050	✗	✗	✓	✓
Eurelectric	Decarbonisation Pathways	✗	✗	✓	✓
RTE	Public consultation for the 2050 scenarios	✗	✗	✓	✓
Trinomics and LBST for FCH JU	Opportunities for Hydrogen considering the NECP	✗	✗	✓	✗
Elia	Electricity scenarios for Belgium towards 2050	✗	✗	✗	✓
CAN Europe	PAC Scenario	✗	✗	✗	✗

As already mentioned when presenting the set of identified common grounds, hybrid projects can be a source of cost reduction when integrating wind offshore projects, but they are also an important source of complexity in terms of maritime spatial planning. All publications analysing the potential benefits of hybrid projects underline the fact that they face significant legal and regulatory barriers that need to be overcome. Strong international coordination is necessary to develop these hybrid projects, and find the appropriate joint financing models. It is important to note that hybrid projects are not always the most appropriate solutions and that dedicated studies should be undertaken for each case, with a careful definition of the counterfactual situation.

Meeting the flexibility needs associated with the variability of the offshore wind generation is one of the key challenges of its integration in the energy system of the North Sea region, and also a driver of the important requirement of energy infrastructure in order to maximise its value. Flexibility needs emerge on all timescales, from the infra-hourly level (e.g. due to forecasting errors) to the seasonal one (e.g. due to the seasonal pattern of wind generation profiles). At the 2050 horizon, part of this flexibility could be met via sector integration between the electricity and gas/hydrogen sectors, notably thanks to the provision of flexibility services by electrolysers. The indirect electrification of the European economy can then be a potential source of flexibility, the hydrogen demand necessary for the different P2X end-uses can be shifted in time in order to accommodate with the moments with the highest renewable generation, thanks to hydrogen storage infrastructure.

The flexibility offered by the P2X is represented differently is the three studies analysing its benefits for the integration of offshore wind capacities. In the *"Integration routes North Sea offshore wind 2050"* by Navigant, electricity can be converted into hydrogen and stored in the gas grid, and then can be converted back into electricity when required via gas-to-power units. This representation does not take into account the possible flexibility that could be offered by the different end-uses (such as industry or transport) consuming directly this hydrogen for their processes, and mainly focuses on the storage role of the gas system. In contrast, *"Offshore wind and infrastructure"* from Ea Energianalyse is explicitly representing the P2X demand of the different countries around the North Sea, in order to determine how and where the hydrogen should be produced to meet these demand levels. The study shows that allowing possible exchanges of hydrogen between the different zones can lead to an important decrease in costs, increasing flows of hydrogen from the offshore wind farms hub to consumer locations using gas infrastructure, and limiting investments in additional power lines. Finally, Energinet in "System perspectives for the 70% target and largescale offshore wind" shows that integrating important amount of offshore wind (+10GW in the North Sea in 2035 compared to the reference scenario) will require sector coupling, and a transformation of the entire energy sector to use this additional production to create synthetic fuels such as ammonia, and increased power and hydrogen interconnectors with neighbouring countries.

The possible integration of hybrid projects and sector coupling are key uncertainties for the evolution of infrastructure, as explained in the previous paragraphs. For example, Ea Energianalyse in *"Offshore wind and infrastructure"* have created different scenarios to assess the impacts of this uncertainty: a reference situation (Main) with only direct connections for wind farms and possibility to exchange hydrogen between the different zones, a scenario with the possibility to have hybrid projects (S1) and a third scenario without the possibility to exchange hydrogen between the different zones (S2). As illustrated by Figure 11, hybrid projects can reduce the total transmission need by 5% (S1 vs Main). Synergies between offshore wind generation and P2X generation is also an important lever to decrease investments in infrastructure: compared to a situation where P2X exchanges are not possible between the different zones (Main vs S2), transmission capacities can be reduced by 15%.

Figure 11 - Benefits in term of installed capacities of transmissions between a situation where investments in hybrid projects are possible (S1) and a reference situation where wind farms can only be connected to the nearest shore (Main), and a situation where hydrogen exchanges between zones are not possible (S2)
Source: Ea Energianalyse, "Offshore wind and infrastructure"

The question of CO_2 infrastructure (for carbon capture and for the production of green fuels with P2X) is emerging, but is only partially addressed in the different publications

In most of the publications, CO_2 is only considered for its associated emissions, and as the main greenhouse gas contributing to global warming. However, CO_2 is also a product like hydrogen or methane, which needs to be transported if it is to be used in a specific process or is to be captured.

In indirect electrification routes, the production of synthetic gas and of some of the e-liquids requires CO_2 in the chemical reactions to transform the H_2 (hydrogen coming from electrolysers) into CH_4 (synthetic methane) or more complex carbon chains (synthetic liquids). A dedicated effort to capture, store and transport CO_2 would then be necessary to enable indirect electrification. Energinet in "System perspectives for the 70% target and largescale offshore wind" already identifies this need of "green" CO_2 as a possible barrier of the development of advanced P2X solutions.

In addition to the CO_2 needs for the P2X processes, a number of publications are considering carbon capture storage (CCS) as a possible mitigation option to reduce the remaining emissions from fossil fuels that are difficult to replace. For example, the 1.5TECH scenario from the EC's Long-Term Strategy strongly relies on CCS to reach carbon neutrality in 2050. The North Sea could play a key role in the carbon capture as the depleted natural gas fields in the Netherlands or geological strata below the seabed in Norway could be used as a storage facility for CO_2. In the "The future of the North Sea", The Netherlands Environmental Assessment Agency is considering these depleted fields as a possible option for CCS. The Agency also mentions that the legislation needs to be adapted to allow CO_2 storage in these fields. Furthermore, the Norwegian government has recently announced significant investments in carbon capture and storage, via the so-called Longship project. One of the key components of this Longship is the Northern Lights, which aims at storing CO_2 2600 meters below the seabed[33].

---

[33] For a general introduction to the Longship project, see https://www.regjeringen.no/en/dokumenter/meld.-st.-33-20192020/id2765361/?ch=1

3. STAKEHOLDER ENGAGEMENT PROCESS

3.1. OBJECTIVES AND METHODOLOGY

3.1.1. *OBJECTIVE*

Often desk research needs to be complemented by questionnaires, interviews and workshops of relevant stakeholders and experts as they provide an important source of evidence to supplement the literature review and to fill in specific information gaps.

Therefore, to complement the literature review around the topics mentioned in the previous chapter and to enrich the list of considered publications, different stakeholders from the energy sector have been consulted about their views and expectations on offshore renewables and grids towards 2050 in the North Sea region.

3.1.2. *METHODOLOGY*

In preparing this report a series of consultative meetings have been held with key stakeholders representing each of the key aspects – governmental, operational, development - of the evolution of the power sector in the North Seas region. Consultations were carried out primarily in three phases. The first and third phase entailed stakeholder workshops, while the second phase involved conducting a series of in-depth semi-formal interviews.

The first online consultative workshop was held on Tuesday February 9th, 2021 with representatives from the selected stakeholder organisations. The workshop was used to provide some background on the study, highlight its relevance and the upcoming interviews, and provided a medium for sharing expectations and recommendations on the outcomes of the study.

In the second round of consultations, in-depth interviews have been carried out with representatives from the various stakeholder groups. A total of 4 stakeholder groups have been identified – Ministries from the North Sea Energy Cooperation (NSEC) countries and the UK Ministry, NSEC countries' TSOs and the UK's TSO, offshore developers and EU level organisations. See *"Annex A: Stakeholder participants"* for the list of all stakeholders consulted. It was crucial to engage with the different stakeholder groups, as the absence of a certain group would have given an incomplete picture of the offshore renewables and grids development vision towards 2050 from the NSEC countries involved in this study.

For the interviews, a questionnaire (see *"Annex B: Stakeholder engagement "*) was developed by the consultants in cooperation with members of the DG ENER project team. The questions focused on: generation, offshore grid infrastructure, flexibility and power-to-x, onshore grid connections and consumption, and market-based incentives. Interviews were conducted online using Microsoft Teams from Tuesday February 23rd to Thursday April 1st, 2021. A total of 35 stakeholders have been interviewed over that period.

In addition to the above-mentioned set of consultations, a second stakeholder online workshop (third phase) for a wider group of stakeholders was hosted by DNV on Tuesday June 15th, 2021. This forum was used as a means for the study team to present the results of the comparison of existing long-term visions for the North Seas Region (via literature review and interviews with stakeholders) and to propose recommendations that can be useful for upcoming scenario-building exercises.

3.2. TAKE AWAY FROM THE STAKEHOLDER CONSULTATION

The consulted stakeholders were largely found to validate the uncertainties identified in the publications reviewed in this study.

There was consistent feedback on the need and increasing importance for internationally aligned Maritime Spatial Planning (MSP) and coordinated grid planning, as both could enable hybrid projects which can be an important source of cost reduction when integrating wind offshore projects.

Stakeholders widely recognised that power-to-x, and specifically hydrogen will play a key role in decarbonising end-uses and providing flexibility where and when it is needed. However, uncertainties of the role of the electricity grid and the role hydrogen still to be addressed. The hydrogen demand and supply methods have profound impacts on the interaction with the electricity sector, and hence on the flexibility services that have to be provided by other technologies.

The stakeholder consultation process also provided an opportunity to get insights into the participants' view on the possibility of creating new market-based incentives with respect to locational aspects. The majority of the responses received were positive about the fact that market-based incentives are the best instrument to steer investments in the right direction ensuring optimal system development.

Overall, stakeholders agree that the North Sea region is a very promising area where synergies can emerge. However, there is work to be done in numerous directions to ensure this can occur (joint electricity-hydrogen-gas planning processes, interoperability, MSP at sea-level basin, permitting and incentives for hybrid grid projects, etc.).

Therefore, getting the framework conditions right is a pre-requisite for future scenario-building exercises to be "plausible/realistic" since these limitations (on planning, interoperability, MSP, etc.) are not explicitly considered in most scenario-building exercises.

3.3. FINDINGS FROM STAKEHOLDER CONSULTATIONS

Stakeholders provided a wide range of feedback throughout the consultation period. For the purpose of this report, the findings are presented under the following sub-headings based on the core set of guiding question on topics. The focus is placed on what stakeholders identified as the relevant factors for the development of a common offshore renewable energy and grids vision towards 2050, and the emerging challenges that could negatively impact this vision. The feedback collected thanks to this work have a dual value: providing useful recommendations for upcoming scenario-building exercises and identifying key points that may prevent ambitious scenarios to develop in the North Sea region.

3.3.1. *GENERATION*

The large majority of respondents held the view that offshore wind - both fixed-bottom and floating - will be the energy form to play the most significant role in the development of the North Sea region, followed by offshore hydrogen. Meanwhile other types of energy forms will only play a minimal role (if not negligible) such as wave and tidal, floating solar, or seaweed (biomass).

Relevant factors to develop a common vision include:

- Industry development and technology maturity
    - Downward trend in the auction prices achieved for bottom-fixed offshore wind projects is observed,
    - Growing competence and experience with floating wind projects in Europe.
- Business case evolution
    - Level of market exposure is likely to grow in the absence of state support, thus most developers advocate for extending existing CfD regimes or their likes,
    - Alternative energy carriers and storage solutions such as hydrogen are likely to play a bigger role in securing profits.
- Policies supporting innovation
    - The need for transitional technologies (i.e. storage) from the system perspective, as peak power plants or redispatch capacity will become an issue for Member States in the future as they ramp up their RES capacity,
    - Offshore wind policies (i.e. permitting) should be aimed at facilitating further growth of offshore wind, while keeping a flexible and adaptive approach to be able to deal with future developments,
    - Regulation and technical innovations regarding GW scale power-to-x onshore and offshore are still immature and lag behind the political will to facilitate sector integration via extensive use of hydrogen or other alternative fuels.

Emerging challenges include:

- Regulation of hybrid projects and offshore bidding zones
    - Vision on hybrid and joint projects, in particular concerning remuneration and business models is required in order to incentivise developers to move away from conventional project-by-project generation build out to a more coordinated one,
    - Absence of regulatory base and clear vision for offshore bidding zones is seen as one of the main barriers for developing hybrid or cross-border projects.
- Coordinated planning among EU Member States and UK
    - Difficulty to work out a bottom-up plan without having a top-down plan on how to land all the generation coming from the North Sea raises concerns about future ability to integrate vast amounts of North Sea wind into national grids.
    - Mismatch between GB not be able to participate in an efficient implicit market coupling with EU, and the wish to have offshore bidding zone for hybrid assets/meshed offshore grids as set out in the offshore strategy

- Diverging national rules
    - Diverging national rules on the allocation of responsibility for the development, management and ownership of offshore assets gives wrong locational signals to project developers and investors.
- Trial projects
    - The "ideal" size for trial projects is not clear, subject to uncertainties in national ambitions and possibility to receive state support for innovations.

3.3.2. *OFFSHORE GRID INFRASTRUCTURE*

All stakeholders acknowledged the need and increasing importance for internationally aligned Maritime Spatial Planning (MSP) and coordinated grid planning. While a few of the respondents admitted that they are not directly engaged in the development of MSPs, the majority of stakeholders participate in the development of MSP either through the different consultation processes, as part of the stakeholder working groups or have a vote.

Coordinated offshore and onshore grid planning is seen as a must have for developing robust and cost-efficient grid solutions enable by anticipatory investments and transmission infrastructure sharing.

Relevant factors to develop a common vision include:

- Maritime Spatial Planning
    - There is a need for MSP coordination at a higher EU level, as national level MSP could prevent the emergence of synergies,
    - A joint MSP at sea-basin level will accelerate development and facilitates sharing of tasks,
    - Optimisation of special planning through the understanding of long-range external wake effects by spatial planners and project developers,
    - The most relevant aspect of developing a common vision will be the effects by and solutions for competition in using the limited offshore space.
- Onshore grid planning
    - Pan-European onshore grid planning is a key enabler to facilitate a more coordinated offshore grid build-out, support integration of renewables and minimise curtailments. TYNDP programme as well as integrated gas – electricity – hydrogen - NDPs will become more relevant,
    - Further onshore interconnection and market integration are key enablers for larger amount of offshore wind to be integrated in the European power system.
- Operation rules
    - Insufficient alignment on the operational rules, i.e. grid codes and requirement – the HVDC grid code is still in its immaturity and leaves a lot of space for interpretation by local operators and network developers.

    For the development of a coordinated international offshore grid technical standards need to be further aligned.

    - Need for standardisation of DC voltage levels to allow for development of meshed HVDC grids. Considering that DC transformers are not technically available, it is not possible to connect parts of the grid operating at different DC voltage. It is required to have the same voltage level across the entire HVDC grid in order to mesh or/and implement more complex interconnected grid structures. This voltage level needs to be agreed upon upfront by all concerned TSOs.

- Financing principles
    - Lack of alignment on the financing rules, i.e. state participation and incentives to private investors for funding, developing and owning the offshore grid,
    - Higher level of private investors' participation is seen as an emerging trend.
- Coordination with the UK
    - The UK is seen as a key player in offshore wind exploration in the North Sea, hence continuous dialog is needed to facilitate joint project development.

Emerging challenges include:

- Competition for marine space utilisation
    - Viable solutions to address cumulative (i.e. cross-border) side effects of offshore wind development and consensus-building with conflicting uses such as nature protection, shipping, military use, fishing, etc.
    - Lack of alignment on the use of North Sea space by different users if 300 GW of offshore wind is going to be built.
- Regulatory barriers
    - Greater clarity is needed in regard to the role of "hybrid" wind/interconnector projects which connect two or more countries. The regulatory regime requires resolution in the short term.
- Operational challenges:
    - Interoperability – even considering single-vendor systems, it can be difficult to prevent negative interactions between the offshore wind turbines and the offshore HVDC terminals. The issue is even more difficult for multi-vendor projects, where different vendors have incompatible control and protection systems often making it challenging to establish connections between projects,
    - Stability – in the integration on the existing onshore network. This challenge is already significant today given the high density of power electronics in the coastal regions and will only become more apparent in the coming decades,

  - Standardisation – for a harmonised development of offshore grid on a North Sea level a minimum set of requirements, specifications and rules is needed in order to capitalise on the synergies that a coordinated grid can deliver. If technical standardisation is not ensured, it will be hard to shift from a radial connection approach to more complex grid structures.

- Power to gas immaturity

  - The urgent need for pilot projects, where offshore electrical systems are coupled with P2G to make the best use of the harvested energy resource, is recognised. Whilst there is an established political will and preliminary proven financial feasibility in such projects, it is evident that at present power to gas technology is not mature enough to achieve the desired cost levels and competing as electrical solutions in delivering the value to the end consumer at a lowest price.

- Anticipatory investments

  - Uncertainty in national energy targets and future technology capability leads to a risk of over-investment or a need to retrofit already existing projects if better solutions are identified in the future. In order to enable future-proof offshore grid development a regulatory base catering for anticipatory investments needs to be in place,

  - TSOs and developers will require state support and incentives to deliver the necessary level of anticipatory investment and ensure cost-efficiency in the longer term.

3.3.3. *FLEXIBILITY AND POWER-TO-X*

Respondents characterise the need for flexibility differently subject to geographic and market specificities of each Member State. It is however widely recognised that power-to-x, and specifically hydrogen will play a key role in providing flexibility where and when it is needed. Whilst most of the participants reflected that their national power systems can cope with an increasing amount of renewables up to about 2035, it was acknowledged that various sources of flexibility such as demand response, battery storage, heat pumps, pumped-hydro storage, hydrogen and interconnectors will be needed to ensure system security on a European level. Generally, countries are already well underway with implementing simple measures such as demand side flexibility and battery storage, while more innovative solutions such as hydrogen are still at the planning stage. EU Member States seem aligned with the EU ambition of building out a hydrogen economy translated into national targets of hydrogen asset development.

Relevant factors to develop a common vision include:

- Variety of solutions for providing flexibility

  - Depending on a national perspective, participants consider different flexibility solutions to be optimal including power to heat, power to hydrogen, demand-side response, EVs, electric batteries, pumped hydro and others,

  - Combinations of technologies and flexibility solutions to cover the system needs at different time horizons.

- Hydrogen as a source of flexibility

    - Hydrogen can play a dual role as a means of decarbonising hard-to-abate sectors and balancing the power system,
    - Maturity level of hydrogen technology by the time the power system will start experiencing too high imbalance levels,
    - Electrolyser technology development - majority of participants agree that Polymer Electrolyte Membrane (PEM) technology is likely to emerge as the most promising solution for hydrogen production.
- Financial viability of hydrogen projects
    - Unequal financial impact that power-to-x systems may have on the business case of offshore wind projects depends on their location and market,
    - Uncertainty about a necessary level of state support for hydrogen projects.
- International collaboration in larger flexibility projects
    - Close collaboration between Member States on infrastructure and RES development,
    - Cross-border and cross-regional infrastructure development to a scale that allows for significant transport of both electricity and alternative energy carriers,
    - State support level is required for innovative technologies and pilot projects,
    - Regulatory treatment of hybrid (combining electricity generation and hydrogen production) projects.

Emerging challenges include:

- Role of electricity grid and role of hydrogen
    - Not all countries seem to have developed scenarios of the required future level of flexibility. A lack of such information hinders investment in flexibility infrastructure and systems,
    - Stakeholders diverge in their assessment of the role that hydrogen can play as a flexibility source as compared to other solutions. Some see it as the most optimal solution, while others conceive demand-side flexibility and heat pumps to be more suitable. The majority of respondents agreed that conventional grid reinforcement will become more complex in the future and may not cover all system needs in terms of balancing supply and demand.
- National strategy development
    - Inclusion of grey/blue hydrogen in national strategies vs green hydrogen only.

- System optimisation
    - Location of hydrogen production will have a major effect both on the business case of windfarms but also on the need for grid reinforcement. A system wide perspective and integrated planning of electricity and gas infrastructure is needed,
    - Due to limited availability and expertise of combined (gas/power) CBA frameworks, optimal system solutions can be difficult to realise in early stages.
- Enabling regulation
    - Strong Guarantees of Origin framework for projects with hydrogen production on-site will be a must in order to ensure competitiveness and level playing field with purely electrical projects,
    - Market mechanisms and regulations encouraging demand side flexibility and emergence of prosumers and flexibility providers need to be established.

3.3.4. *INTEGRATION WITH ONSHORE GRID*

All stakeholders agreed that integration with onshore grids can become challenging under status quo.

Relevant factors to develop a common vision include:

- Collaboration and alignment
    - The level of collaboration between all parties (TSOs, gas system operators, project developers, planning authorities and regulators),
    - A degree to which planning authorities will consider electrical and gas infrastructure as an integrated energy system,
    - Realistic scenarios reflecting future energy needs, generation mix, efficiency and network capabilities,
    - Identification of projects that bring value to European consumers (e.g. Project of Common Interest).
- Technical considerations
    - Technical compatibility of offshore and onshore grid technologies,
    - Compatibility of gas grid infrastructure to carry hydrogen molecules as well.
- Wider system development
    - Creation of demand clusters and industrial clusters in the vicinity of onshore landing points,
    - Ability to route offshore cables and offshore hydrogen pipes further inland to existing industrial clusters,
    - Development of interconnectors.

Emerging challenges include:

- Risk of not achieving economic level playing field
  - Potential divergence between market principles and support schemes for onshore and offshore,
  - Potential divergence between connection rules onshore and offshore, but also across EU member states,
- Insufficient onshore grid capacity and local opposition
  - Reinforcement of onshore grid in the coastal areas often faces opposition from local communities where visual amenity is harmed by large infrastructure roll-out.
- Uncertainty in sector coupling potential and ambitions
  - The way of integrating the electricity generated into the system (transmission of electricity, generation of hydrogen on- or offshore, etc.) still shows a high degree of uncertainty.

3.3.5. *MARKET-BASED INCENTIVES*

As it pertains to the possibility of creating new market-based incentives with respect to locational aspects (build offshore wind farms and electrolysers where they can be connected to existing systems/expected demand at lowest costs), the majority of the responses received were positive about the fact that market-based incentives are the best instrument to steer investments in the right direction ensuring optimal system development.

A number of respondents perceived the market-based incentives to have the potential to reduce overall costs by signalling favourable locations due to e.g. grid capacity, thereby increasing deployment speed and reducing local opposition by making more efficient use of infrastructure. While some stakeholders pointed out that discussion on this topic is underway, others mentioned that some incentives are already in place. In contrast, other stakeholders have mentioned that locational signals should not be applied when new infrastructure needs to be built, and that grid development should be driven by wind resource availability.

When asked about the type of incentives they foresee to be implemented, stakeholders expressed varying views in response to this topic. These suggested incentives include:

Generation and grid infrastructure:
- Definition of offshore bidding zones,
- Importance of defining incentives for generators and the use of infrastructure that do not affect participation in the market,
- Allowing participation of technology-neutral units in ancillary markets,
- Integrated tenders for electricity generation and flexibility solutions,

Flexibility and power-to-x:
- Locational dispatch incentives. Units could participate in redispatching services by making use of their flexibility in order to support any infrastructure needs. This is particularly relevant for onsite electrolysers that are less flexible in their localisation,
- Locational investment incentives, which could be directly included in market-based support schemes to support a timely ramping up of the hydrogen market while accounting for the implications on the infrastructure. This could be

achieved, for instance, by tendering infrastructure-optimal locations or regions in the support auctions for electrolyser investments,

- Having financial support and tendering scheme for hydrogen (i.e. CfD or similar) with the idea to create the demand and support the supply. It is important to incentivise the industry to start using clean and green hydrogen,
- Hydrogen quotas/targets for clean hydrogen should also be set for the industrial, transport, and heating sectors for 2030 and 2050. This should start with specific materials or products,
- According to current regulation, in some setups of hydrogen production from offshore renewables, double grid (power and gas) charging relating to the conversion/production of hydrogen would apply. This is unjustified and should be removed so as not to impose an undue burden and unfair competition
- Reduction in the connection tariff if grid utilisation is optimised through flexibility,

Cross-border incentives:

- Carbon border adjustment mechanism would be needed to prevent carbon leakage outside of the EU,
- Incentives would need to be designed as needed across all aspects of supply (offshore wind/electrolysers), demand (for renewable hydrogen and green products such as green steel) as well as transmission. These policies may vary by need at a particular location or country and would need to consider the EU Emission Trading System (as some incentives/mandates could undermine the robustness of the EU ETS. Further assessment of this option would be required

Tariffs:

- The locational incentive may not need to be limited to the market ramp up phase and be rather permanent. Possibilities are, among others, locational components in network tariffs, more regional electricity price setting to make regions with high-RES surplus more attractive, or even a strict spatial and temporal character of Guarantees of Origin (GoO),
- The first type of incentives relates to transmission tariffs, which should be cost-reflective. This is typically a national competence, but EU guidance can be helpful,

General:

- In the short term, a solid system of Guarantees of origin based on life-cycle carbon content should be determined and implemented, ensuring traceability, traceability, transparency, and tradability,
- The use of existing market solutions and regulations as much as possible, to secure an efficient market and a levelled playing field,
- At the end the support should be market driven rather than subsidies.

4. COMMON GROUNDS AND KEY UNCERTAINTIES – HOW TO TRANSLATE THEM INTO ACTIONABLE RECOMMENDATIONS?

In this section, we provide a consolidated analysis of the common grounds and key uncertainties that have emerged from the two activities presented in the previous sections.

The **review of recent publications** has mainly aimed at covering a set of existing scenarios, with identification of common and diverging aspects. While the key observations have already been presented in the section dedicated to the analysis of scenarios, we continue the analysis in this section by providing recommendations for upcoming scenario-building exercises, in particular on the way to treat the uncertainties that have been identified. We also propose some actions by third parties related to the establishment of datasets that are required for most scenario-building exercises and very highly labour-intensive to create (e.g. cost curves for renewable potentials, adequacy with MSP, generation time-series, etc.).

The **consultation of stakeholders** has mainly informed the identification of areas where a high level of uncertainty lies, confirming the results of the literature survey in many cases. Interestingly, as stakeholders have not only provided valuable opinion on the way scenarios need to integrate some aspects that are currently neglected in their opinion, but have also provided their view on potential risks that may prevent the emergence of scenarios that are being built, we have found it useful to provide an overview of these concerns, which can be the starting point of future work of various support groups of the NSEC.

The objective of this section is twofold: to provide a set of recommendations related to aspects of scenarios that require particular attention according to our analysis, and to provide a list of challenges belonging to the technical, regulatory and market design dimensions that need to be tackled for the scenarios to have a chance to effectively emerge.

4.1. COMMON GROUNDS

As discussed in the two previous sections, there are significant and robust common grounds that can be identified in existing scenarios, as well as in the feedback provided by stakeholders.

On one hand, the fact that a given topic has reached a “common ground” status can be a sign of a **high level of maturity** and that stakeholders and scenarios have progressively reached alignment. This is the case for a number of topics, as has been explored in the section related to the literature review (section 2), such as the ambition to decarbonise the European economy at the 2050 time horizon, the fact that offshore wind will play an important role, that hydrogen will trigger important need for renewable energy sources, etc.

On the other hand, common grounds can also be a sign that a large share of scenarios or stakeholders shows **broad agreement that further work is required** in particular aspects of scenario-building or policy framework. These common grounds can be understood as calls for action, and are thus treated as uncertainties related to the fitness of the current modelling practices or definition of the regulatory framework. These common grounds are therefore discussed in Section 4.2, together with uncertainties that originate from disagreements or misalignments between the views expressed in different scenarios we have reviewed and/or by the different stakeholders we have interviewed.

This section therefore focuses entirely on common grounds that are not attached to particular recommendations. We therefore treat them relatively briefly and expand more in the next sections on the topics that are characterised by uncertainties. An analysis of the origin of discrepancies and associated recommendations on the way to tackle them in scenario-building exercises will also be provided in the next section.

The key common grounds that have been identified are the following:

- **Ambitious decarbonisation levels** – The vast majority of the considered scenarios are in line with the net zero objective at the 2050 time horizon. Only a very limited number of scenarios are not on a pathway to reach that target, but, most often than not, this is engineered to test the robustness of the analysis. Therefore, while it is of crucial importance to continue building scenarios that are compatible with the 2050 net zero target, especially if they are underpinning infrastructure investment choices, it seems that this dimension is already well integrated by modellers and that no further recommendations on the decarbonisation levels to be imposed at that time horizon is required according to our analysis.

- **Final electricity demand in 2030 is quite robust across scenarios** – As can be read from the analysis in Section 2, there is a very good level of consistency on the level of electricity demand at the 2030 time horizon, especially when compared to the 2050 time horizon. Indeed, in many of the analysed scenarios, the trade-offs between direct and indirect electrification routes mostly appear in the 2040s and 2050s when buildings, transport and industry sectors are undergoing structural changes to decarbonise their end-uses. Therefore, the uncertainties associated to this choice are not yet materialising in terms of electricity demand in 2030.

- **Electrolytic hydrogen will be a key contributor to the decarbonisation and will drive investments in RES capacities** – All the scenarios that have been considered include hydrogen as one of the options to decarbonise hard-to-abate sectors, and in some scenarios as a competitor to direct electrification routes. Some scenarios foresee a role for alternatives to electrolytic hydrogen production in the EU (e.g. SMR/ATR with CCS, hydrogen imports, etc.). While it is satisfactory that hydrogen is explicitly considered in most scenarios as its production has a strong impact on the need for RES capacities and infrastructure, there are numerous uncertainties that will be discussed in the next section.

- **The ambition in terms of deployment of offshore wind is in line with the offshore strategy at the 2030 time horizon** – The scenarios that cover the countries in the North Sea region are compatible with the deployment levels targeted by the offshore strategy for the offshore wind technologies at the 2030 time horizon. However, as emphasised in the next section, key questions remain around market design supporting hybrid assets or the deployment of other offshore technologies, which is highly uncertain according to publications and stakeholders (e.g. floating solar, offshore electrolysis, etc.).

To conclude, recent initiatives related to scenario-building are based on solid grounds. Ambitious decarbonisation targets are at the core of the latest set of scenarios, and the importance of the contributions of offshore wind is recognised by all types of stakeholders. There is a broad agreement on the level of demand, with limited variability between scenarios. However, important uncertainties remain, both on the characteristics of the 2050 configuration of the energy system, and on the way to get there (e.g. at the 2030 time horizon). The next sections explore the key uncertainties, their drivers and the way upcoming modelling exercises can tackle them.

4.2. KEY UNCERTAINTIES AND ASSOCIATED RECOMMENDATIONS

In this section, we provide an exhaustive list of the uncertainties that have been identified in terms of modelling of prospective scenarios of the evolution of the energy system of the North Sea region. For each of them, we discuss the drivers that may cause the observed discrepancies, and identify if they are linked with different visions about the future, or if they are due to the different scope of the various modelling exercises we have analysed.

Furthermore, we enrich this list of uncertainties by including the feedback collected via the interview of key stakeholders active at various levels of the transition in the North Sea region (public authorities, TSOs, project developers). In particular we expand on the key uncertainties that could put some of the scenarios at risk, not from the point of view of the inner consistency of the scenario, but from the point of view of the enabling technological solutions and regulatory frameworks that have to be put in place for such ambitious scenarios to materialise.

4.2.1. *UNCERTAINTIES RELATED TO THE EVOLUTION OF THE NORTH SEA ENERGY SYSTEM AND ASSOCIATED RECOMMENDATIONS FOR UPCOMING MODELLING EXERCISES*

We devote this section to the discussion of the key uncertainties that have been identified, and, most importantly, to providing recommendations that we think will be relevant for upcoming modelling exercises in order to recognise these uncertainties and manage them appropriately.

4.2.1.1. Pace of decarbonisation

The majority of scenarios that have been considered in this analysis have been established prior to the proposal by the European Commission of adopting more ambitious decarbonisation targets at the 2030 time horizon, from a 40% level of GHG emissions reduction compared to 1990 levels to a 55% reduction level.

Furthermore, a number of studies have used the National Climate and Energy Plans (NECPs) as a basis for the evolution of the energy system in the near future. These plans, when considered collectively, reach a GHG reduction level of 41% according to an EU-wide assessment carried out by the European Commission[34].

We therefore observe a lack of consistency between the pace of decarbonisation in existing scenarios and the updated 2030 GHG reduction targets. While the reasons for this discrepancy are understandable, it will be important that upcoming scenarios integrate this new target, as it may have profound consequences on the pace of deployment of renewable technologies and on the needs for infrastructure, triggered by a quicker phase-out of unabated fossil-based electricity and hydrogen generation technologies and a quicker adoption of new technologies on the demand side.

---

[34] COM(2020) 564 final

Recommendation #1 - 2030 GHG reduction target

Ensure alignment with the 55% GHG reduction target in upcoming scenario-building exercises.

Since some scenarios only have a partial representation of GHG emitting sectors (e.g. LULUCF), sectoral GHG reduction targets may be required. The pathways included in the impact assessment of the Climate Target Plan[35] can help set such targets.

4.2.1.2. Hydrogen demand in 2030

While the electricity demand in 2030 has been seen to be consistent across scenarios, it is worth mentioning that the demand for hydrogen at the same horizon is rather consistent between scenarios, too. However, the demand levels are, in most cases, not compatible with the hydrogen strategy, which proposes the following objectives[36]:

- By 2024, installation of at least 6 GW_e of electrolysers and production of up to 1 million tonnes of renewable hydrogen
- By 2030, installation of at least 40 GW_e of electrolysers and production of up to 10 million tonnes of renewable hydrogen

Following the publication of the hydrogen strategy by the European Commission, several Member States have also prepared national and regional hydrogen strategies focusing on the deployment of electrolysers, amongst which 6.5 GW in France, 5 GW in Germany, 5 GW in Italy, 4 GW in Spain, 3-4 GW in the Netherlands, 2-2.5 GW in Portugal.

The deployment of electrolysis can have a profound impact on the electricity systems and grids of the countries surrounding the North Sea, as several of them are developing ambitious hydrogen strategies. Indeed, scenario-building exercises will have to ensure appropriate electricity generation levels are available to meet the demand by electrolysers (in a way that is compatible with the principle of additionality).

Furthermore, depending on the dynamics of hydrogen consumption (e.g. rather flat consumption profiles in the industry) and of hydrogen production (dependent on available RES generation levels, and on the presence or not of a connection of RES capacities to the electricity grid), the need for flexibility services may be impacted on all timescales. Different candidate solutions can be combined to meet these needs, depending on the level of connection between renewables and electrolysers.

Recommendation #2 - 2030 hydrogen demand levels

Ensure alignment with the most recently published hydrogen strategies. The impacts of these targets on RES deployment, the needs for flexibility services on all timescales, and the way solutions may be combined to meet these flexibility needs should be examined. This recommendation also applies to the upcoming revision of NECPs.

At the 2030 time horizon, most studies and stakeholders expect that hydrogen ecosystems will mainly develop at the level of industrial clusters. However, in the case of the North Sea region, it is plausible that these clusters will be interlinked early in the transition compared to other areas, with current hydrogen networks potentially

---

[35] SWD(2020) 176 final

[36] COM(2020) 301 final

expanding to connect additional areas between France, Belgium, the Netherlands, Germany, or Denmark.

Given that the North Sea region and hinterland could be a candidate area for a rapid deployment of electrolysers and hydrogen infrastructure compared to other areas, upcoming scenarios for the North Sea region should consider with care the dynamics of hydrogen consumption and production, and the interaction with the existing gas infrastructure (via repurposing) to assess trade-offs between transporting energy via electrons or via molecules. See following recommendations for more details on these aspects.

4.2.1.3. Trade-off between decarbonisation routes and resulting hydrogen demand in 2050

One of the key findings of the analysis of existing scenarios, and which also applies to scenarios looking more specifically at the hydrogen demand, is the very important variability between the hydrogen demand levels at the 2050 time horizon. At the European level, the variability can reach a five-fold factor in some sectors between the lowest hydrogen demands and the highest ones. For example, a recent study by Agora Energiewende[37] estimates that the no-regret hydrogen demand in the industry is of circa 270 TWh, while in its most recent publication[38] Gas for Climate estimates that the industrial demand for hydrogen may reach circa 1200 TWh.

This uncertainty reflects the fact that several decarbonisation routes are available for a number of end-uses in all sectors of the energy systems in the North Sea region. Scenarios with the lowest hydrogen demand levels consider that the large majority of end-uses that can be directly electrified should be, and that hydrogen should be directed towards end-uses that cannot be electrified in a direct way and towards the industry as feedstock. This reasoning is based on the comparison between the overall efficiency of alternative decarbonisation routes (e.g. from RES to wheel in case of electric mobility versus hydrogen mobility for passenger cars; from RES to useful heat in the case of heat pumps versus gas boilers), which are favourable to the direct electrification option thanks to the absence of conversion processes (mobility) and of the high efficiency of electricity-consuming technologies notably heat pumps[39].

In some countries low hydrogen demand can also reflect more ambitious biomethane strategies to supply hard-to-abate sectors.

The uncertainty related to the level of hydrogen demand that has been identified in existing scenarios is not expected to reduce in the coming years. Indeed, the current trend is that electrification technologies are being considered in more and more applications (e.g. in some maritime applications close to shores, in trucking applications

---

[37] Agora Energiewende, ”No regret hydrogen”, 2021

[38] Gas for Climate, ”Analysing future demand, supply and transport of hydrogen”, 2021

[39] The validity of this argument should be examined by taking a holistic view, and including considerations related to the wider impacts on electricity generation needs and on flexibility needs. In some cases, hybrid consumption technologies such as hybrid heat pumps can be a way to benefit from the most efficient technologies during most of the year without impacting peak electricity demand as much as with pure electric solutions.

potentially combined with hydrogen back-ups, electricity for high-temperature processes in steel production via electric arc furnaces[40], etc.).

Recommendation #3 - 2050 hydrogen demand levels

In order to account for the important uncertainties related to the level of hydrogen demand that will be reached at the 2050 time horizon, we recommend that upcoming scenario-building exercises **consider and compare multiple ways of decarbonising end-uses where there is competition** between direct electrification, the use of hydrogen (and potentially derivatives obtained via subsequent conversion processes), and routes based on the use of biomethane.

For each of the considered decarbonisation routes, one should carefully analyse the resulting dynamics of the electricity and hydrogen demands, and in particular the levels of thermo-sensitivity of both demands (which will mainly be impacted by the way heating is to be provided to the residential and tertiary sectors).

The impact of these different demand levels and dynamics on the required electricity generation capacity and flexibility solutions are explored in subsequent recommendations.

The resulting scenarios based on the various demand assumptions can then be compared, so as to identify no-regret investments (investments that are found to be appearing consistently across scenarios, or investments that minimise the costs of adapting course in case some of the factors required to emerge for a scenario to successfully deliver a decarbonised energy system do not materialise and risks of lock-in increase).

4.2.1.4. Hydrogen supply options and their impacts

The second key source of uncertainty related to hydrogen, in addition to the demand levels, which are discussed above, is the way hydrogen is sourced. While there is a consensus amongst stakeholders and in scenarios that unabated hydrogen production is unlikely to still be present at the 2050 horizon, various supply options are being considered, electrolytic hydrogen and SMR/ATR combined with CCS/CCU being the main ones. Other options such as (bio)methane pyrolysis and partial oxy-combustion of CH4 have also been mentioned in some publications/stakeholders.

The source of hydrogen can have profound impact on the development of the energy system of the North Sea region. Indeed, while one expects the so-called blue hydrogen (production via SMR combined with carbon capture technologies) to be produced in a stable manner across the year, the production pattern of electrolytic hydrogen will be much more complex, leading to challenges and opportunities in terms of provision of flexibility to the other components of the energy system.

To be more precise, we need to distinguish several ways of producing electrolytic hydrogen. We provide below two archetypical configurations, which can be combined.

---

[40] See e.g. Agora Energiewende, "No-regret hydrogen", 2021

- The first option is to **power electrolysers with dedicated renewable generation capacities**. For example, an electrolyser could be installed within an industrial cluster, with onsite solar PV and/or wind turbines feeding the electrolyser directly. The relative dimensioning of the renewable generation capacities and of the electrolyser would be such that it ensures a satisfactory number of running hours for the electrolyser. If there are periods of excess RES generation, the electricity can be consumed/stored locally. In this configuration, priority is given to feeding electrolysers and not to performing arbitrage operations on the electricity markets. In other words, the flexibility that electrolysers can provide to the energy system is limited since stopping electrolysers to inject electricity back into the grid is not considered in this archetypical configuration.

- The second option is to **power electrolysers via the electricity grid**. For example, a large-scale electrolyser could be connected to the electricity transmission grid and produce hydrogen in a price-responsive way and only run when electricity prices are below a certain threshold (which is a good indicator of the marginal carbon content of the electricity being consumed). In this configuration electrolysers can provide important levels of flexibility. The dimensioning of electrolysis capacity would have to be larger than in a case with dedicated renewables, in order to be able to supply the same volume of hydrogen in a shorter amount of effective run time. Electrolysers could provide flexibility on all timescales, from infra-hourly to seasonal levels. Let us also note that one could consider running electrolysers in a baseload mode when connected to the grid. However, the impacts of this operational mode should be assessed with care. Indeed, adding a baseload consumption will divert low-carbon electricity from being exported to decarbonise other power systems, resulting in overall higher level of GHG emissions.

Finally, the third potential source of hydrogen is related to **imports**. There are various initiatives in countries around the North Sea to consider imports of (mainly electrolytic) hydrogen into Europe via ports[41]. Several carriers are being considered: liquid hydrogen, e-methane, e-methanol, e-ammonia or liquid organic hydrogen carriers (LOHCs) such as dibenzyltoluene. However, substantial uncertainties remain with respect to the cost of the different forms of hydrogen transport, to supplying regions (North Africa, South America, the Middle East, and even Australia are being investigated), and to the functioning of the underlying hydrogen markets (and hence the prices of internationally traded hydrogen). Imports of hydrogen into Europe via pipeline are also being considered, mainly from countries across the Mediterranean and from Ukraine or Turkey. A recent analysis from the JRC[42] shows that import via hydrogen pipelines is expected to be the most cost-competitive way of importing hydrogen especially if based on repurposed pipelines, but, at the same time, that substantial uncertainties remain as only very limited experience has been gained due to the small number of limited-scale pilots that currently exist.

Recent studies and publications, as well as the opinions voiced by the stakeholders we have interviewed, show that there is a high level of uncertainty on the configuration of hydrogen supply that is likely to emerge. However, the balance between dedicated renewables, grid-fed electrolysers and imports has profound consequences in terms of the optimal location of electrolysers, the level of flexibility that can be provided by

---

[41] See e.g. the Hydrogen Import Coalition, which is considering imports via the Port of Antwerp, or the Transhydrogen Alliance considering imports via the Port of Rotterdam for example.

[42] JRC, ”Assessment of Hydrogen Delivery Options”, 2021

electrolysers, and hence the need for flexibility that has to be met by other solutions such as electricity interconnectors, batteries and other storage technologies, demand-response, hydrogen pipelines (new or repurposed), hydrogen storage (new or repurposed), and gas- or hydrogen-fired turbines. Therefore, the following recommendation is that future scenario-building exercises treat these uncertainties either via dedicated scenarios or sensitivity analyses, so as to allow for the identification of no-regret options and/or risks of expensive lock-ins.

Recommendation #4 – Hydrogen supply options and provision of flexibility

In order to account for the important uncertainties related to the supply of hydrogen, we recommend that upcoming scenario-building exercises consider and compare **multiple supply options**:

- Role of non-electrolytic hydrogen supply sources
- Balance between grid-connected electrolysers and electrolysers with dedicated RES capacities
- Role of imports (via ports and/or pipelines)

The key aspect to investigate when considering the impacts of different supply options is related to the provision of flexibility services. Indeed, the various sources do not have the same level of interlinkage with the electricity sector and hence do not have the same impacts:

- Non-electrolytic hydrogen and imported hydrogen may play a role in the provision of flexibility services to the electricity sector by enabling hydrogen-powered turbines to run during periods of high residual load
- Electrolytic hydrogen has a much deeper level of interlinkage with the electricity sector. The balance between grid-connected electrolysers and electrolysers with dedicated RES impacts (a) the level of renewables that has to be built to power electrolysers, (b) the capacity of electrolysers, and (c) the set of additional flexibility solutions that are required.

Several ways of tacking this uncertainty can be engineered. One way is to let models find the optimal set of investments in RES, flexibility solutions and the use of supply sources. The optimal solution can then be disturbed via sensitivity analysis to assess the potential impacts of other supply configurations, feeding a no-regret analysis.

Given the complexity of the interactions between the various components of the energy system, the use of models that can endogenously optimise investments in supply/production/generation, storage, conversion and transmission technologies while maintaining a high level of time resolution of the dispatch (e.g. hourly time resolution over entire climatic years) should be favoured. Such models can assess the trade-offs between the various supply options and provide insights into the following questions:

- What are the needs for energy infrastructure? What are the trade-offs between transporting electricity or hydrogen?

- Considering the current infrastructure, where should electrolysers preferably be built? Near consumptions centres or close to generation sites? On offshore platforms, with desalination, purification and compressor stations?
- How to scale-up RES and operate electrolysers to ensure hydrogen production is not resulting in adverse environmental impacts?
- How do investments depend on the level of hydrogen demand?
- What is the competition between biomethane and hydrogen (via repurposing) to use existing gas assets?
- How is seasonal flexibility handled? What is the role of hydrogen storage? And of methane storage? Is power-to-hydrogen-to-power a solution?

Finally, let us stress that the different sources of hydrogen supply not only impact investments, but also GHG emissions. Indeed, depending on the operational behaviour of grid-connected electrolysers, carbon-intensive electricity may be consumed (especially if electrolysers are running in baseload). The sources of GHG emissions of alternative supply options also include fugitive emissions during transport (e.g. for e-methane transport via ships) or upstream of hydrogen production processes in the case of SMR+CCS.

4.2.1.5. Compatibility of RES deployment scenarios with MSPs

A large number of stakeholders have provided comments and expressed concerns about the way competition for the different uses of maritime areas is to be taken into account in scenario-building exercises.

One of the obligations under Directive 2014/89/EU establishing a framework for maritime spatial planning is for coastal Member States to develop a Maritime Spatial Plan by 31 March 2021. Amongst the objectives of MSPs, Article 5(2) includes "[..] contribute to the sustainable development of **energy sectors at sea**, of maritime transport, and of the fisheries and aquaculture sectors, and to the preservation, protection and improvement of the environment, including resilience to climate change impacts."

In practice, when analysing recent MSPs[43], Member States and third countries are found to adopt heterogeneous approaches to maritime spatial planning, and to be at different stages of the establishment of their respective plans:

- Belgium: Plan in force since March 2020 (PAEM 2020-2026)[44]
- Denmark: Draft published, ongoing public consultation[45]

---

[43] Plans and their statuses are collected and disseminated by the MSP Platform, which is financed by the European Climate, Infrastructure and Environment Executive Agency (CINEA) - https://www.msp-platform.eu/. Plans for the UK are available at: https://www.gov.uk/government/publications/uk-marine-policy-statement

[44] https://www.health.belgium.be/en/royal-decree-msp-2020-english-courtesy-translation

[45] https://havplan.dk/en/page/info

- France: Strategic facade documents published in 2019, ongoing public consultation of operational aspects[46]
- Germany: Draft published, ongoing public consultation[47]
- Ireland: National Marine Planning Framework in public consultation[48]
- The Netherlands: Ontwerp Programma Noordzee 2022 – 2027 published[49]
- Norway: Management plan for the North Sea 2013[50]
- Sweden: Excerpts of the submission to the government in 2019 published[51]

One of the key difficulties that is found to drive the uncertainty of the adequacy between MSPs and scenarios is that MSPs report areas that are dedicated to offshore wind projects or infrastructure in different ways. Some use areas (square kilometres), others project GW of installed capacities, and others report annual production potentials in TWh per year. A study has been carried out by Fraunhofer Center for Maritime Logistics and Services (CML) on behalf of the German Federal Maritime and Hydrographic Agency (BSH) in the context of the NorthSEE project in 2019. It has identified how regulations and practices differ amongst countries. The study also considers how a common language (mostly for maps) can be developed in order to establish cross-border MSPs.

In order to reduce the uncertainties related to a potential mismatch between the ambition levels of the EU offshore strategy and of individual Member States, it would be very valuable that MSPs provide a standardised metric of the availability for offshore wind development (e.g. in MW of installable capacity). The calculation of such installation potentials has to be explicit, since the use of different offshore wind technologies may result in different spacing between wind turbines and different densities in terms of MW per square kilometre[52] .

Since this translation effort of the latest available MSPs would be valuable for all upcoming scenario-building exercises, we have included a recommendation in Section 4.2.3 that one entity be in charge of that effort so that it is not to be repeated by all study teams involved in modelling efforts.

---

[46] https://www.merlittoral2030.gouv.fr/

[47] https://www.bsh.de/DE/THEMEN/Offshore/Meeresraumplanung/Fortschreibung/fortschreibung-raumplanung_node.html

[48] https://www.gov.ie/en/publication/a4a9a-national-marine-planning-framework/

[49] https://www.rijksoverheid.nl/documenten/rapporten/2021/03/18/4-ontwerp-programma-noordzee-2022-2027

[50] https://www.regjeringen.no/en/dokumenter/meld.-st.-37-2012-2013/id724746/

[51] https://www.havochvatten.se/en/eu-and-international/marine-spatial-planning.html

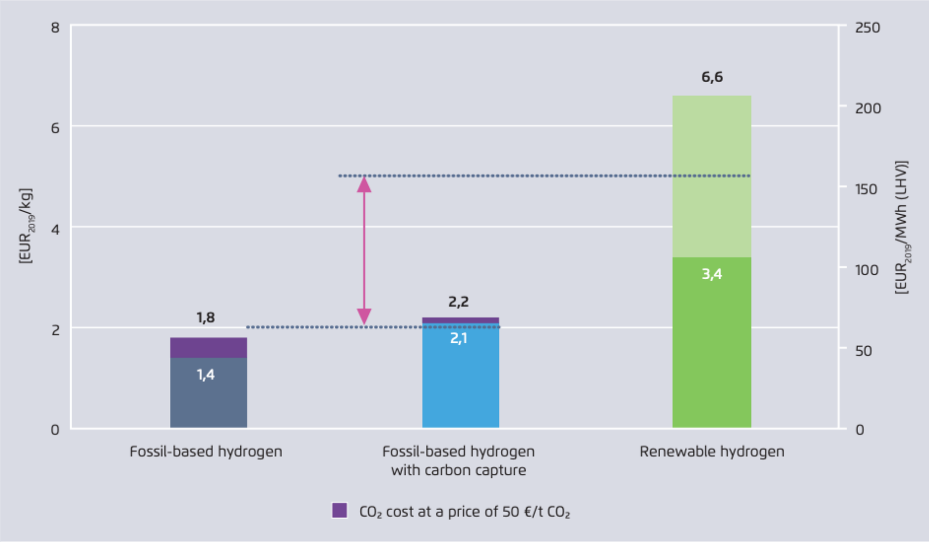
[52] See e.g. report by Deutsche WindGuard GmbH on behalf of BSH in the context of the Interreg project Baltic LINes "Capacity densities of European offshore wind farms", 2018 – Retrieved from https://www.msp-platform.eu/practices/capacity-densities-european-offshore-wind-farms

4.2.2. *UNCERTAINTIES RELATED TO THE ABILITY TO IMPLEMENT VISIONS FOR THE NORTH SEA REGION*

In this section we shortly summarise some of the key points that are not directly related to scenario building, but that – for some of them - could inform the design of sensitivity analyses. The key objective is to collect a number of uncertainties that have been identified during interviews and in publications, that we estimate should be on the agenda of policy makers when considering the framework for the development of the energy system of the North Sea region.

4.2.2.1. Incentives to stimulate the demand

For end-uses to be decarbonised, the correct set of incentives should be put in place so that consumers favour acquiring products that have been produced using efficient technologies based on the use of renewable energy. At the moment, the cost of electrolytic hydrogen is not competitive with alternatives (notably with grey hydrogen), leading to concerns about the demand for electrolytic hydrogen in the short to medium term.



Based on Guidehouse (2021).

The figures assume a natural gas price of €20/MWh and a CO_2 capture rate of around 75%. All figures are in 2019 euros.

Figure 12 - Comparison between the current costs of electrolytic hydrogen and fossil-based alternatives. Source: Agora Energiewende, "Making renewable hydrogen cost-competitive", 2021

While scenarios generally impose decarbonisation targets as constraints, either by imposing that hydrogen be consumed or by letting the model choose how to decarbonise end-uses, there are uncertainties about the way the demand for electrolytic hydrogen can be stimulated. Numerous ongoing discussions relate to the evolution of the EU ETS, the potential introduction of carbon contracts for difference (CCfDs) or commercialisation contracts[53]. Clarity on support schemes would provide more certainty to project promoters looking at scaling up RES generation and linking it to hydrogen ecosystems around the North Sea.

---

[53] See e.g. Bruegel, "Commercialisation contracts: European support for low-carbon technology deployment", 2021

Potential sensitivity analysis: increase the share of direct electrification to represent a more limited demand for electrolytic hydrogen due to inefficient or insufficient incentives.

4.2.2.2. Offshore market design for hybrid projects

While many publications and stakeholders point to the potential benefits that can be brought by offshore hybrid projects, which combine an interconnector with offshore generation assets, there is a broad agreement that the market design needs to be well adapted to avoid the need to over-size the transmission capacities or to curtail renewables so as to meet the requirements on the absence of discrimination of cross-zonal flows.

As underlined by the Staff Working Document accompanying the EC offshore strategy[54], offshore bidding zones are currently being considered as being the most efficient option to integrate offshore projects into European electricity markets.

However open points remain for example on the way congestion revenues are shared between the transmission system operator and the wind farm owner, in cases where congestion appears between the offshore bidding zone and the bidding zone ashore.

Finally, there are also questions on how efficient the processes leading to investment decisions related to hybrid assets will be. Indeed, part of the project will be assessed via the TEN-E process (Annex II of the proposed TEN-E revision mentions offshore grids with dual functionality as one of the eligible type of projects[55]), which will assess the interconnection itself and not the project in its entirety. If a separate procedure has to be followed for offshore wind farms, the entire process could prove to be lengthy.

Potential sensitivity analysis: replace part of the considered hybrid projects by non-hybrid counterfactuals (e.g. interconnectors and radially connected offshore wind farms) to represent potential risks to hybrid projects.

4.2.2.3. Permitting

An important number of projects developers have expressed concerns related to permitting, in particular in view of the efforts that are required to scale-up investments in renewable technologies and infrastructure projects. The potential impacts of permitting processes on the deployment of offshore assets, and in particular for joint and hybrid projects that require international cooperation, has also been underlined in the impact assessment accompanying the proposal for a revised TEN-E Regulation[56], notably based on the report by ACER on the progress of electricity and gas Projects of Common Interest[57]. In particular, ACER underlines that the most frequently reported reason for delays of electricity projects is related to permitting (while for gas projects, financing is the most frequently reported reason).

Potential sensitivity analysis: limit the build-up rate of offshore renewable energy and infrastructure projects to currently observed rates to represent potential limitations due to permitting.

---

[54] SWD(2020) 273 final
[55] COM(2020) 824 final
[56] SWD(2020) 346 final
[57] ACER, ”Consolidated Report on the progress of electricity and gas Projects of Common Interest”, 2020

4.2.3. RECOMMENDATIONS RELATED TO MODELLING APPROACHES AND TO THE ESTABLISHMENT OF SHARED DATASETS FOR EFFICIENT SCENARIO-BUILDING EXERCISES

The establishment of scenarios is a complex task, and requires more and more data as the interlinkages between various part of the energy sector and the economy at large interact with one another. The datasets and their geographic/temporal/technological resolution may depend on the methodology that is being used to establish the scenarios.

Considering the interlinkages between the different sectors and vectors advocate for models that can capture:

- **Interlinkages between vectors and sectors** – As emphasised in the relevant strategies accompanying the European Green Deal, sector integration is a key tool at our disposal to reach carbon neutrality in a cost-efficient and secure manner. If interlinkages between vectors and sectors are not well addressed by scenarios, one risks identifying investment needs based on inconsistent visions of the future, to over-invest (since opportunities at the interface between sectors are not properly accounted for) and to underestimate the benefits of harnessing the flexibility in the various sectors of the European economy. A joint electricity-hydrogen-methane approach would be especially well adapted for the North Sea region, for example to evaluate how the considered energy islands can be linked with coastal areas (via electricity cables, new hydrogen pipelines or repurposed methane infrastructure).

- **Flexibility needs on all timescales** – Future energy systems will be characterised by very high deployments of variable RES technologies, to power the direct and indirect electrification of end-uses in all sectors of the economy. Variable RES will participate in powering electrolysers. Therefore, the ability to produce electricity and hydrogen will be strongly correlated with RES generation profiles (with daily flexibility needs driven by solar diurnal cycles, weekly flexibility needs driven by wind regimes and seasonal flexibility needs by the seasonality of PV and wind production levels[58]). On the demand side, the structure of flexibility will also evolve as the electricity sector can be expected to inherit part of the seasonal flexibility needs linked with heating that are currently covered by gas assets (including storage).

- **Investment pathways** – One of the clear tendencies observed in European-level modelling efforts is the emerging need to build pathways describing the way to structure the transition instead of only concentrating on the establishment of a long-term vision. Indeed, we are now in a phase of implementation, where shovels need to hit the ground and projects have to emerge. All stakeholders need to gain a better understand what to do first, what investments are robust to the uncertainties that still exist (no-regret analysis), and policy-makers are also interested in reducing the risk of lock-ins. Such analyses can only be produced by building pathways (e.g. 2020 to 2050 with 5-year time steps) and not only visions for 2050.

- **Sub-national spatial resolution** - In order to ensure we can identify what projects are most promising in the short-term, not only do we need to build pathways (see previous point), but we also need to increase the spatial resolution

---

[58] See e.g. European Commission, "Mainstreaming RES - Flexibility portfolios" for a more thorough discussion of flexibility needs on various timescales - https://ec.europa.eu/energy/studies/mainstreaming-res-%E2%80%93-flexibility-portfolios_fr

of modelling exercises. Indeed, it is only be adopting resolution on e.g. a NUTS1 basis (instead of a country-level) that one can ensure local specificities (e.g. RES potentials, interaction with existing infrastructure, public acceptance of projects, etc.) are well taken into account, leading to more realistic and cost-effective pathways. Furthermore, adopting a more precise spatial resolution can also help identify the role of technologies aiming at optimising the operations of existing networks, and not only consider investments into new assets as solutions to increase power transfer capacity. Finally, in order to also be able to measure the impacts of the location of offshore hubs, due to the quality of the RES potential, the importance of the RES potential due to other uses of the considered area, and the potential links with existing infrastructure, it could prove beneficial to introduce maritime areas for the specific purpose of energy planning exercises.

Models that comply with these recommendations are very complex, and use as inputs datasets that are very highly labour-intensive in terms of efforts required to create them and in terms of validation processes. In particular, the analysis carried out herein has shown that the following datasets are used in most of the scenario-building exercises:

- **RES potentials and MSPs –** Many publications tackle the question of the evolution of CAPEX and OPEX of various key technologies over the coming decades. However, only a small number of datasets exist characterising the effective techno-economic potentials for these technologies. As discussed earlier, one of the key uncertainties that have been identified, in particular by project developers, is the alignment (or lack thereof) between foreseen deployment of offshore RES technologies and MSPs. It would therefore be very valuable that an effort is undertaken to (a) ensure common metrics are included in MSPs, as currently some MSPs report zones dedicated to RES in heterogeneous units such as areas, GW, TWh/year, etc. (b) a comparison between RES potentials and the most recent MSPs is carried out and made publicly available. The ENSPRESO database[59], built and made available by the Directorate General Joint Research Centre of the European Commission, could be a candidate to include such analyses.

Remark on the proposal for a revised TEN-E Regulation.

The European Commission has recently proposed[60] a revision of the TEN-E Regulation (Regulation (EU) No 347/2013 on guidelines for trans-European energy infrastructure).

One of the key novelties compared to the current regulatory framework is the introduction as a first step of a strategic sea-basin approach for a number of processes (e.g. planning, permitting one-stop-shop). In particular, the Commission proposes:

- In Article 14(1) that Member States jointly define and agree to cooperate on the amount of offshore renewable generation to be deployed within each sea basin, and
- In Article 14(2) that ENTSO-E shall develop and publish integrated offshore network development plans starting from the 2050 objectives for each sea basin, with intermediate steps in 2030 and 2040.

---

[59] https://data.jrc.ec.europa.eu/dataset/6d0774ec-4fe5-4ca3-8564-626f4927744e

[60] COM(2020) 824 final

Environmental protection and other uses of the sea are explicitly mentioned in the two paragraphs. This will likely result in a stronger interlinkage between MSPs and scenario-building exercises, should these provisions be part of the revision.

Furthermore, some of the recommendations mentioned in this study may also be valuable in the context of the development of the scenarios underpinning the assessment of candidate projects of common interest and projects of mutual interest.

- **Offshore wind generation profiles** – The North Sea is an area that is very well adapted to hybrid projects, i.e. projects that combine an interconnector with offshore generation technologies. A growing number of countries, including landlocked ones, have shown interest in investing in offshore energy islands. However, given the uncertainties listed above, in particular related to the level of hydrogen demand and the role of hydrogen imports from extra-EU countries, there is uncertainty related to the number of such islands that would present a clear and positive economic case. Therefore, no-regret approaches may be relevant. In order to analyse these aspects, it is important to assess the complementarity between offshore energy islands, in particular in terms of RES generation profiles. Therefore, we recommend that databases that provide wind generation profiles use an appropriate spatial resolution in the North Sea, so as to enable the analysis of the best suited locations of the first offshore energy islands, and how to build on them to establish a meshed network of energy islands, should the demand for electricity and hydrogen reach sufficient levels and such project be cost-competitive. A candidate database to host such profiles is the Pan-European Climate Database[61] developed by ENTSO-E in collaboration with the Technical University of Denmark (DTU).

The publication of robust pan-European datasets accompanied by comparison exercises could be very beneficial to upcoming scenario-building exercises. Indeed, while the information on RES potentials or generation time-series could be collected from MS-level sources or regional sources, the fact that the methodology used to establish them differs from one source to the other can introduce biases in the analysis. Therefore, there would be a clear advantage that these datasets are generated at the EU level, covering neighbouring third countries where relevant.

Finally, as building scenarios is an endeavour that gets more and more complex as more and more sector-specific assumptions are required, there are important benefits to the organisation of modelling fora allowing for a cross-fertilisation of ideas and approaches, not only amongst modellers, but also involving policy-makers. Such fora can be extremely valuable to structure the conversation, identify key research questions and discuss potential approaches. Organising this vertical dialogue, starting from policy related questions to the architecture of models, can be very useful, but is time-consuming. There could be opportunities to organise such exchanges in the context of currently ongoing modelling efforts that involve parties such as ENTSO-E, ENTSOG, the NSWPH, the European Commission, etc. The Offshore Coalition for Energy and Nature (OCEaN), moderated by RGI and whose members include NGOs, wind developers and TSOs, is also active in the assessment of available information and experiences, to identify the need for further research, in particular to improve the planning offshore

---

[61] Database available at https://www.entsoe.eu/outlooks/midterm/#download. The PECD database - retrieved on 13 July 2021, includes offshore wind profiles for 35 climatic years for each of the coastal bidding zones.

wind development. The study to be undertaken by NSEC’s SG2 could probably benefit from establishing exchanges with this coalition.

ANNEX A: STAKEHOLDER PARTICIPANTS

Participants	First engagement	Second engagement	Third engagement
BE - Federal Public Service (FPS) Economy – General Directorate Energy	Participated	Participated	Participated
BE - CREG - Commission for Electricity and Gas regulation	Participated	Participated	Participated
DK - Danish Energy Agency	Participated	Participated	Participated
FR - Ministry of Ecology, Sustainable Development and Energy	Participated	Participated	*
DE - Bundesministerium der Finanzen	n/a	n/a	Participated
DE - Bundesministerium für Wirtschaft und Energie	Participated	Participated	Participated
DE - Federal Maritime and Hydrographic Agency of Germany	Participated	Participated	Participated
IE - Department of Communications, Climate Action and Environment	Participated	Participated	Participated
LU - Ministry of Energy and Spatial Planning	Participated	Participated	Participated
NL - Ministerie van Economische Zaken en Klimaat	Participated	Participated	Participated
NL - Ministerie van Infrastructuur en Waterstaat	Participated	n/a	Participated
NO - Ministry of Petroleum and Energy	Participated	Participated	Participated
SE - Ministry of Infrastructure	Participated	*	Participated
UK - Department for Business, Energy and Industrial Strategy (BEIS)	n/a	Participated	*
BE - Elia	Participated	Participated	Participated
BE - Fluxys	Participated	Participated	*
DK - Energinet	Participated	Participated	Participated
DE/NL - TenneT	Participated	Participated	Participated
DE - 50 Hertz	Participated	Participated	Participated
IE - EirGrid	Participated	Participated	Participated
FR - RTE	Participated	Participated	Participated
LU - Creos Luxembourg	Participated	*	*
NL - Gasunie	Participated	Participated	Participated
NO - Statnett	Participated	Participated	Participated
SE - Svenska Kraftnät	Participated	Participated	Participated
UK - National Grid	n/a	Participated	Participated
Ørsted	Participated	Participated	Participated
Vattenfall	Participated	Participated	*
RWE	Participated	Participated	Participated
Iberdrola	Participated	*	Participated
Equinor	Participated	Participated	Participated
Shell	Participated	Participated	Participated
NSWPH (initiative)	Participated	Participated	Participated
Port of Rotterdam	Participated	Participated	Participated
EBN	Participated	Participated	*
Benelux	Participated	*	Participated
France Energie Eolienne	Participated	Participated	Participated
NSEC support group 2	Participated	n/a	Participated
NSEC support group 4	Participated	n/a	Participated

ENTSO-E	Participated	Participated	Participated
ENTSOG	Participated	Participated	Participated
Hydrogen Europe	Participated	Participated	Participated
Wind Europe	Participated	Participated	Participated

*Did not reply

ANNEX B: STAKEHOLDER ENGAGEMENT SURVEY

Introduction

This survey is divided into 5 topics - Generation, Offshore Grid Infrastructure, Flexibility and Power-to-X, Integration with Onshore Grid and Potential Incentives. All questions are referring to the end state in 2050 (information about intermediate steps will also be appreciated).

Your responses will be treated confidential and will be anonymised if included in the report.

Question 1: Your organisation
Question 2: Your position
Question 3: Your name (optional)

Generation

Question 4: Which installed capacities and locations do you foresee for offshore wind in your country/ country you operate in?
Question 5: What other energy forms are expected to play a role offshore, in what quantity and which locations?
Question 6: What cost development do you expect for offshore wind and innovation projects?
Question 7: Do you expect your country/country you operate in to be net importer/exporter of electricity?
Question 8: Which future generation projects in the Northern Seas are you working on?
Are they actively supported?
What are the support instruments that are practiced?
Which political and/or regulatory barriers could affect the development of the listed projects?
How to mitigate risks for both society as well as for a project developer?

Offshore Grid Infrastructure

Question 9: In what locations/areas do you expect offshore grid infrastructure?
Question 10: How do you deal with maritime spatial planning?
Question 11: What offshore grid technologies are you expecting to use (and what does it mean for standardisation and interoperability)
Question 12: Which future offshore grid projects in the Northern Seas are you working on?
Are they actively supported?
What are the support instruments that are practiced?
Which political and/or regulatory barriers could affect the development of the listed projects?
How to mitigate risks for both society as well as for a project developer?

Flexibility and Power-to-X

Question 13: What are the flexibility needs in order to cover residual load in your country/country you operate in?
Question 14: Which flexible energy production methods are you planning/expecting (and in what quantity and where)?

Question 15: What amount of flexibility will demand side response (DSR) provide in your country/country you operate in?

Question 16: What is the foreseen role of Power-to-X related to the needed flexibility?

Question 17: What system value could partly-grid-connected offshore wind provide by transforming electricity into molecules close to where it is generated, while the other share is fed into the electricity system? (In this way, peak RES production would not undermine the electricity system operability and alleviate the need for balancing high ramps)

Question 18: Which Power-to-X technologies will be available? To what extent will they be needed and integrated in the system?

Question 19: Which future Power-to-X projects in the Northern Seas are you working on?
Are they actively supported?
What are the support instruments that are practiced?
Which political and/or regulatory barriers could affect the development of the listed projects?
How to mitigate risks for both society as well as for a project developer?

Integration with Onshore Grid

Question 20: How high will electricity demand be in your country/country you operate in?

Question 21: What will drive this demand?

Question 22: Where the largest consumption areas will be located?

Question 23: What do you expect as necessary developments in onshore landing points and onshore bottlenecks (electricity, gas, hydrogen) to enable offshore grid integration?

Question 24: Which future projects facilitating integration with onshore grid in the Northern Seas are you working on?
Are they actively supported?
What are the support instruments that are practiced?
Which political and/or regulatory barriers could affect the development of the listed projects?
How to mitigate risks for both society as well as for a project developer?

Potential Incentives

Question 25: What do you think on the possibility of creating new market-based incentives with respect to locational aspects (build OWF and electrolysers where they can be connected to existing systems/expected demand at lowest costs)?

Question 26: How do you foresee these incentives to be defined?

Your Inputs

Question 27: Please let us know if there are any other important factors or opinions based on your experience which you believe to be relevant for developing a common vision on the deployment of renewables in the Northern Seas until 2050.

Question 28: Please let us know based on your knowledge and experience the most diverging visions on the pathway of renewables deployment in the Northern Seas until 2050.

Question 29: Please let us know which other studies, publications or research you deem to be relevant for developing a common vision on the deployment of renewables in the Northern Seas until 2050.

ANNEX C: QUANTITATIVE INDICATORS DATA FROM THE LITERATURE REVIEW

Power demand 2030 (TWh)

	TYNDP 2020-NT	TYNDP 2020-DE	TYNDP 2020-GA	NECP-Low	NECP-High	Energinet 70% target - Low	Energinet 70% target - High	Elia - Low	Elia - High	PBL Future North Sea - Low	PBL Future North Sea - High	EirGrid - Low	EirGrid - High	RTE-Low	RTE-High	DNV-GL North Sea Outlook	EU PAC scenario	ETIP Wind Road map	National Grid UK - Low	National Grid UK - High	Wnd Europe	EA Energi analyse	PROMOTioN - Low	PROMOTioN - central scenario
BE	4,3	5,6	5,5	4,0				2,3	4,0												4,0			3,4
DE	16,7	19,8	20,5	20,0																				16,0
DK	1,1	2,3	2,0	6,3		3,0																		3,1
FR	4,9	3,9	5,2	5,2	6,2									5,2	6,2						5,2			2,0
IE	3,5	1,6	1,7	3,5	5,0							0,3	3,0								3,5			1,5
LU																								
NL	11,3	7,7	10,2	10,6						4,5	15,0					10,8					11,5			8,9
NO																								
SE	0,8	1,2	0,9	0,2																				
UK																			25,0	42,0				19,0
EU	78,0	57,0	86,0														95,0	70,0			89,0	143,0	63,0	70,0

Power demand 2050 (TWh)

	TYNDP2020-NT	TYNDP2020-DE	TYNDP2020-GA	Tennet&Gasunie - High electrification	Tennet&Gasunie - High gas demand	DNV North Sea Outlook - Low	DNV North Sea Outlook - High	LTS 1.5 Tech[62]	LTS 1.5Life	Eurelectric - Low	Eurelectric - High	EU PAC scenario	ETIP Wind Roadmap	ETIP Wind Roadmap - High	National Grid - Low	National Grid - High	ASSET Energy outlook - Low	ASSET Energy outlook - High
BE								140										
DE				936	630			680										
DK								58										
FR								649										
IE								45										
LU								15										
NL				160	147	192	240	148										
NO																		
SE								204										
UK								561							374	451		
EU	**3696**	**4269**	**3478**	**5 500**	**4000**			**3997**	**3583**	**4200**	**4900**	**3581**	**3989**	**5450**			**3433**	**4258**

---

[62] 1.5TECH figures are only available at the EU level. A disaggregation at the country level has been carried out based using the electricity demand of the METIS Study S1 2050 scenario (https://ec.europa.eu/energy/studies/optimal-flexibility-portfolios-high-res-2050-scenario_en, and see https://ec.europa.eu/energy/data-analysis/energy-modelling/metis_en for more details on the METIS models, datasets and studies).

Hydrogen demand 2030 (TWh)

	TYNDP2020-DE	TYNDP2020-GA	NECP-Low	NECP-High	RTE - Low	RTE - High	EU PAC scenario	CH 2 JU - Low	CH 2 JU - High
BE	7,2	10,4	1,0	7,0				1,0	7,0
DE	61,1	110,0	9,0	41,0				9,0	41,0
DK	0,5	0,5	0,4	2,0				0,4	2,0
FR	5,0	-	4,0	20,0	9,7	25,0		4,0	20,0
IE	3,1	4,5		1,0				0,1	1,0
LU	0,5	0,5		0,4				0,1	0,4
NL	3,7	11,5						3,0	12,0
NO	0,8	1,0							
SE	2,7	3,0	2,0					2,0	5,0
UK								4,0	21,0
EU							**737,0**	**42,0**	**183,0**

Hydrogen demand 2050 (TWh)

	TYNDP2020-DE	TYNDP2020-GA	Tennet&Gasunie - High electrification	Tennet&Gasunie - High gas demand	RTE - Low	RTE - High	DNV North Sea Outlook - Low	DNV North Sea Outlook - High	LTS 1.5Tech [63]	LTS 1.5Life	Eurelectric - Low	Eurelectric - High	EU PAC scenario	National Grid - Low	National Grid - High
BE									90						
DE			170	366					437						
DK									37						
FR					32	122			417						
IE									29						
LU									10						
NL			100	168			34	137	95						
NO															
SE									131						
UK									361					8	491
EU	**1075**	**468**							**3264**	**3112**	**510**	**1020**	**1440**		

---

[63] 1.5TECH figures are only available at the EU level. A disaggregation at the country level has been carried out based using the electricity demand of the METIS Study S1 2050 scenario (https://ec.europa.eu/energy/studies/optimal-flexibility-portfolios-high-res-2050-scenario_en, and see https://ec.europa.eu/energy/data-analysis/energy-modelling/metis_en for more details on the METIS models, datasets and studies).

Offshore wind capacity 2030 (GW)

	TYNDP 2020-NT	TYNDP 2020-DE	TYNDP 2020-GA	NECP -Low	NECP-High	Energinet 70% target - Low	Elia - Low	Elia - High	PBL Future North Sea - Low	PBL Future North Sea - High	EirGrid - Low	EirGrid - High	RTE - Low	RTE-High	DNV-GL North Sea Outlook	EU PAC scenario	ETIP Wind Roadmap	National Grid UK - Low	National Grid UK - High	Wind Europe	EA Energi analyse	PROMOTioN - Low	PROMOTioN - central scenario
BE	4,3	5,6	5,5	4,0			2,3	4,0												4,0			3,4
DE	16,7	19,8	20,5	20,0																			16,0
DK	1,1	2,3	2,0	6,3		3,0																	3,1
FR	4,9	3,9	5,2	5,2	6,2								5,2	6,2						5,2			2,0
IE	3,5	1,6	1,7	3,5	5,0						0,3	3,0								3,5			1,5
LU																							
NL	11,3	7,7	10,2	10,6					4,5	15					10,8					11,5			8,9
NO																							
SE	0,8	1,2	0,9	0,2																			
UK																		25,0	42,0				19,0
EU	**78**	**57**	**86**													**95**	**70**			**89**	**143**	**63**	**70**

Offshore wind capacity 2050 (GW)

	Tennet&Gasunie - High electrification	Tennet&Gasunie - High gas demand	PBL North Sea - Low	PBL North Sea - High	DNV North Sea Outlook - Low	DNV North Sea Outlook - High	LTS 1.5Tech [64]	LTS 1.5Life	EU PAC scenario	ETIP Wind Roadmap	National Grid - Low	National Grid - High	Wind Europe	EA Energieanalyse - Low	EA Energieanalyse - High	PROMOTioN
BE							8,3						6			5,2
DE	53	64					102,4									52,7
DK							23,6									14,4
FR							60,6									27,0
IE							6,7									2,8
LU																
NL	53		12	60	38	72	71,0									28,0
NO							0,4									
SE							4,0									
UK							85,8				65	88	75			53,7
EU	**250,0**	**280,0**					**451,4**	**396,1**	**150,0**	**457,0**			**450,0**	**223,0**	**451,0**	**159,0**

---

[64] 1.5TECH figures are only available at the EU level. A disaggregation at the country level has been carried out based using the electricity demand of the METIS Study S1 2050 scenario (https://ec.europa.eu/energy/studies/optimal-flexibility-portfolios-high-res-2050-scenario_en, and see https://ec.europa.eu/energy/data-analysis/energy-modelling/metis_en for more details on the METIS models, datasets and studies).

Getting in touch with the EU

In person

All over the European Union there are hundreds of Europe Direct information centres. You can find the address of the centre nearest you at: https://europa.eu/european-union/contact_en

On the phone or by email

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

– by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),

– at the following standard number: +32 22999696 or

– by email via: https://europa.eu/european-union/contact_en

Finding information about the EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website at: https://europa.eu/european-union/index_en

EU publications

You can download or order free and priced EU publications at: https://publications.europa.eu/en/publications. Multiple copies of free publications may be obtained by contacting Europe Direct or your local information centre (see https://europa.eu/european-union/contact_en).

EU law and related documents

For access to legal information from the EU, including all EU law since 1952 in all the official language versions, go to EUR-Lex at: http://eur-lex.europa.eu

Open data from the EU

The EU Open Data Portal (http://data.europa.eu/euodp/en) provides access to datasets from the EU. Data can be downloaded and reused for free, for both commercial and non-commercial purposes.

MJ-07-22-043-EN-N

Publications Office
of the European Union

DOI 10.2833/693330