

# A vision for Europe's energy production and infrastructure in 2050



CIP

Copenhagen Infrastructure Partners

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# Preface

## Europe at a crossroad

The European global context is undergoing fundamental change. We are facing geopolitical transformations, technological revolutions, macroeconomic volatility and challenges to the rule-based global order. In addition, the climate crisis constitutes a historical challenge to the future of the European continent. Energy is at the center of this challenge.

Energy resilience and cost-competitive energy are pre-conditions for any country or continent to be successful on a global scale. The design of the future European energy system will define the competitiveness of European industries, determine its ability to deliver affordable and predictable energy to consumers, and our ability to protect the European economy against external energy shocks. At the same time, the fight against the global existential threat of climate change will require a fundamental transformation of the European energy system to deliver upon net-zero by 2050.

This all boils down to what we in Copenhagen Infrastructure Partners (CIP) have coined the energy triple challenge of delivering clean, resilient and affordable energy to the European continent. A monumental challenge that will require unprecedented levels of investment, technical insight, innovation, and cross-European coordination. But also, a challenge that can be managed, and if resolved provides Europe with opportunities and advantages. To provide an overview of the challenge ahead and to present a data-driven roadmap to deliver on the triple challenge, CIP has developed an associated energy model integrating data from Europe's current electricity, hydrogen, and heat systems.

The model has been developed in collaboration with "Ea Energianalyse" (a specialist Danish consultant) with input from the renewable technology pioneer Stiesdal, the Danish transmission system operator (TSO), Energinet, and the independent Copenhagen-based policy center Think Tank Europe.

The model and this report are a first-of-its-kind. It presents a fact-based, technical bottom-up study of the build-out of Europe's energy infrastructure ahead. The purpose has been to - independently of and separate from political ambitions - show how a European integrated energy system could look like in 2050. And in the process provide a roadmap of where, how and when to invest to achieve the optimal build out that can deliver clean energy at affordable prices and contribute to energy resilience for Europe.

## Interconnected energy infrastructure is needed

The report and associated model reveal at least three important findings for policymakers. Firstly, delivering a green transition of the European energy system is possible. It will require a considerable but not impossible effort: The needed land, seabed and supply chains are available to build-out onshore wind, offshore wind and solar PV. The build-out will deliver an energy resilient Europe for the first time in 100 years, consistent with the ambitions set out in the Paris Accord and with energy prices on par

with or lower than the current system and CO2 prices similar to today. Secondly, the build-out of transmission systems for power will be as essential as the build-out of generating capacity and thirdly, affordable hydrogen will become a result of the intermittency of the renewable energy production - and governments will need to accelerate the build out of a European hydrogen transmission system as well.

CIP has undertaken this work to deliver a structured input to the debate of the development of the European energy system. We recognize the shortcomings of modelling but hope the below can contribute to the discussion. CIP remain committed to playing our part in building Europe's energy system of the future. We will continue to connect the world of capital with the world of renewable energy projects to build value that matters: attractive risk adjusted returns to our investors while providing clean, affordable energy and creating local growth and jobs.

*Copenhagen, Berlin, Paris, Brussel  
September, 2024*

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# Addressing the triple challenge: Clean, resilient, and affordable energy

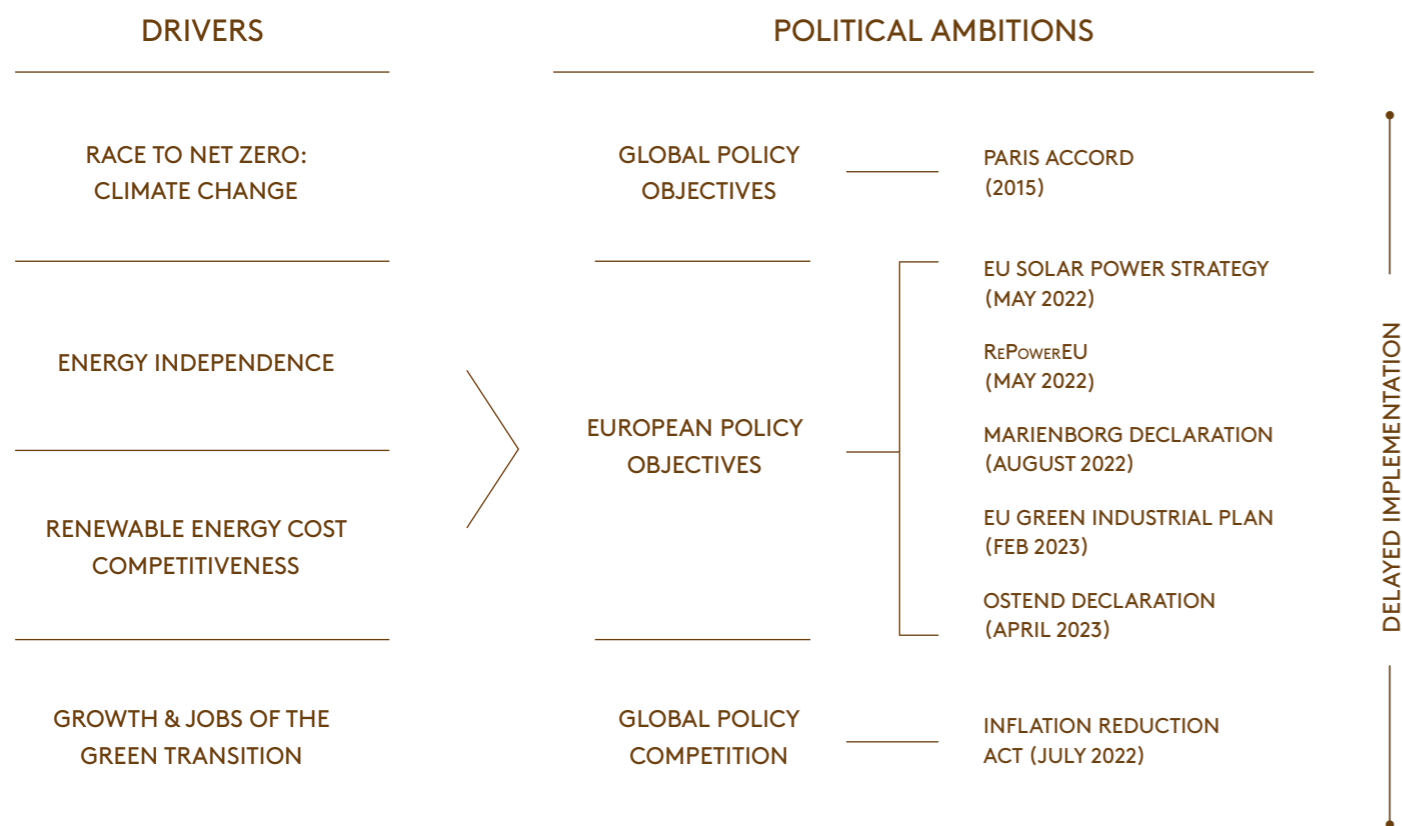
**By 2050, Europe can have a fully clean, resilient, and integrated energy system. An energy system that will produce affordable electricity for Europeans, provide an industrial base for clean growth, job creation, and contribute to competitive European industries.**

There seems to be an aligned ambition throughout Europe to create a clean European energy system that delivers affordable energy independent of Russian fossil fuels. It is, however, also being debated whether such a task is both viable and cost effective, and whether the political targets are realistic and attainable.

To provide a coherent and data-based answer, CIP has developed an energy model that integrates data from Europe’s current electricity, hydrogen, and heat systems – and has the ability to illustrate the most cost-effective build-out of the European

energy system by 2050. The model outcome has been converted into a first-of-its-kind study with conclusions and insights into Europe’s outlook for energy production and infrastructure in 2050.

The conclusion is equally comforting and concerning. Comforting as it is both practically and economically feasible for Europe to achieve a clean and resilient energy system that provides affordable electricity to consumers and industry, while also fostering green growth and European competitiveness. Concerning because substantial action is required for this vision to become reality.



## Successfully addressing the triple challenge, requires success on three key parameters

1. Europe must drive a substantial expansion of renewable energy sources, particularly wind and solar - but likely also nuclear - by establishing effective market conditions and increasing market volumes.
2. Europe must develop an integrated and enhanced European energy system, including build-out of power transmission infrastructure by fostering new public-private partnerships and financing models.
3. Europe must increase the production of hydrogen in conjunction with the renewable energy build-out and the supporting transmission hydrogen infrastructure by establishing clear regulatory frameworks ensuring long-term investment predictability.

Delivering on the three parameters is a monumental undertaking and will require unprecedented levels of investment and coordination, which is in line with the report from Mario Draghi on European competitiveness from September 2024.

## Supporting Europe’s energy push towards 2050

Three key challenges are behind Europe’s energy push towards 2050.

First and foremost, a sense of urgency for a clean energy transition has prevailed. The tangible risks and costs of climate change have become apparent, and an imperative for energy security has become evident since Russia’s invasion of Ukraine.

Secondly, there is a growing awareness of the socioeconomic benefits of the green transition particularly related to the cost competitiveness of clean energy promoting the European clean energy transition on the path the Net Zero.

And thirdly, lowering the cost of living and ensuring affordable energy costs to sustain competitive European industries has become a fundamental priority for European governments and the European Commission.

These challenges have in recent years driven strong political ambitions – at both national and the EU level. Unfortunately, implementation of these ambitions into concrete action is still needed.

# A vision for Europe's energy production and infrastructure in 2050

An integrated and resilient energy system in Europe in 2050 is both realistic and achievable. It requires a combination of offshore wind, onshore wind, and solar power as the main sources of electricity. Green hydrogen is also poised to play a pivotal role in ensuring efficient and affordable decarbonisation of industries. However, the increase in renewable energy production capacity must be accompanied by a build-out of the European transmission infrastructure. The benefits will be a reliable and resilient energy system supporting European industries and consumers with affordable clean electricity.

To achieve a clean, affordable and resilient energy system by 2050, a massive expansion of Europe's green energy production capacity is needed. A total production capacity of 3,310 GW is necessary to supply an estimated ~6,270 TWh of power in 2050. This corresponds to more than double the electricity demand in 2024.

According to the model-based forecast, the economically optimal distribution of renewable energy production capacity in Europe by 2050 will include<sup>1</sup>:

This corresponds to an increase in offshore wind capacity by a factor of nine, an increase in onshore wind capacity by a factor of three, and an increase in solar power capacity by a factor of seven compared to 2023 levels. To transport this energy across national borders, it is crucial to expand the European energy infrastructure. This expansion is vital to enable cross-border electricity transmission as well as distribution of green hydrogen across Europe.



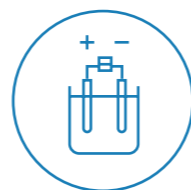
~325 GW  
OFFSHORE WIND



~550 GW  
ONSHORE WIND



~1,600 GW  
SOLAR PV

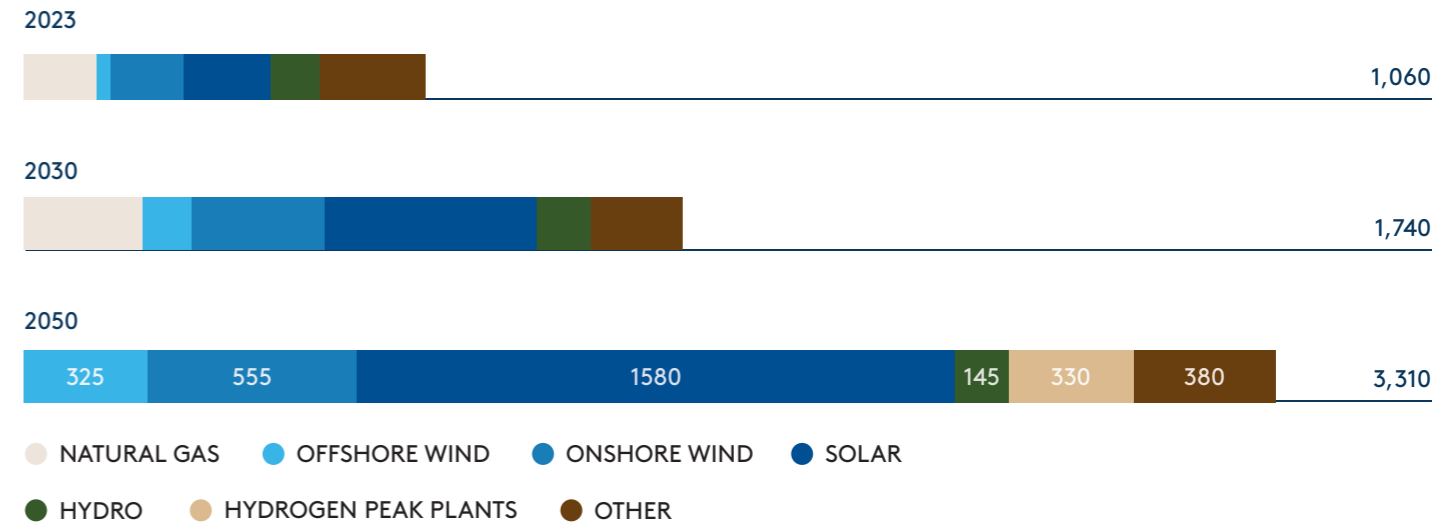


~500 GW  
POWER-TO-X

1. Numbers rounded to nearest multiple of 5. See Appendix VI for actual numbers.

## POWER CAPACITY AND GENERATION MIX FOR THE NET ZERO SCENARIO IN EUROPE, 2021-2050

European electricity production capacity (GW)<sup>1</sup>



European domestic production and global import of green hydrogen will also be crucial to the future energy system in Europe, playing a key role in decarbonising sectors that are difficult to electrify. With less than 200 MW electrolysis capacity installed today, Europe faces massive future investments and need to grow the current capacity levels towards 2050 by more than x2,500.

### Wind and solar to cover 80% of Europe's electricity demand in 2050

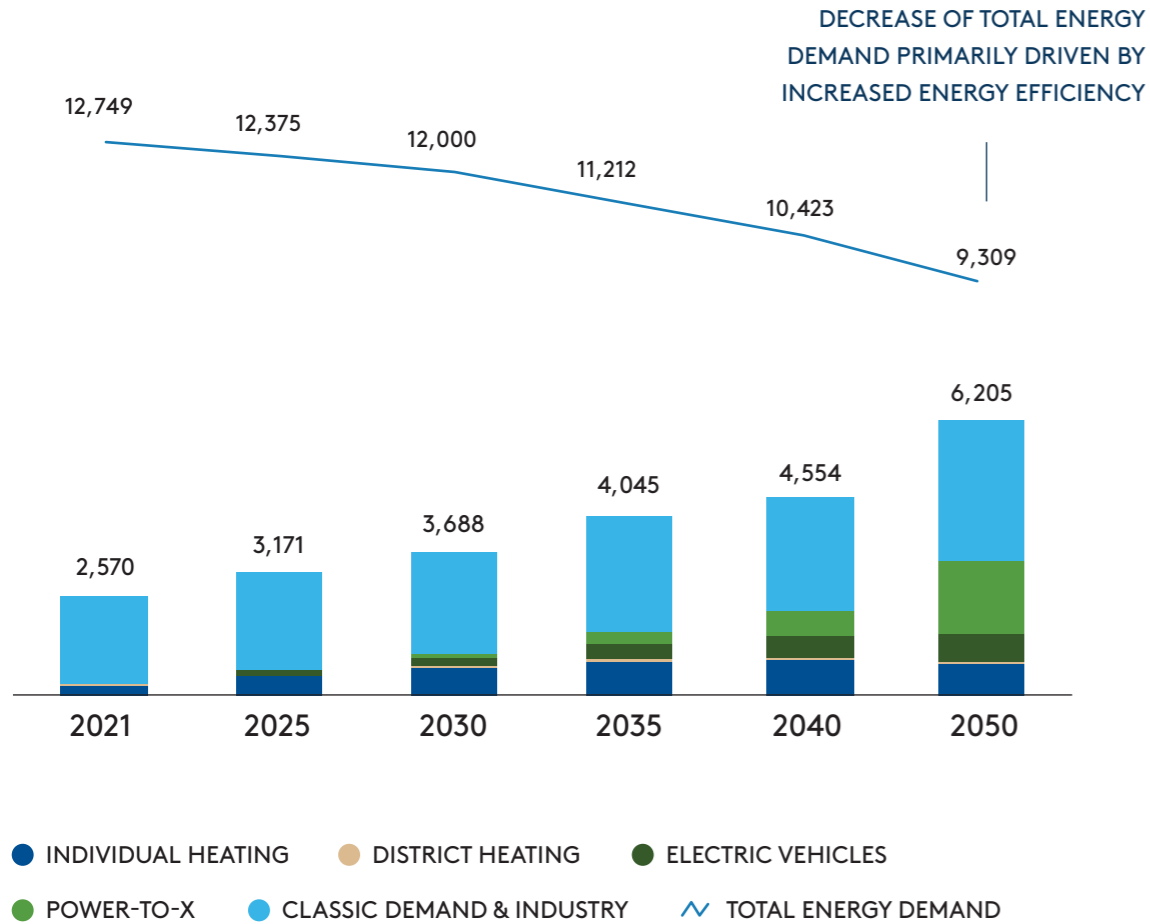
Based on the model, offshore wind, onshore wind and solar PV are expected to cover roughly 80% of Europe's power demand in 2050 (each supplying approximately a third). A mix of hydro-energy, nuclear power, and other renewable sources will cover the remaining 20%. This distribution reflects the cost competitiveness of wind and solar and the practical and political feasibility of rapid large-scale build-out of these sources.

### Projected distribution of renewable energy generation in Europe in 2050



Resulting average European power price ~67 €/MWh

## ELECTRICITY DEMAND IN EU + UK (TWH)



### Faster capacity build-out needed

Increased energy efficiency is expected to lower the total power demand by roughly 33% by 2050. However, the forecast also shows that we will need more than double the power we produce today. This is necessary to power new electrical applications, data centres, storage solutions and to produce green hydrogen used for clean fuels for hard-to-electrify sectors such as chemicals, steel, refining, shipping and aviation. Over the past two years, only 3.2 GW of offshore wind have been installed in Europe annually<sup>2</sup>. This obviously falls short of the year-on-year average build-out of at least 11 GW that is needed to reach a capacity of 325 GW offshore wind in 2050.

### Modest impact on landscape

While the build-out of renewable energy will be significant, the impact on the European land- and sea area will be modest. As a case in point, the solar

2. WindEurope, Wind energy in Europe: 2023 Statistics and the outlook for 2024-2030

capacity build-out estimated by the model would not take up more than 1.5% of the current European agricultural land. Therefore, it needs to become easier and more attractive to invest in the expansion of wind and solar energy both onshore and offshore. The policy proposals at the end of the report provide further details on the need for political initiatives.

### OFFSHORE WIND BUILD-OUT NEEDS TO BE FASTER

11 GW

REQUIRED AVERAGE YEARLY BUILD-OUT UNTIL 2050

3.2 GW

AVERAGE YEARLY BUILD-OUT 2022-2023

# Benefits of an integrated European system



### Stable clean energy supply, no matter the weather

The optimal distribution of offshore wind, onshore wind and solar energy capacity, in combination with battery storage solutions and green hydrogen spread across the continent, will secure a stable energy supply, regardless of season and weather. This requires expanding the transmission network to transport energy across countries, connecting energy production centres and consumers, and deploying battery storage solutions and green hydrogen production.

### Affordable clean power for consumers and industries

The proposed energy system will enable an average power price, including associated transmission costs, in 2050 of 67 €/MWh, 18% lower than if we continue relying on a large share of fossil energy sources<sup>3</sup>. This assumes a modest but stable carbon price of 100 €/tonCO<sub>2</sub>.

*"18% lower average power prices,"*

### An integrated European energy system will ensure resilience

An integrated European energy system based on renewable energy will be independent of fossil fuel imports and less sensitive to global geo-political developments. It will secure Europe's energy supply and ensure energy resilience.

3. Ea Energianalyse, Value of green transition in Europe (estimate)

# Critical elements in a European integrated energy system

To provide an in-depth understanding of the study and model, four deep-dives into the results are presented below. The deep-dives each represent key parameters for the main results and provide additional background and nuances on some of the most interesting findings. The deep dives cover:

OFFSHORE WIND PLAYS A KEY ROLE IN SUPPLYING EUROPE WITH AFFORDABLE, CLEAN ENERGY

01

TRIPLING EUROPE'S ELECTRICAL TRANSMISSION CAPACITY IS A CRITICAL STEP TOWARDS ENERGY RESILIENCE

02

GREEN HYDROGEN: KEY TO DECARBONISING EUROPE'S HARD-TO-ELECTRIFY SECTORS BY 2050

03

MAJOR EXPANSION OF EUROPEAN HYDROGEN INFRASTRUCTURE NEEDED TOWARDS 2050

04

# Offshore wind plays a key role in supplying Europe with affordable, clean energy

**A massive and rapid expansion of offshore wind capacity is necessary for a European renewable energy system. According to our model, a ~x9 build-out, which is in line with European political ambitions, is optimal.**

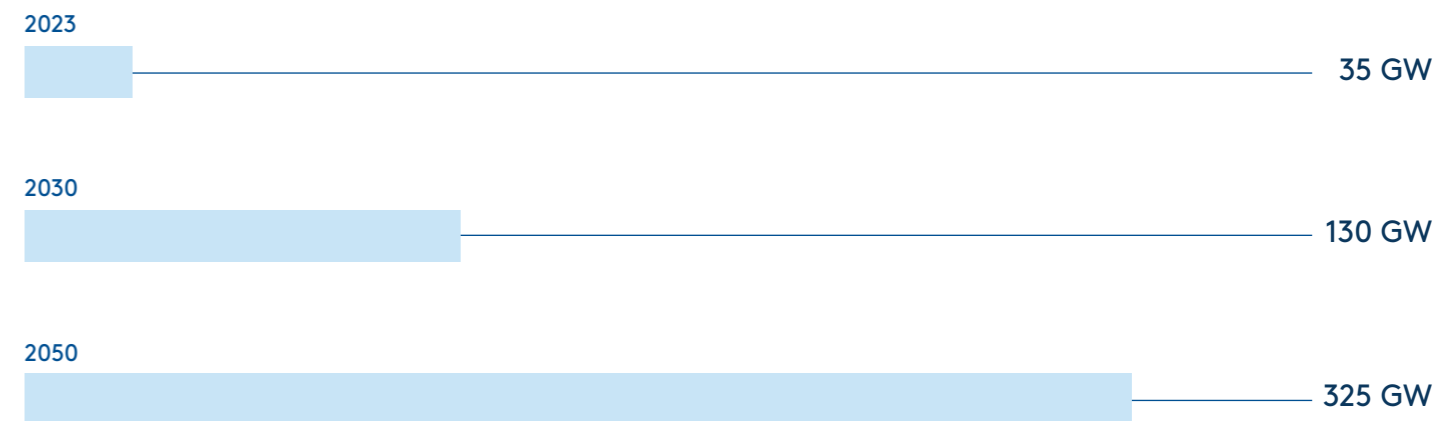
Offshore wind will play a vital role in the net zero transition. Our model estimates that offshore wind should deliver 21% of Europe's electricity supply by 2050. This corresponds to an offshore wind capacity of 325 GW, about nine times the 2023 capacity. This estimate aligns with commitments and acknowledgements in the Esbjerg/Ostend and

Marienburg/Vilnius high-level declarations signed by Prime ministers and Energy ministers from across Europe, announcing up to 393 GW combined offshore wind capacity in the North Seas and the Baltic Sea. This underlines both the enormous potential and the urgent need to develop offshore wind capacity in these regions.



## EUROPEAN OFFSHORE WIND CAPACITY TO EXPAND ~X9 BY 2050

Forecasted offshore wind power production capacity in GW<sup>4</sup>



### Stable wind output

Offshore wind is an efficient way to produce green energy. In places such as the North Sea, where the wind blows reliably all year, offshore wind can reach a capacity factor of up to 60%. For comparison, land wind has a capacity factor of about 40%, while solar energy has a capacity factor of 12-18%. Due to its high capacity factor and reliable output, offshore wind is a stabilising factor in the energy system.

Unlike solar energy, offshore wind does not need to be combined with electrical storage solutions to supply electricity at night and during winter. This makes offshore wind an economically competitive alternative to solar power, especially in Northern Europe.

### OFFSHORE WIND ADVANTAGES

# 01

STABILISATION OF SUPPLY DUE TO HIGH CAPACITY FACTOR

# 02

AS OFFSHORE WIND IS CONSTRUCTED FAR FROM SHORE, IT IS NOT AFFECTED BY THE 'NOT IN MY BACK YARD'-SYMPTOM (NIMBY) TO THE SAME DEGREE AS ONSHORE WIND AND SOLAR POWER, ALLOWING FOR FASTER BUILD-OUT

# 03

OFFSHORE WIND PARKS CAN SERVE AS INTERCONNECTOR POINTS, INTEGRATING TRANSMISSION SYSTEMS BETWEEN COUNTRIES

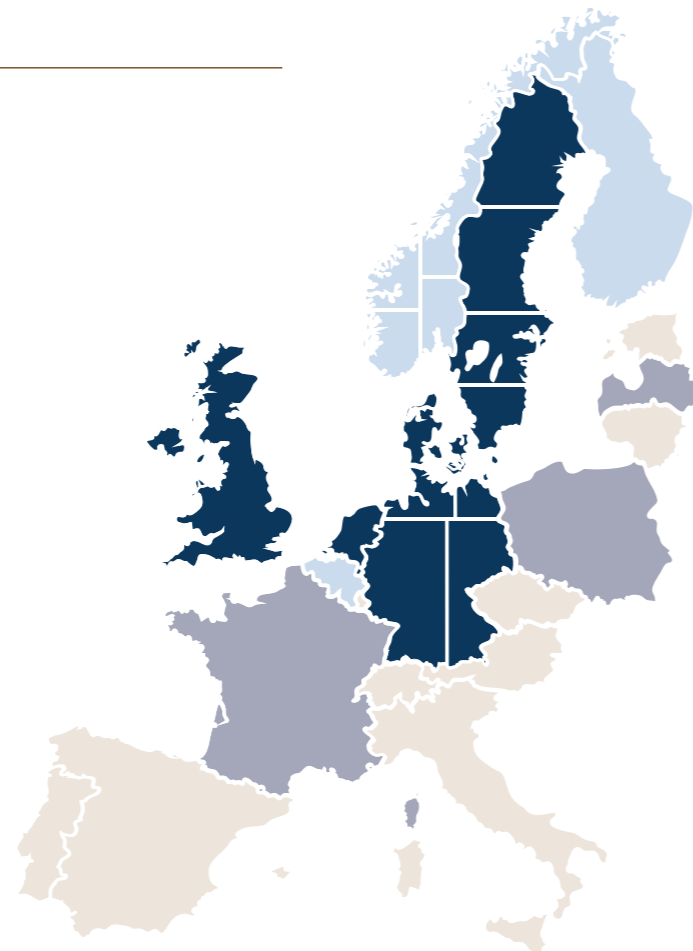
4. Numbers rounded to nearest multiple of 5

# Tripling Europe's electrical transmission capacity is a critical step towards energy resilience

Expanding the European electricity transmission infrastructure is key to realising a renewables-based energy system that will allow energy to be shared across borders. The transmission grids need to be expanded to three times their current capacity.

SELECTED CROSS-BIDDING ZONE TRANSMISSION GRID<sup>5</sup> EXPANSION FROM 2025-2050 (GW)<sup>6</sup>

- >45 GW
- 20-45 GW
- 10-19 GW
- <10 GW



5. The total transmission is the sum of all links in and out of the country, the links transmission capacity is therefore included in both countries total.  
 6. Denmark, Sweden, Norway have multiple bidding zones. Germany currently has one bidding zone, but to reflect fundamental differences, we have split it into four for the purpose of the model.

Renewable energy production is subject to natural seasonal and meteorological variations. For example, Denmark benefits from frequent strong winds, while Spain enjoys more consistent sunny days. This means wind turbines perform well in Denmark, while solar panels are very effective in Spain. This leads to variations in local energy generation due to weather and season. Alongside battery storage solutions, transmission grids help balance these variations. They allow energy to be shared across borders, ensuring a reliable electricity supply for all Europeans, even when local wind turbines are at a standstill or the sun is not shining.

### European transmission infrastructure to be expanded by ~200% by 2050

Transmission interconnectors are high-voltage power lines that connect countries and bidding zones, usually underground or on the seafloor. Bidding zones are geographical areas where energy is traded. According to our model, the current European transmission capacity of 170 GW will need to be

expanded to 500 GW by 2050, a growth of 194%. The required build-out varies significantly by country and bidding zone. For instance, the Netherlands will need to expand its transmission capacity from 15 GW to 90 GW, while France will need to expand its capacity from 20 GW to 50 GW<sup>7</sup>.

### Large investments in grid infrastructure needed

Our model estimates the need for investments of EUR ~120 bn (~5 bn per year) to build new cross-bidding zone interconnectors in Europe from 2025-2050. This number does not include large and necessary investments in internal bidding zone transmission and local distribution systems. Countries in the North and Baltic Seas regions would require especially large and unprecedented interconnector transmission investments. For instance, Germany alone will need investments in interconnectors of EUR ~25 bn. The financing of this across countries is something that governments, industry and investors must agree upon (see Appendix V for currently planned transmission projects).

|                | INTERCONNECTOR BUILD-OUT (2025-2050) <sup>7</sup> |                       | INTERCONNECTOR CAPEX INVESTMENTS (2025-2050) |
|----------------|---|-----------------------|--|
| GERMANY        | 70 GW   | +114% → 150 GW        | EUR ~25 bn                                   |
| UNITED KINGDOM | 10 GW   | +700% → 80 GW         | EUR ~20 bn                                   |
| NETHERLANDS    | 20 GW   | +350% → 90 GW         | EUR ~20 bn                                   |
| FRANCE         | 20 GW   | +150% → 50 GW         | EUR ~10 bn                                   |
| REST           | 50 GW   | +160% → 130 GW        | EUR ~45 bn                                   |
| <b>TOTAL</b>   | <b>170 GW</b>                                     | <b>+194% → 500 GW</b> | <b>EUR ~120 bn</b>                           |

7. Numbers rounded to nearest multiple of 10

# Green hydrogen: key to decarbonising Europe's hard-to-electrify sectors by 2050

Hydrogen technology is essential for the decarbonisation of hard-to-electrify sectors. European production can meet most of the demand.

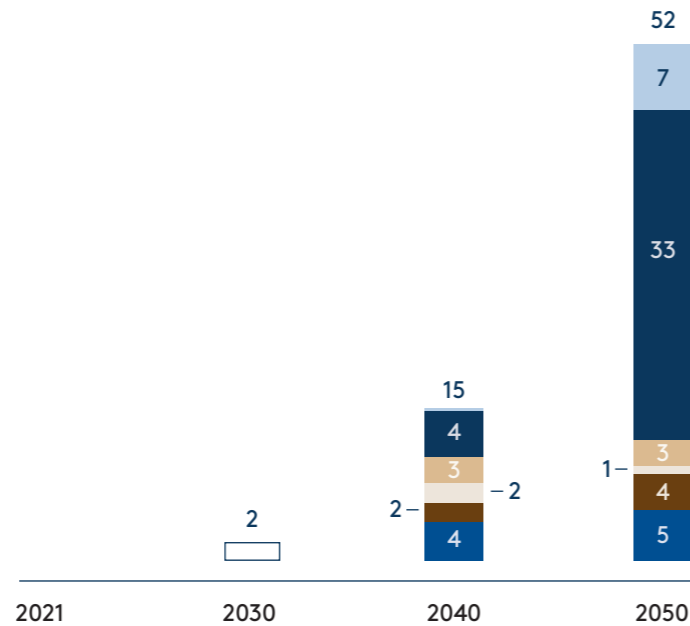
Green hydrogen is set to play a central part in a renewable energy system. Crucially, hydrogen allows for the decarbonisation of hard-to-electrify sectors such as steel production and heavy transport, and is expected to power a wide range of new applications towards 2050. Furthermore, hydrogen will be used to supply fossil-free electricity during periods of peak demand. Hydrogen production will emerge as a key and beneficial byproduct of the increased renewable energy build-out, supporting the decarbonisation of European industries.

Green hydrogen is produced through electrolysis, which requires two key components: electricity from renewable sources and water. During electrolysis, the electricity splits the water into two elements: hydrogen and oxygen. This process enables the production of green hydrogen in large quantities.

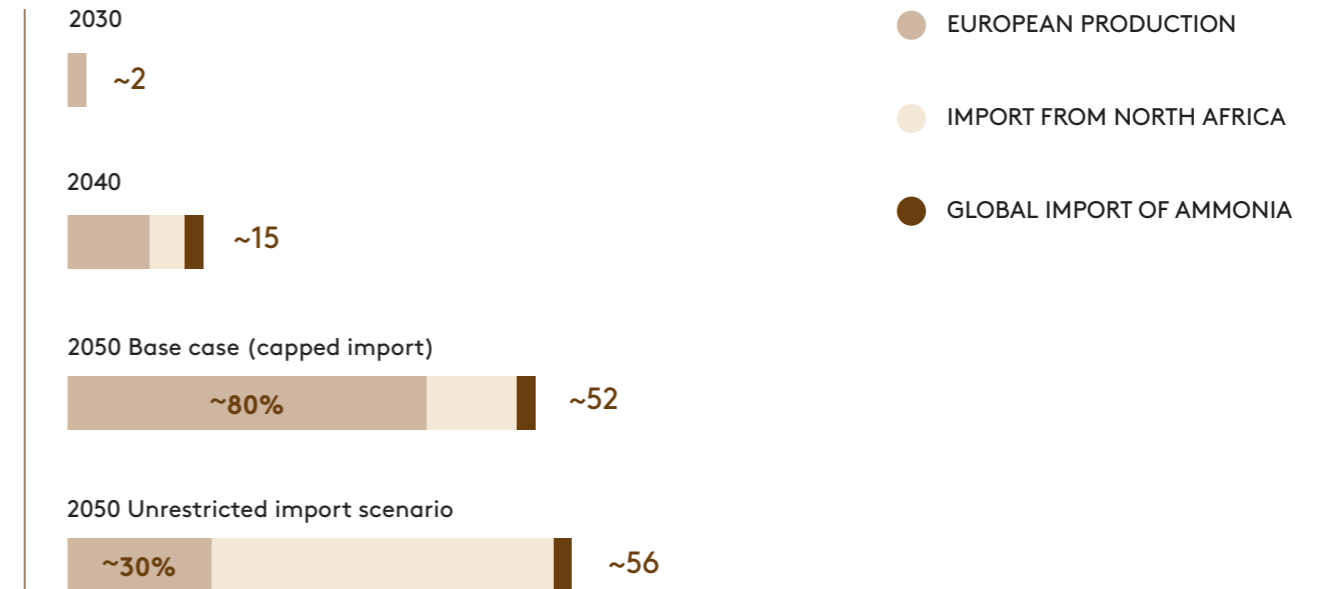
Our model points to an electrolysis capacity of ~500 GW in Europe supplying a hydrogen demand of 42 mtpa (million tonnes per year) of the total 52 mtpa European demand in 2050. This is despite the slower ramp-up period indicated by recent models and market voices. We assume a rise in hydrogen demand during the 2030'ies and 2040'ies and a relatively modest two mtpa green hydrogen demand by 2030, covering just 20% of the current total hydrogen demand in Europe. Similarly, delayed hydrogen demand does not affect the 2050 renewable energy generation capacity. Hydrogen can be supplied from primarily three sources: domestic European production, imports from North Africa, and global imports in the shape of ammonia. Our base case model predicts domestically produced green hydrogen to account for ~80% of Europe's green hydrogen supply.

## GREEN HYDROGEN DEMAND OUTLOOK SPLIT ON SELECTED SECTORS (mtpa)

- STEEL
- CHEMICALS
- REFINING
- AMMONIA
- NEW APPLICATIONS
- H<sub>2</sub> PEAK PLANTS



## CLEAN HYDROGEN SUPPLY MIX FOR EUROPE (mtpa hydrogen-equivalent)



- 3 GLOBAL IMPORT
- 1 EUROPEAN PRODUCTION
- 2 NORTH AFRICA



## EUROPEAN HYDROGEN PRODUCTION IN 2050

(Net-importer/exporter)

- H<sub>2</sub> NET-EXPORTERS
- H<sub>2</sub> NET-IMPORTERS



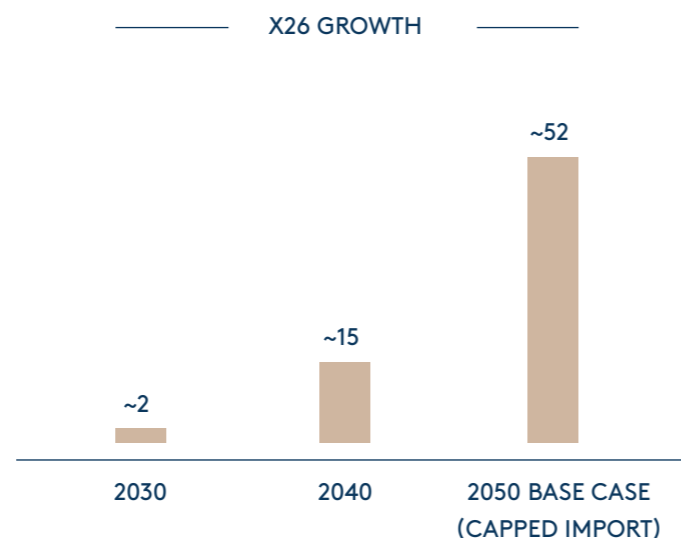
### Domestic hydrogen production

Domestic hydrogen production is financially advantageous in regions with high potential for green electricity generation and low power prices. Our model forecasts the Iberian Peninsula, Scandinavia, and the Baltic states as hydrogen net exporters. These regions will produce more hydrogen than is consumed in local industries and will export to markets in the rest of Europe. The model also predicts that the Netherlands will be a significant exporter of green hydrogen in 2050.

If Europe decides to produce vast amounts of green hydrogen domestically, it will secure European energy resilience as most fossil-based hydrogen is imported from outside of Europe today. However, there may be reasons, such as cost considerations, that could advocate for importing green hydrogen from outside Europe.

## CLEAN HYDROGEN DEMAND FOR EUROPE

(mtpa hydrogen-equivalent)



### Affordable hydrogen imports

A large potential for onshore wind and solar energy in North Africa will create power prices that are significantly lower than the power prices in most of Europe. This will make the production and export of green hydrogen economically attractive. However, it would make the European energy supply more reliant on foreign markets. Therefore, one might expect political or regulatory restrictions on such imports in order to maintain European energy sovereignty over time. In our base case model, we have imposed a cap on these imports to 10 mtpa (~20% of European demand) from 2040 onwards.

An unrestricted import would contribute to an average lower energy price in Europe and a smaller domestic production of green hydrogen (see p. 28).

Global imports of ammonia are not expected to make up a large part of Europe's clean hydrogen supply mix.

Green hydrogen will undoubtedly play a central part in the future energy system. However, political decisions have to be made regarding how much green hydrogen should be produced within Europe and to what extent there should be imports from non-European countries, in which case supporting regulatory framework should be put in place.



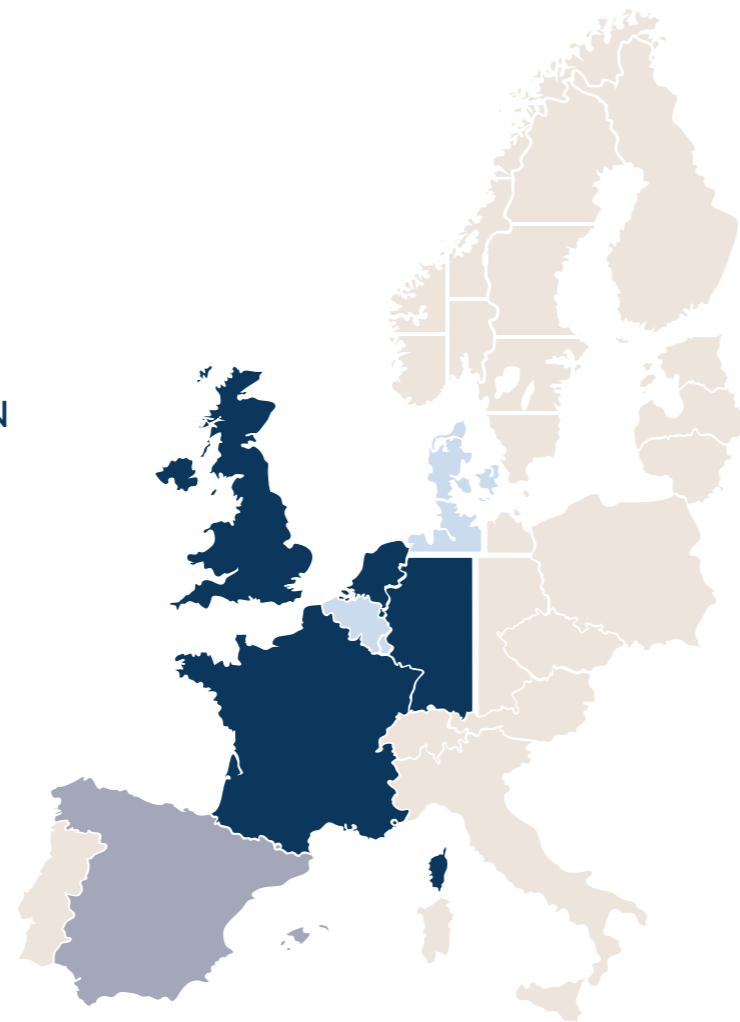
# Major expansion of European hydrogen infrastructure needed towards 2050

**As the demand for hydrogen will increase throughout Europe, a significant expansion of the hydrogen transmission network is required - both onshore and offshore. This will require considerable investments.**

To enable a European market for hydrogen, we need to build an interconnected hydrogen infrastructure across Europe. This will allow the import of green hydrogen from North Africa and the distribution of hydrogen from European production hubs, such as the North Sea region and the Iberian Peninsula, to the major demand centres notably in Germany, the Netherlands and France. Hydrogen is transported in pipelines that can be purpose-built or adapted from other uses such as natural gas.

## SELECTED HYDROGEN TRANSMISSION GRID EXPANSION FROM 2025-2050 (mtpa)<sup>8</sup>

- >25 mtpa
- 16-25 mtpa
- 5-15 mtpa
- <5 mtpa



8. Denmark, Sweden, Norway have multiple bidding zones. Germany currently has one bidding zone, but to reflect fundamental differences, we have split it into four for the purpose of the model.

### Investments of EUR 45 bn needed for hydrogen transmission grids build-out

Our model predicts the needed hydrogen transmission grid capacity to be ~100 mtpa in 2050. This includes, for instance, a capacity of 15 mtpa between Spain and France that will allow the transportation of green hydrogen produced on the Iberian Peninsula and in North Africa to North and Central Europe.

To reach the required transmission capacity, there is a need for investments of EUR ~45 bn towards 2050 in hydrogen transmission.

Significant investments in European hydrogen transmission grids are necessary to create a hydrogen market and stimulate supply and demand. The industry, private equity, and policymakers need to agree on financing and risk sharing these investments.

|   | PIPELINE CAPACITY | COST OF HYDROGEN NETWORK EXPANSION <sup>9</sup> |
|---|-------------------|---|
| SPAIN $\xrightarrow{H_2}$ FRANCE                                  | ~15 mtpa          | EUR ~8 bn                                       |
| FRANCE $\xrightarrow{H_2}$ LUXEMBOURG $\xrightarrow{H_2}$ GERMANY | ~7 mtpa           | EUR ~6 bn                                       |
| FRANCE $\xrightarrow{H_2}$ UK                                     | ~3 mtpa           | EUR ~8 bn                                       |
| UK $\xrightarrow{H_2}$ NETHERLANDS                                | ~7 mtpa           | EUR ~3 bn                                       |
| DENMARK $\xrightarrow{H_2}$ GERMANY                               | ~3 mtpa           | EUR ~2 bn                                       |
| OTHER EU COUNTRIES  | ~65 mtpa          | EUR ~20 bn                                      |
| <b>TOTAL</b>  | <b>~100 mtpa</b>  | <b>EUR ~45 bn</b>                               |

9. Hydrogen transmission assuming only new build hydrogen pipelines cost in accordance with European Hydrogen Backbone Implementation Roadmap – Cross Border Projects and Costs Update, November 2023. Rounded to nearest billion.

# Policy recommendations towards a clean, affordable, and resilient Europe

To deliver on the triple challenge and creating a clean, resilient and affordable energy system, Europe will need to: 1) accelerate the deployment of renewable energy, 2) enhance production and transportation of green hydrogen, 3) foster new public-private partnerships around grids build-out and financing models.



## 01 ESTABLISHING EFFECTIVE MARKET CONDITIONS PROMOTING SUBSTANTIAL EXPANSION OF RENEWABLE ENERGY

In the efforts to achieve climate targets, European governments and the European Commission must work towards building a truly integrated Energy Union, which includes:

- Effective and sustainable auction designs for offshore wind:
  - Ensure that the Commission’s 2024 guidelines for offshore wind auctions are implemented as consistently as possible across member states to avoid fragmented national practices and increase speed and economic viability of projects.
  - Ensure simple and transparent auction designs, catering for new and changing market conditions impacted by macro changes and employment of non-price criteria focusing on transparent, price-based auction criteria, avoiding unnecessary non-price factors.
- Implement and enforce Fit-for-55 legislation from the previous mandate:
  - In the Commission’s upcoming Clean Industrial Deal, the Commission should support a swift implementation and strict enforcement of the Renewable Energy Directive III and its related initiatives in order to streamline approvals and ensure compliance with key energy policies. Additionally, political action is needed to secure the careful enforcement and monitoring of the Electricity Market Design, the Wind Power Action Plan, and the Wind Power Charter, which contain crucial provisions.

## 02 RAMP-UP OF THE GREEN HYDROGEN ECONOMY

Green hydrogen will play a pivotal role in the Commission’s ambitions to accelerate the decarbonisation of European industries. European domestic production and global imports of green hydrogen will be crucial to the future energy system in Europe, playing a key role in decarbonising sectors that are difficult to electrify such as steel, chemicals, shipping and aviation. To achieve this goal, the European governments and the European Commission should:

- Continue and increase investments into the European Hydrogen Bank and expand national support schemes utilizing the auction-as-a-service tool:
  - Sustain investment levels with annual allocations to support the maturation of the hydrogen industry and launch industrial-scale projects.
  - Provide clear guidance on the budget and timing of hydrogen auctions to build investor confidence.
- Implementation of Green House Gasses (GHG) legislation passed in previous mandate: Finalise and enforce GHG legislation to provide regulatory clarity and support the hydrogen economy’s growth, including the upcoming Delegated Act on Low-carbon Fuels and sector-specific requirements in the Renewable Energy Directive (industry), RefuelEU Aviation and FuelEU Maritime.

## 03 SIGNIFICANT GRID EXPANSIONS

It is crucial to expand the European energy infrastructure to transport power and hydrogen across national borders. This expansion is vital for enabling cross-border electricity transmission as well as distribution of green hydrogen across Europe. To deliver on this, European governments and the European Commission should:

- Initiate a discussion on new public-private partnerships for transmission deployment, which could involve:
  - Visibility, certainty and limited delays in European Ten-Year-Network-Development-Plans (TYNDPs), including both power transmission and hydrogen infrastructure.
  - Embracing the concept of 'anticipatory investments' is key to ensure investment certainty for any generation project. Governments and TSOs could consider phased infrastructure projects to promote early-starters, notably in the hydrogen industry.
  - Development of new financing models to unlock more private capital, balancing a fair cost and risk allocation, with involvement of TSOs and the industry.
  - Development of a clear guidance on a pan-European regulatory framework for cross border hydrogen infrastructure, especially offshore infrastructure anchored in the EU Grid Action Plan.

# Scenarios – stress testing the model conclusions

In this report, we will highlight four relevant scenarios:

WHAT WILL HAPPEN IF  
GLOBAL GAS PRICES PLUMMET?

---

01

WHAT WOULD BE THE IMPACT OF UNRESTRICTED  
GREEN HYDROGEN IMPORTS FROM NORTH AFRICA?

---

02

WHAT WILL HAPPEN IF SOLAR CAPACITY BUILD-OUT  
DOES NOT MEET THE FORECASTED HIGH LEVELS?

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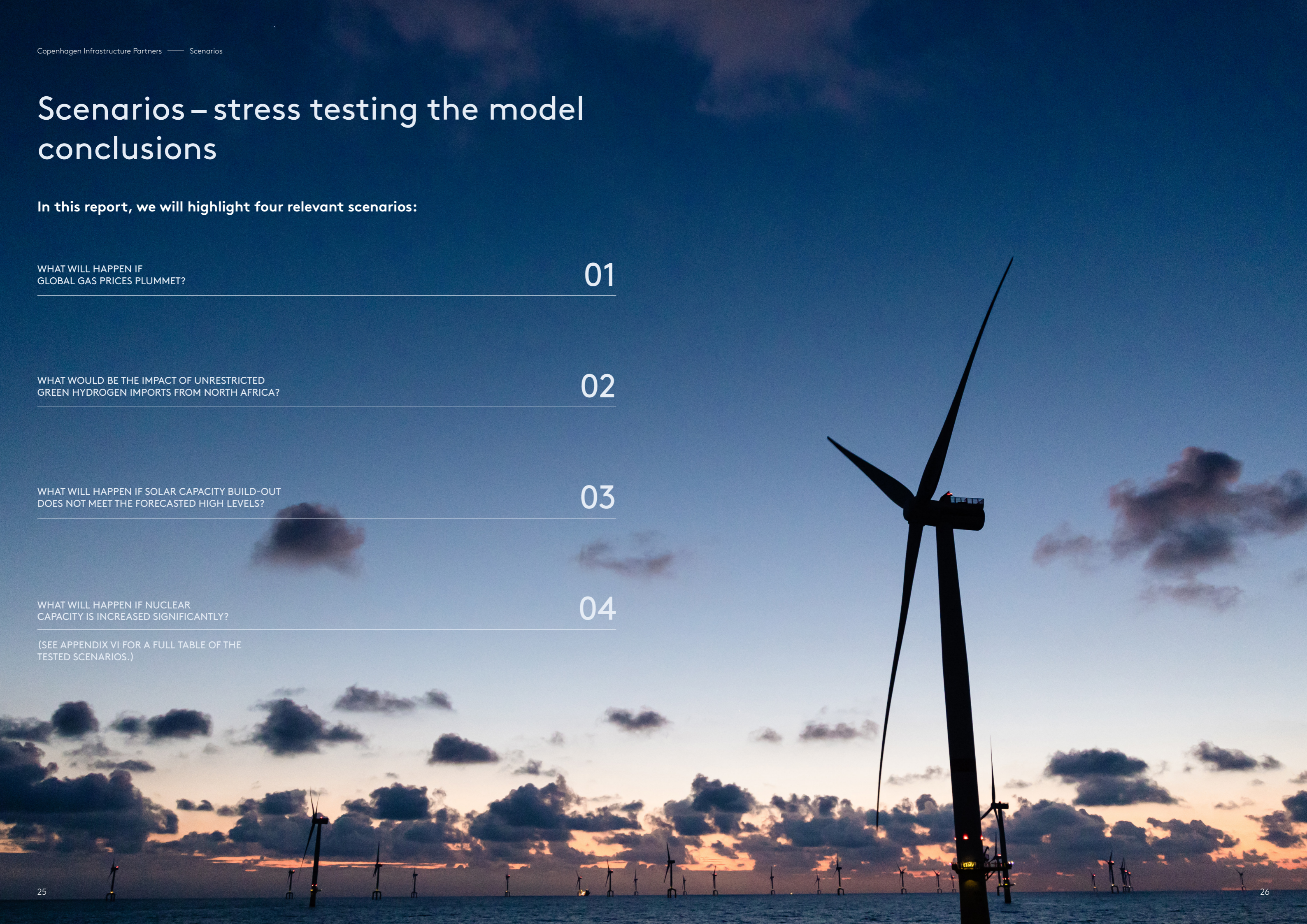
03

WHAT WILL HAPPEN IF NUCLEAR  
CAPACITY IS INCREASED SIGNIFICANTLY?

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04

(SEE APPENDIX VI FOR A FULL TABLE OF THE  
TESTED SCENARIOS.)



Scenario 01

# What will happen if global gas prices plummet?

## Lower gas prices have no significant impact on offshore wind build-out

It is valid to question what would happen if global gas prices were to decrease further from the latest years' historically high levels. For instance, if a change in the geopolitical situation made importing cheap Russian gas politically viable again.

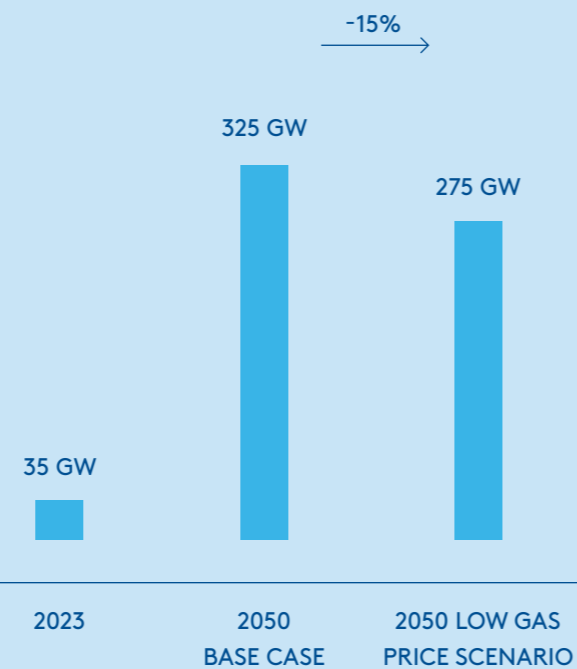
To test this, we modelled a scenario with no constraint on usage of fossil fuels and even lower long-term prices than we experienced before the Russian invasion of Ukraine<sup>10</sup>.

The answer to this question is that a massively reduced gas price would impact the build-out of renewable energy, but not dramatically so. With cheap gas, the offshore wind power capacity in 2050 would be around 275 GW, 14% lower than the base case scenario. This would still require an expansion of offshore wind power capacity of x8 compared to the 2023 level.

This shows that it is the carbon price rather than the gas price that is the primary driver of the green transition in Europe.

### OFFSHORE WIND CAPACITY NEED REMAINS HIGH IN LOW GAS PRICE SCENARIO

(Offshore wind capacity in GW)<sup>11</sup>



10. IEA World Energy Outlook 2023 "Announced Pledges Scenario"

11. Numbers rounded to nearest multiple of 5

Scenario 02

# What would be the impact of unrestricted green hydrogen imports from North Africa?

## Unrestricted import of North African green hydrogen would impact renewable energy generation and electrolyser capacity in Europe negatively

North Africa holds an enormous potential for green hydrogen production at an affordable price due to high renewable energy potential. This provides Europe with a unique opportunity to import vast amounts of affordable green hydrogen to speed up decarbonisation. Increased hydrogen imports from North Africa alone would contribute to a significantly lower European electricity price, reducing it by approximately 7%.

Considering European security of supply, European produced hydrogen is expected to be prioritised politically. Consequently, we have effectively imposed a cap on the import of green hydrogen from North Africa to 10 mtpa in 2050 (~20% of European supply in 2050) in our base case scenario.

But what would the effects be on European power and hydrogen production in a scenario with no restrictions on hydrogen imports from North Africa?

Without restrictions, imports of North African green hydrogen would amount to 38 mtpa in 2050, making up ~68% of the European supply mix in 2050. The resulting lower demand for European hydrogen would negatively impact the build-out of renewable energy production capacity in Europe. Our study estimates a resulting offshore power capacity of 230 GW in 2050, ~30% lower than the base case. This, however, would still amount to a x7 expansion compared to the 2023 level.

12. Numbers rounded to nearest multiple of 5, excluding electricity price.

### UNRESTRICTED IMPORT OF H<sub>2</sub> FROM NORTH AFRICA<sup>12</sup>

|                             | BASE CASE |         | UNRESTRICTED IMPORT OF H <sub>2</sub> FROM NORTH AFRICA |
|-----------------------------|-----------|---------|---|
| HYDROGEN IMPORT (mtpa)      | 10        | +280% → | 38  |
| OFFSHORE WIND CAPACITY (GW) | 325       | -30% →  | 230   |
| ONSHORE WIND (GW)           | 555       | -5% →   | 525   |
| SOLAR PV (GW)               | 1,580     | -34% →  | 1,050   |
| ELECTROLYSER (GW)           | 510       | -54% →  | 235   |
| ELECTRICITY PRICE (EUR/MWh) | 67        | -7% →   | 62  |

Scenario 03

# What will happen if solar capacity build-out does not meet the forecasted high levels?

## Restricted solar PV build-out allowance would be offset by more offshore wind

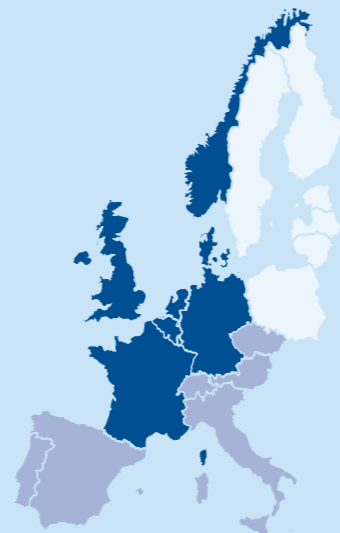
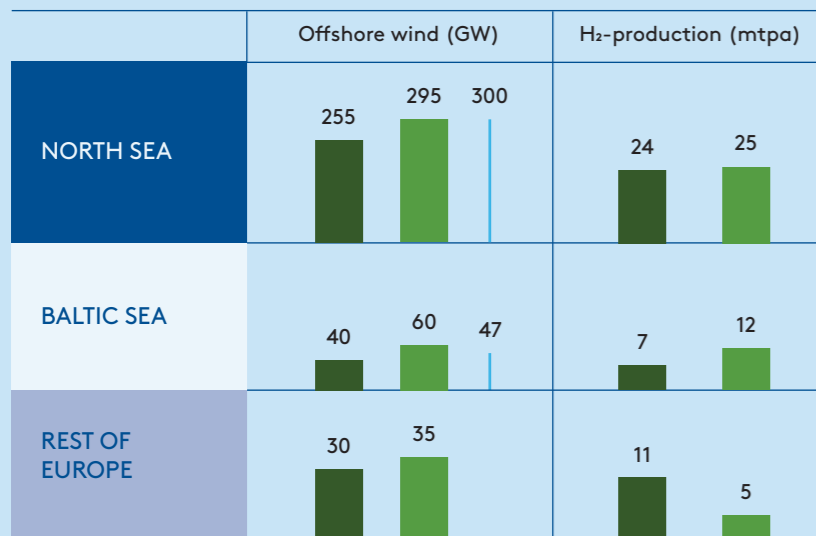
Our base case model assumes that no more than 1.5% of current agricultural land in each bidding zone can be used for solar PV by 2050. Considering ongoing NIMBY-effects and local and political opposition towards solar PV build-out, this assumption carries significant uncertainty.

To examine the effect of reduced solar PV build-out, we modelled a scenario with a solar PV build-out restriction of 50% of the base case scenario for each bidding zone.

With this assumption changed, our model predicts that the solar PV capacity will be 1,160 GW by 2050, which is 27% less than in the base case scenario. As a result, we would see a more extensive offshore wind build-out. This would impact the build-out in the Baltic Sea region in particular, where the offshore wind capacity would grow by ~50% compared to the base case scenario. Accordingly, green hydrogen production in the region would expand.

### RESULT OF DECREASING PV ASSUMPTION ON OFFSHORE WIND AND HYDROGEN PRODUCTION IN EUROPE<sup>13</sup>

● BASE CASE ● 50% LESS SOLAR PV ALLOWANCE — AGREED COMMITMENT OF MEMBER COUNTRIES



13. Numbers rounded to nearest multiple of 5, excluding commitments of member countries

Scenario 04

# What will happen if nuclear capacity is increased significantly?

## Nuclear energy capacity ramp up has limited impact on build-out of renewables towards 2050

Our base case model does not assume a significant net expansion of the total nuclear capacity towards 2050. The assumption is that the maintenance and potential expansion of nuclear capacity is complex and not cost competitive. Furthermore, it is not conducive to fast expansion in green energy generation capacity.

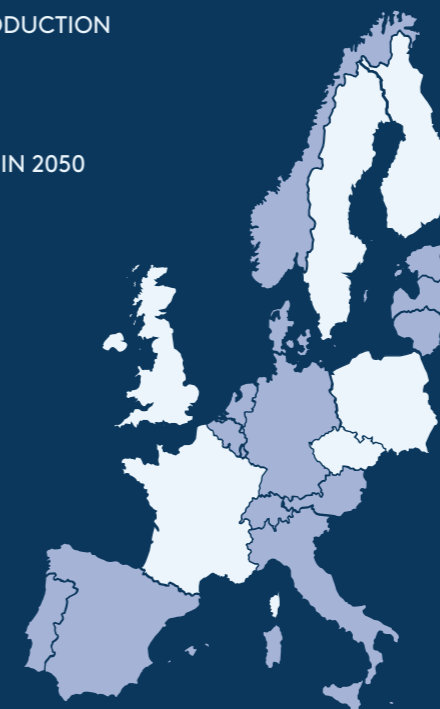
To investigate impact of European nuclear expansion, we have stress tested the model assumptions and expanded nuclear capacity with 50% from 90 GW to 135 GW in 2050 in countries with existing nuclear capacity, namely Sweden, Finland, the United Kingdom, Poland, Czech and France.

The build-out of renewable energy sources remains robust to the increased nuclear capacity. The increased nuclear capacity mainly replaces offshore wind as it is the marginal investment in the model. The offshore wind decreases by 20% in the Baltic states and by 13% in North Sea region.

The renewable energy build-out in Southern Europe remains almost unchanged, indicating the build-out in Northern Europe is most sensitive to the nuclear capacity growth.

### INCREASED NUCLEAR CAPACITY BY 50%

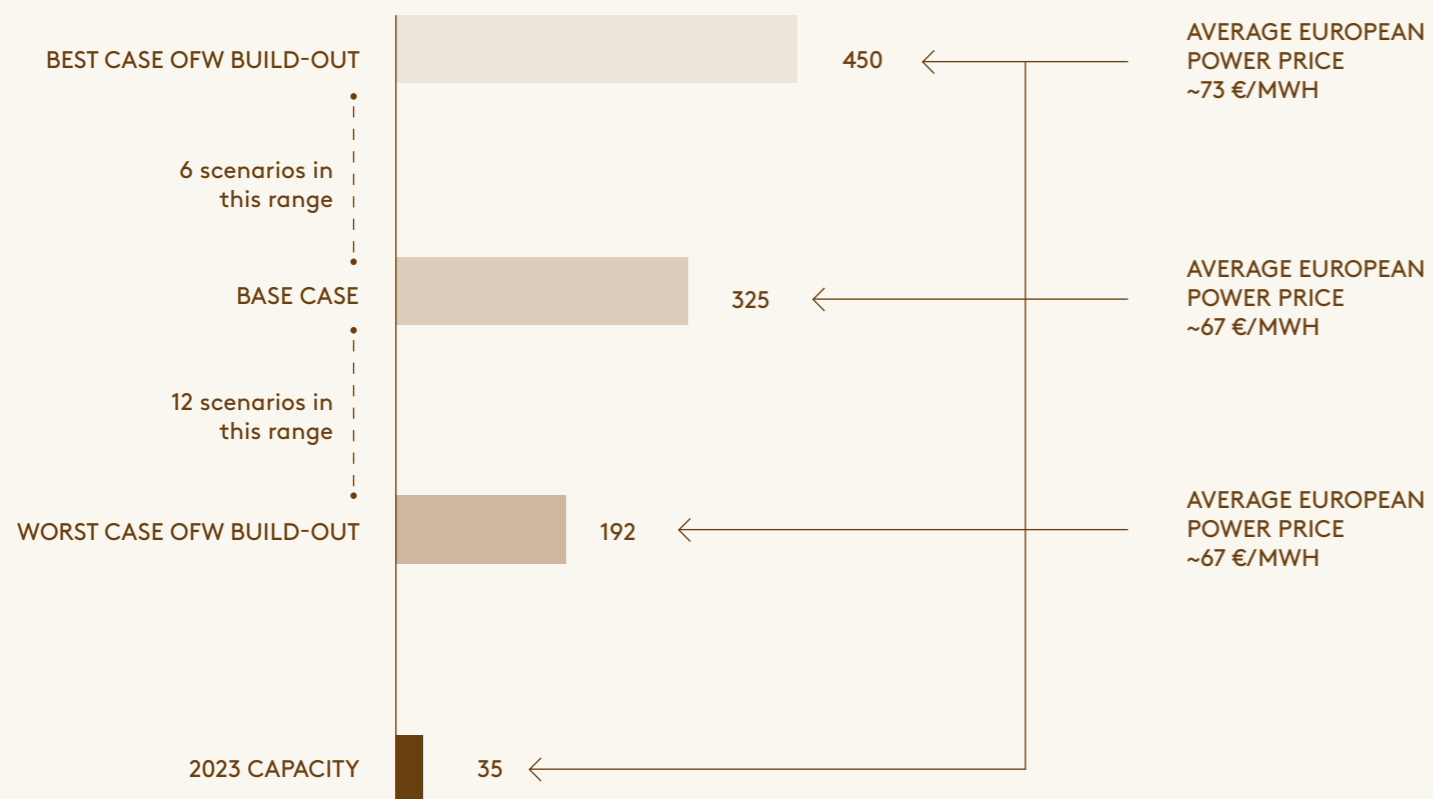
● NUCLEAR PRODUCTION IN 2050  
● NO NUCLEAR PRODUCTION IN 2050



|                             | BASE CASE |      | INCREASED NUCLEAR |  |
|-----------------------------|-----------|------|-------------------|--|
| NUCLEAR CAPACITY (GW)       | 90        | +50% | 135               |  |
| OFFSHORE WIND CAPACITY (GW) | 325       | -12% | 285               |  |
| ONSHORE WIND (GW)           | 555       | -2%  | 545               |  |
| SOLAR PV (GW)               | 1,580     | -6%  | 1,480             |  |
| ELECTROLYSER (GW)           | 510       | -4%  | 490               |  |

# European offshore wind build-out is robust across all tested scenarios

## OFFSHORE WIND BUILD-OUT CAPACITY IN GW



As illustrated in the four scenarios in this study, the predictions of our model are no better than the assumptions they rest on. Therefore, testing model predictions and assumptions are key. We conducted a sensitivity analysis, testing 19 different scenarios to determine how changed assumptions would impact the outcome of offshore wind build-out.

Our sensitivity analyses show a significant and stable build-out of offshore wind across all scenarios. In six scenarios, the offshore wind build-out is larger than our base case estimate of 325 GW, while it is smaller in 12 scenarios.

The most optimistic scenario forecasts an offshore wind capacity of 450 GW while the most pessimistic scenario forecasts a capacity of 192 GW. In any case, we need to invest at an unprecedented scale in new offshore wind projects in Europe in the coming years, where the worst case scenario would still require an x6 increase of the current capacity.



# Achieving more affordable power price raises dilemmas

Ensuring affordable energy remains key to foster competitiveness of European industries and affordable energy for consumers. A lower energy price than predicted in our 2050 forecast can be achieved through political decisions. However, this raises several political dilemmas.

In an alternative modelling exercise, the lowest possible power prices for European consumers and industries were optimised. By loosening some of the model's restrictions, we were able to achieve an average European power price of 59 €/MWh in 2050, which is 12% lower than our base scenario of 67 €/MWh. Ultimately, it is a political question whether these adaptations can be made to achieve an even lower power price.

|  | BASE CASE |        | OPTIMIZED FOR EUROPEAN CONSUMERS |
|--|-----------|--------|----------------------------------|
| EUROPE average price (EUR/MWh)         | 67        | -12% → | 59                               |
| DENMARK average price (EUR/MWh)        | 61        | -7% →  | 57                               |
| NETHERLANDS average price (EUR/MWh)    | 66        | -9% →  | 60                               |
| UNITED KINGDOM average price (EUR/MWh) | 66        | -9% →  | 60                               |

### To achieve this lower power price, four political concessions are necessary:

1. Increased import of cheap green hydrogen via pipelines from North Africa, at the same time increasing the energy dependence in Europe: 5 mtpa hydrogen imports in addition to the 10 mtpa in the base scenario.
2. Allowance for additional build-out of onshore wind and solar PV capacity overcoming NIMBY, opposition and resistance from farmers and local communities: 25% increase in onshore wind capacity allowance and a 100% increase in solar PV allowance.
3. Faster and heavier build-out of both power and hydrogen infrastructure. No delays in European TYNDPs and a 100% increase in expansion options for electrical transmission (750 MW per corridor every five years instead of 375 MW).
4. Increased participation of electric vehicles in vehicle-to-grid systems: 50% of all-electrical vehicles to participate in vehicle-to-grid systems using 50% of their battery capacity. Vehicle-to-grid systems allow for more flexibility in electricity demand.



Appendix I

# Model and assumptions

The insights and predictions in this report are based on our state-of-the-art energy model that we leveraged to predict the most socio-economically efficient build-out of Europe’s energy system.

The insights and predictions in this report are based on our state-of-the-art energy model that we leveraged to predict the most socio-economically efficient build-out of Europe’s energy system.

**We built the model to answer five questions essential for Europe’s green transition:**

1. Is it attainable and realistic to reach net zero by 2050?
2. How can stability in the energy mix be maintained?
3. What is the role of offshore wind power?
4. Where can green hydrogen be sourced?
5. What are the effects on consumer prices?

Our model is based on the “Balmorel”-model<sup>14</sup>, which is developed to optimise energy generation and transmission subject to various constraints. The model integrates the European electricity, heating and hydrogen systems into one energy model, always ensuring a balanced energy system across Europe. The model accounts for the hour-by-hour energy generation and transmission from today towards 2050. This approach offers coherence across borders and thus provides a detailed overview of the European integrated energy landscape of the future.

The model was developed in collaboration with Ea Energianalyse, a best-in-class energy economics consultancy based in Copenhagen, Denmark. It was peer-reviewed by our partners at Stiesdal and Danish TSO Energinet. Jointly, Copenhagen Infrastructure Partners and Copenhagen Infrastructure Service Co. (CISC) managed the project.

The model has several inputs in the form of economic, technological, and meteorological data. Wherever available, it is based on external sources. To determine the robustness of the model outputs, we tested 19 scenarios with different assumptions (See Appendix VI for the sensitivity analysis results).

**The model optimises for net zero in 2050**

The model was restricted to the central condition of reaching net zero by 2050. As an effect of this condition, the model forecasts the use of hydrogen peak plants in periods of especially high electricity demand. Hydrogen peak plants consume valuable green hydrogen to produce electricity. In a practical political reality, this may, however, be unviable as the resulting cost of electricity drives the average European power price significantly upwards.

**Examples of assumptions built into the model**

- A key assumption is that the total energy demand (electricity and bioenergy) in Europe will decrease by roughly 1/3<sup>15</sup>. This is primarily driven by increased energy efficiency. Meanwhile, electricity demand will more than double by 2050.
- The model includes economic data on, for instance, fuel and CO2 prices<sup>16</sup> (see Appendix II). A central assumption is that the capital expenditures of offshore wind, onshore wind, solar energy, and gas turbines will decrease from 2030-2050<sup>18</sup> (e.g. -13% for offshore wind and -25% for solar energy (see Appendix III)).
- The model includes technological data such as wind and solar capacity factors for various locations and efficiency estimates of electrolyzers, gas turbines, and lithium batteries. It also includes meteorological data<sup>19</sup> (see Appendix IV).
- Finally, the model includes restrictions on the build-out of renewable energy sources. These include, for example, a national-level restriction on solar energy of 1.5% of agricultural land by 2050. Similarly, onshore wind is restricted by NIMBY or national targets, while offshore wind is restricted by available sites, based on depth, distance to shore, and wind speeds. Grid build-out is limited to a maximum expansion of each corridor of 375 GW every five years.

**MODEL INPUT<sup>15</sup>**

DEMAND: POWER, HEAT AND HYDROGEN DEMAND

ECONOMIC: FUEL AND CO2 PRICES, COST OF CAPITAL

TECHNOLOGY: CAPACITY FACTOR, EFFICIENCY, METEOROLOGY

SYSTEM CONSTRAINTS: RESERVE CAPACITY, MAX RENEWABLES BUILD-OUT P.A.

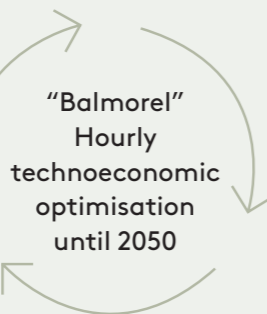
**MODEL OUTPUT**

OPTIMAL CAPACITY ADDITIONS PER POWER TECH./TRANSMISSION LINE

OPTIMAL GENERATION DISPATCH AND POWER FLOWS

ELECTRICITY AND HYDROGEN SUPPLY COST

CO<sub>2</sub> EMISSIONS



**MODEL INPUT**

Demand: Power, heat and hydrogen demand

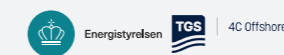
**DIVERSE SOURCES**



Economic: Fuel and CO2 prices, cost of capital



Technology: capacity factor, efficiency, meteorology



System constraints: Transmission & RES build-out restrictions



14. Model developed by EA EnergiAnalyse.

15. The model covers the EU-27 countries and the UK

16. Global Ambition scenario from TYNDP2022, adjusted for geographical scope and hydrogen demand

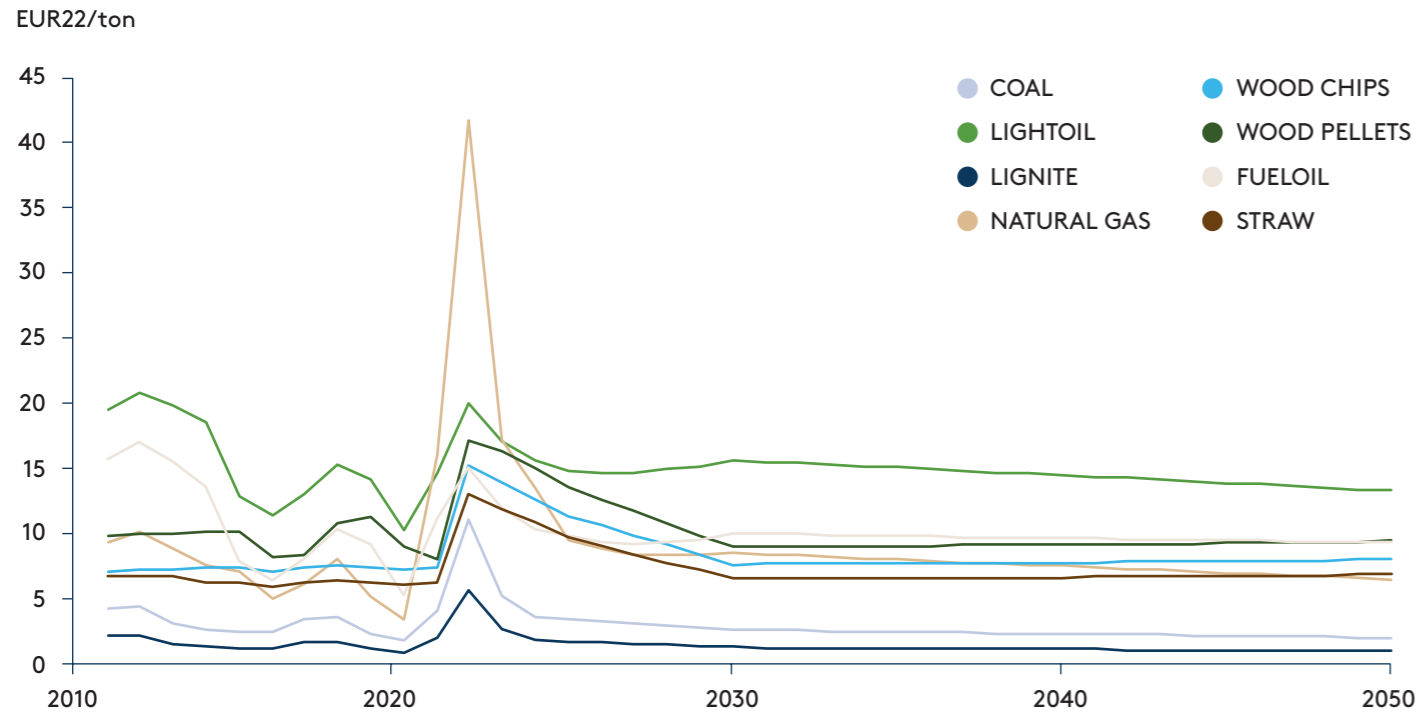
17. Short term pricing based on futures; long-term pricing based on IEA World Energy Outlook 2023 “Announced Pledges Scenario”

18. CAPEX assumptions based on Danish Energy Agency’s CAPEX in Energikataloget adjusted for recent changes to CAPEX cost on wind turbines

19. Wind/solar annual profiles uses NASA MERRA 2 database

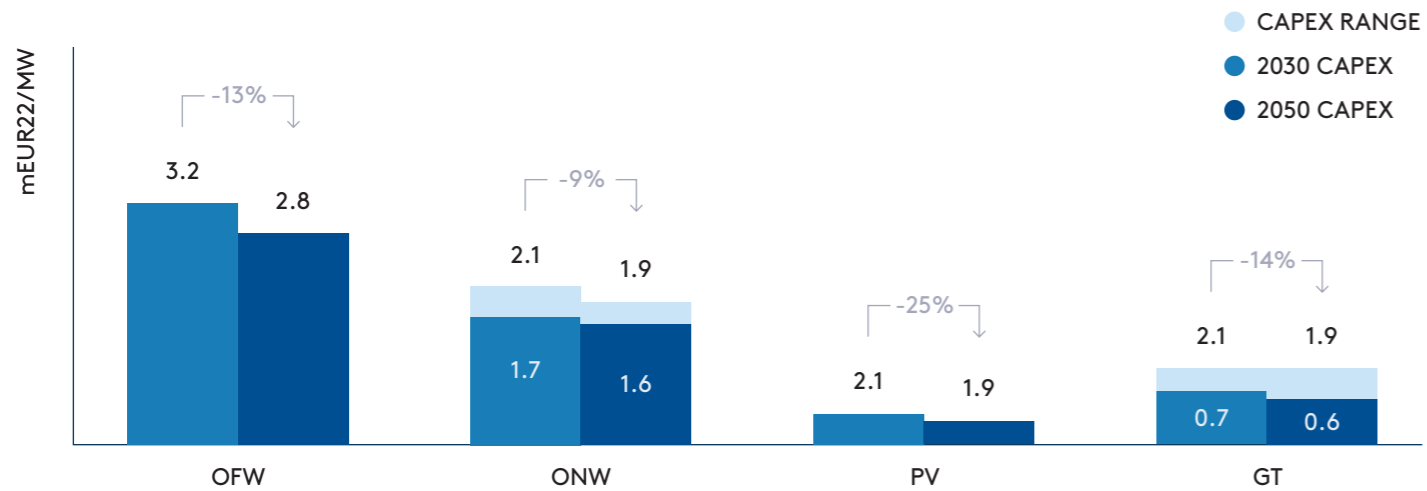
## Appendix II

### FUEL PRICES



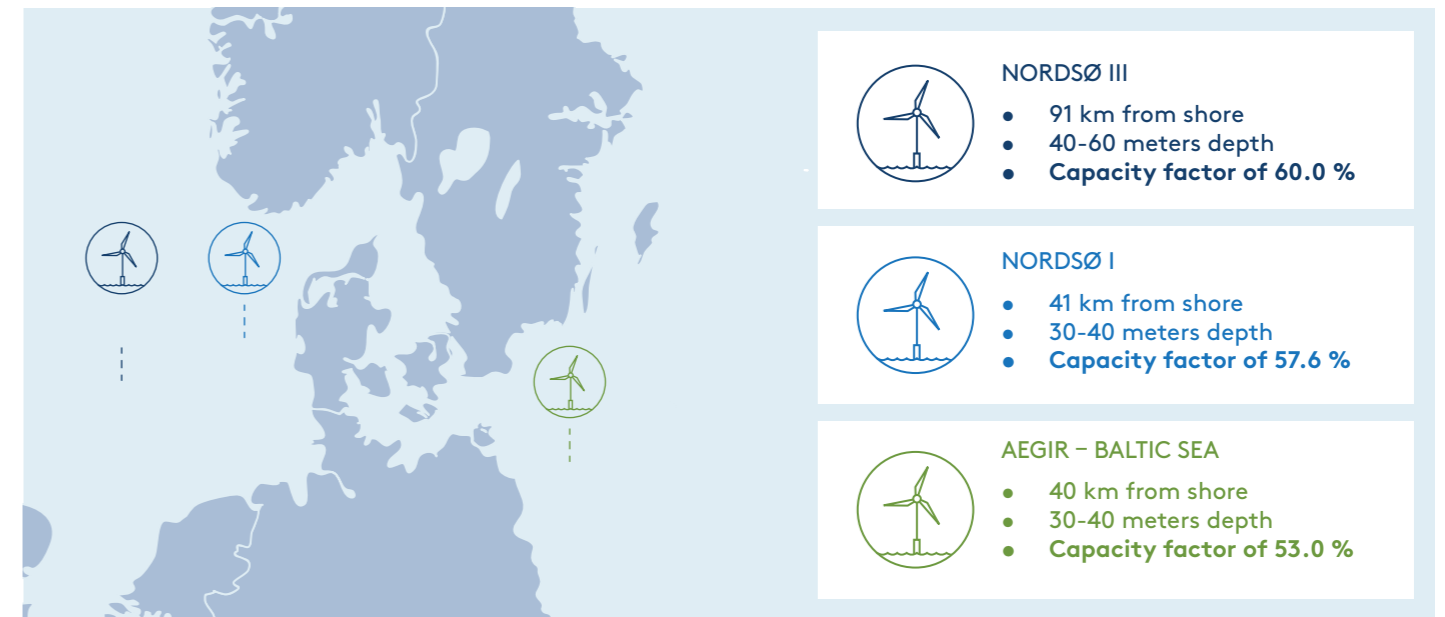
## Appendix III

### TECHNOLOGY CAPEX



## Appendix IV

### EXAMPLE OF KEY ASSUMPTION



|                              | CAPACITY FACTOR |       | EFFICIENCY |      |      |
|------------------------------|-----------------|-------|------------|------|------|
|                              | 2030            | 2050  | 2030       | 2040 | 2050 |
| DK                           | 44.2%           | 11.8% |            |      |      |
| DE                           | 41.4%           | 11.7% |            |      |      |
| ESP                          | 38.9%           | 17.9% |            |      |      |
| Electrolyser (Alkaline)      | 0.57            | 0.59  | 0.60       |      |      |
| Gas turbine (combined cycle) | 0.58            | 0.58  | 0.60       |      |      |
| Gas turbine (simple cycle)   | 0.41            | 0.41  | 0.43       |      |      |
| Lithium-ion batteries        | 0.92            | 0.92  | 0.92       |      |      |

## Appendix V

### TRANSMISSION GRID

- CONSTRUCTED
- UNDER CONSTRUCTION
- PLANNED – NOT PERMITTED
- UNDER CONSIDERATION
- UNDER PERMITTING
- UNKNOWN

| ENTSO-E TYNDP planned link towards 2030 (GW) |          |           |               |        |  |
|--|----------|-----------|---------------|--------|--|
| Link   | From     | To        | Capacity (GW) | Status |  |
| NORTH SEA LINK                               | GB       | NO (NO2)  | 1.4           | ●      |  |
| VIKING LINK                                  | GB       | DK (W)    | 1.4           | ●      |  |
| NEUCONNECT LINK                              | GB       | DE (NW)   | 1.4           | ●      |  |
| MULTIPLE LINKS                               | GB       | FR        | 5.8           | ●      |  |
| AVELIN-HORTA                                 | FR       | BE        | 1.5           | ●      |  |
| VIGY-UCHTELFANGEN                            | FR       | DE (CS)   | 3.7           | ●      |  |
|  | FR       | CH        | 0.6           | ●      |  |
|  | FR       | IT        | 0.1           | ●      |  |
|  | IT       | CH        | 1.7           | ●      |  |
|  | IT       | AT        | 0.6           | ●      |  |
|  | CH       | AT        | 0.5           | ●      |  |
|  | CH       | DE (CS)   | 0.8           | ●      |  |
|  | AT       | DE (CS)   | 2.5           | ●      |  |
|  | DE (CS)  | CZ        | 2.2           | ●      |  |
|  | DE (CS)  | LU        | 1             | ●      |  |
|  | DE (CS)  | NL        | 0.7           | ●      |  |
|  | DE (CS)  | DE (NW)   | 10            | ●      |  |
|  | DE (CS)  | DE (MW)   | 7             | ●      |  |
|  | NL       | BE        | 2.9           | ●      |  |
|  | NL       | DE (NW)   | 0.2           | ●      |  |
| WEST COASTLINE & OTHER                       | DE (NW)  | DK (W)    | 1.9           | ●      |  |
|  | DE (ME)  | PL        | 2.2           | ●      |  |
|  | DE (ME)  | DE (NE)   | 5.3           | ●      |  |
|  | DE (NE)  | PL        | 0.1           | ●      |  |
| KRIEGERS FLAK CGS                            | DE (NE)  | DK (EAST) | 3.2           | ●      |  |
|  | DE (NE)  | SE (SE4)  | 0.7           | ●      |  |
|  | PL       | LT        | 2             | ●      |  |
| 3 <sup>RD</sup> IC                           | LV       | EE        | 0.7           | ●      |  |
| 3 <sup>RD</sup> AC                           | FI       | SE (SE1)  | ?             | ●      |  |
|  | FI       | SE (SE1)  | ?             | ●      |  |
|  | FI       | SE (SE3)  | 0.8           | ●      |  |
|  | NO (NO3) | NO (NO4)  | 1.2           | ●      |  |

## Appendix VI

### SENSITIVITIES PERFORMED ON RESULTS FROM 2050 (1/2)

- HIGHEST #
- LOWEST #

| Category   | Parameter  | Sensitivity Scenarios  |                                       |              |                 |                     |                      |                      |                                    |         |                      |                   |     |
|--|--|--|---------------------------------------|--------------|-----------------|---------------------|----------------------|----------------------|------------------------------------|---------|----------------------|-------------------|-----|
|  |  | Base case  | Unrestricted import of H <sub>2</sub> | Low ELZ cost | More PV and ONW | Offshore Capex +50% | Reduced PV build-out | WACC1 %-point higher | No DK/DE H <sub>2</sub> connection | More PV | Behind the meter ELZ | Consumer scenario |     |
| ELECTRICITY  | Total power consumption (TWh)                                  | 6,221  | 5,177                                 | 6,246        | 6,271           | 6,096               | 6,184                | 6,205                | 6,219                              | 6,254   | 6,260                | 5,951             |     |
|  | Offshore power capacity (GW)                                   | 325  | 227                                   | 314          | 239             | 239                 | 390                  | 323                  | 325                                | 284     | 297                  | 219               |     |
|  | Onshore power capacity (GW)                                    | 553  | 526                                   | 554          | 632             | 515                 | 584                  | 550                  | 553                                | 549     | 556                  | 627               |     |
|  | PV power capacity (GW)   | 1,580  | 1,051                                 | 1,575        | 1,605           | 1,849               | 1,162                | 1,570                | 1,581                              | 1,673   | 1,617                | 1,445             |     |
|  | Installed electricity storage (GW)                             | 187  | 187                                   | 187          | 187             | 187                 | 187                  | 187                  | 187                                | 187     | 187                  | 187               |     |
|  | Average electricity price (EUR/MWh)                            | 66.8   | 62.5                                  | 65.5         | 61.4            | 79.5                | 72.4                 | 71.5                 | 66.9                               | 64.0    | 64.8                 | 59.0              |     |
|  | North Sea offshore wind capacity (GW)                          | 253.3  | 166.6                                 | 243.3        | 181.9           | 190.0               | 295.7                | 250.8                | 252.5                              | 217.6   | 227.3                | 172.2             |     |
|  | Baltic offshore wind capacity (GW)                             | 39.1   | 28.1                                  | 37.9         | 27.8            | 23.4                | 59.3                 | 38.9                 | 39.2                               | 34.4    | 36.0                 | 21.5              |     |
|  | UK average electricity price (EUR/MWh)                         | 65.6   | 60.6                                  | 63.9         | 62.9            | 77.8                | 71.5                 | 70.3                 | 65.6                               | 64.0    | 63.4                 | 60.2              |     |
|  | ES average electricity price (EUR/MWh)                         | 66.4   | 61.9                                  | 65.7         | 53.9            | 80.3                | 75.0                 | 71.3                 | 66.4                               | 58.7    | 65.4                 | 51.1              |     |
|  | HYDROGEN   | Total installed ELZ capacity (GW)                                | 511                                   | 236          | 570             | 547                 | 543                  | 469                  | 508                                | 510     | 549                  | 614               | 462 |
|  |  | Average H <sub>2</sub> -production cost (EUR/KG H <sub>2</sub> ) | 2.4                                   | 2.2          | 2.3             | 2.2                 | 2.6                  | 2.6                  | 2.5                                | 2.4     | 2.2                  | 2.2               | 2.1 |
|  |  | European H <sub>2</sub> -production (Mt of H <sub>2</sub> )      | 42                                    | 18           | 43              | 43                  | 43                   | 42                   | 42                                 | 42      | 43                   | 43                | 36  |
| External H <sub>2</sub> -imports (Mt of H <sub>2</sub> )     |  | 10   | 38                                    | 10           | 10              | 10                  | 10                   | 10                   | 10                                 | 10      | 10                   | 15                |     |
| Peak plant consumption (Mt of H <sub>2</sub> )               |  | 7  | 11                                    | 7            | 8               | 8                   | 6                    | 7                    | 7                                  | 7       | 8                    | 6                 |     |
| North Sea H <sub>2</sub> -production (Mt of H <sub>2</sub> ) |  | 24.1   | 8.7                                   | 23.8         | 18.5            | 23.7                | 25.0                 | 24.1                 | 24.1                               | 17.4    | 23.6                 | 14.4              |     |
| Baltic H <sub>2</sub> -production (Mt of H <sub>2</sub> )    |  | 6.7  | 3.2                                   | 10.2         | 7.9             | 6.2                 | 11.8                 | 6.6                  | 6.7                                | 5.7     | 6.8                  | 4.0               |     |
| GRID   | Power Grid investments (billion EUR)                           | 120  | 101                                   | 115          | 110             | 109                 | 145                  | 122                  | 120                                | 117     | 113                  | 133               |     |
|  | H <sub>2</sub> Infrastructure investments (GW H <sub>2</sub> ) | 371  | 511                                   | 380          | 434             | 353                 | 348                  | 361                  | 372                                | 451     | 317                  | 437               |     |

Appendix VI

SENSITIVITIES PERFORMED ON RESULTS FROM 2050 (2/2)

- HIGHEST #
- LOWEST # COMBINED SCENARIO

|             | Parameter  | Base case | No pipeline | High ELZ cost | Faster transmission build-out | No fossil constraint + Cheap NG | No fossil constraint +500% gas price | Nuclear 150% capacity | WACC 1%-point lower | Best case OFW | Worst case OFW |
|-------------|--|-----------|-------------|---------------|-------------------------------|---------------------------------|--------------------------------------|-----------------------|---------------------|---------------|----------------|
| ELECTRICITY | Total power consumption (TWh)                                    | 6,221     | 6,655       | 6,203         | 6,194                         | 5,917                           | 6,134                                | 6,199                 | 6,249               | 6,328         | 6,006          |
|             | Offshore power capacity (GW)                                     | 325       | 360         | 333           | 325                           | 277                             | 320                                  | 285                   | 330                 | 450           | 192            |
|             | Onshore power capacity (GW)                                      | 553       | 570         | 552           | 555                           | 555                             | 566                                  | 544                   | 557                 | 443           | 617            |
|             | PV power capacity (GW)   | 1,580     | 1,815       | 1,573         | 1,574                         | 1,438                           | 1,458                                | 1,482                 | 1,591               | 1,582         | 1,543          |
|             | Installed electricity storage (GW)                               | 187       | 187         | 187           | 187                           | 187                             | 187                                  | 187                   | 187                 | 187           | 187            |
|             | Average electricity price (EUR/MWh)                              | 66.8      | 67.5        | 68.0          | 65.6                          | 61.4                            | 64.3                                 | 63.8                  | 62.6                | 72.9          | 67.1           |
|             | North Sea offshore wind capacity (GW)                            | 253.3     | 281.0       | 259.3         | 252.4                         | 218.8                           | 248.0                                | 221.3                 | 254.6               | 336.9         | 153.7          |
|             | Baltic offshore wind capacity (GW)                               | 39.1      | 44.0        | 40.2          | 39.6                          | 27.0                            | 40.5                                 | 31.2                  | 40.5                | 77.2          | 14.1           |
|             | UK average electricity price (EUR/MWh)                           | 65.6      | 66.7        | 67.0          | 65.3                          | 61.0                            | 63.5                                 | 63.9                  | 61.1                | 71.4          | 68.4           |
|             | ES average electricity price (EUR/MWh)                           | 66.4      | 66.9        | 66.9          | 64.8                          | 58.2                            | 57.6                                 | 61.4                  | 62.0                | 78.3          | 62.6           |
| HYDROGEN    | Total installed ELZ capacity (GW)                                | 511       | 637         | 481           | 509                           | 442                             | 497                                  | 488                   | 520                 | 531           | 470            |
|             | Average H <sub>2</sub> -production cost (EUR/KG H <sub>2</sub> ) | 2.4       | 2.5         | 2.5           | 2.4                           | 2.3                             | 2.4                                  | 2.3                   | 2.3                 | 2.7           | 2.3            |
|             | European H <sub>2</sub> -production (Mt of H <sub>2</sub> )      | 42        | 52          | 42            | 42                            | 36                              | 40                                   | 42                    | 42                  | 45            | 38             |
|             | External H <sub>2</sub> -imports (Mt of H <sub>2</sub> )         | 10        | 0           | 10            | 10                            | 10                              | 10                                   | 10                    | 10                  | 6             | 15             |
|             | Peak plant consumption (Mt of H <sub>2</sub> )                   | 7         | 6           | 7             | 6                             | 0                               | 4                                    | 6                     | 7                   | 6             | 7              |
|             | North Sea H <sub>2</sub> -production (Mt of H <sub>2</sub> )     | 24.1      | 30.9        | 24.4          | 23.4                          | 18.9                            | 21.5                                 | 24.1                  | 24.1                | 26.8          | 17.7           |
|             | Baltic H <sub>2</sub> -production (Mt of H <sub>2</sub> )        | 6.7       | 8.9         | 6.7           | 6.7                           | 5.9                             | 7.2                                  | 6.2                   | 7.0                 | 10.5          | 6.9            |
| GRID        | Power Grid investments (billion EUR)                             | 120       | 122         | 124           | 143                           | 98                              | 132                                  | 110                   | 116                 | 174           | 103            |
|             | H <sub>2</sub> Infrastructure investments (GW H <sub>2</sub> )   | 371       | 340         | 368           | 359                           | 340                             | 371                                  | 373                   | 381                 | 328           | 362            |

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