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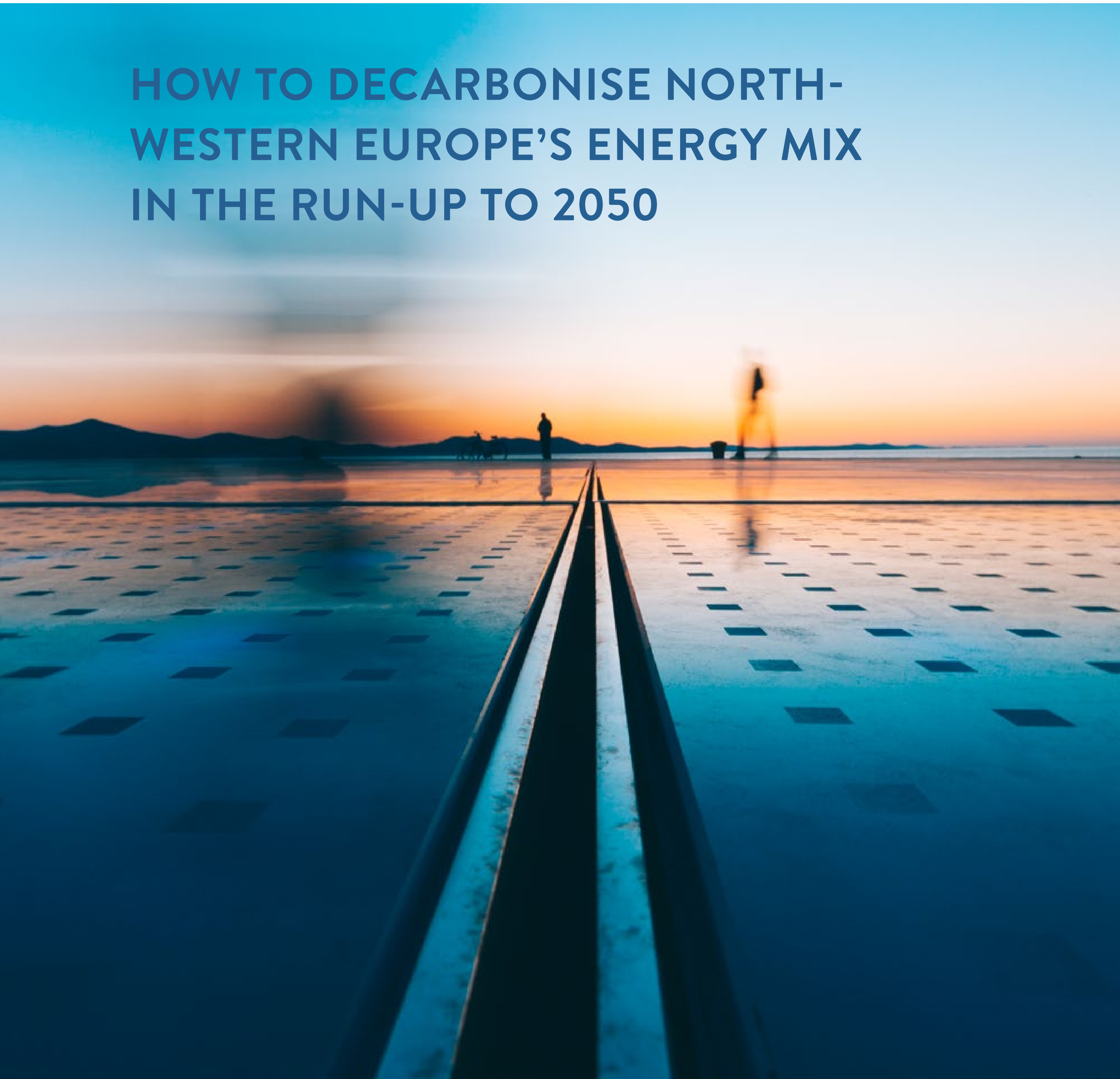
THE NETHERLANDS

PHASING OUT CARBON

HOW TO DECARBONISE NORTH-WESTERN EUROPE'S ENERGY MIX IN THE RUN-UP TO 2050



WORLD ENERGY COUNCIL | THE NETHERLANDS

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World Energy Perspective

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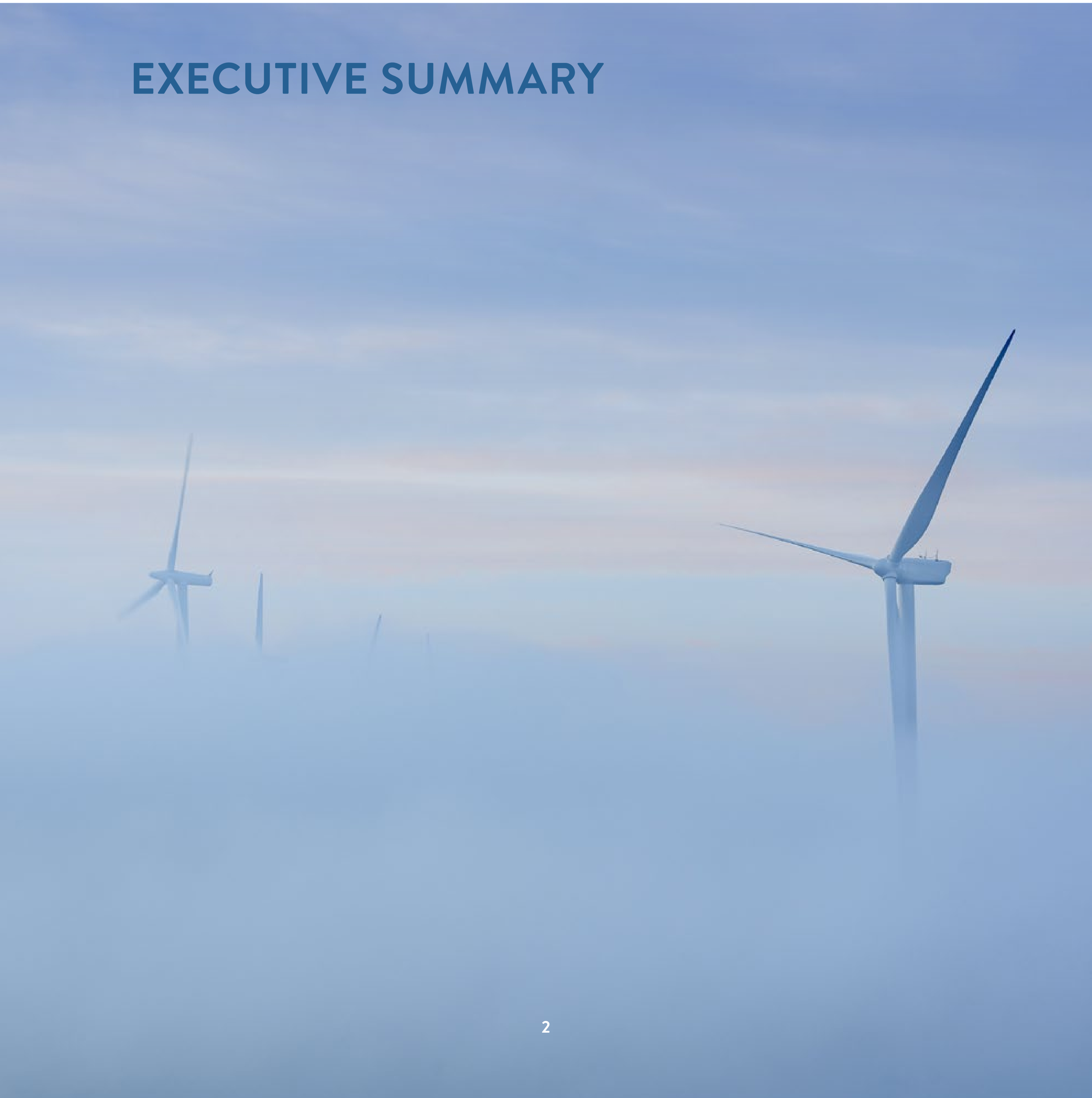
TABLE OF CONTENTS

1

EXECUTIVE SUMMARY



1.1 ABOUT THIS REPORT

- Europe is one of the richest continents on the planet. It has a relatively energy-intensive economy and yet has relatively few fossil-based resources remaining. Given this context, Europe is keen to achieve the Paris objectives of curbing greenhouse gas emissions to the extent that the warming of the planet can be kept under 2 degrees Celsius, or preferably even under 1.5 degrees.

- Europe's latest actions underline this bold intention. The European Commission (EC) launched a new strategy in February 2015 for an increasingly resilient Energy Union in combination with a forward-looking climate change policy. The 2019 European Parliament elections have given the EC the mandate to draw up a European Green Deal – its commitment was demonstrated by the fact that the European Green Deal was published before the new Commission had even been officially installed.

- The goal of the Energy Union and the European Green Deal is to give EU citizens and businesses secure, affordable, competitive and, above all, sustainable energy. This is beneficial for the prosperity, health and wellbeing of all Europeans and crucial for the mid- and long-term competitiveness of EU industry.

- In this report, the Dutch Chapter of the World Energy Council addresses the challenges that arise around the fundamental energy system transformation required to achieve this goal. The report takes a closer look at the future energy mix that would serve Europe's determination to remain a prosperous and innovative economy. It is one thing to formulate ambitions related to the decarbonisation of our entire economic system and to map a corresponding future energy mix. As the report demonstrates, however, we can only expect this to be achieved through unprecedented and considerable changes to our energy production and transport infrastructure (supply), as well as to the ways we consume energy (demand).

- This report is a new release in the annual series of studies carried out under the auspices of the World Energy Council Netherlands. In line with the other studies in the series, we focus on North-Western Europe. More specifically, we consider the ten countries which have formed the North Seas Energy Cooperation (NSEC) since 2016[1]. These countries are linked together via their proximity to the North Sea and its great potential for offshore wind generation, EU membership (except for the UK and Norway), and future and existing economic and energy infrastructure and interconnector capacity. In the remainder of this report, we will refer to this group of countries as NWE.

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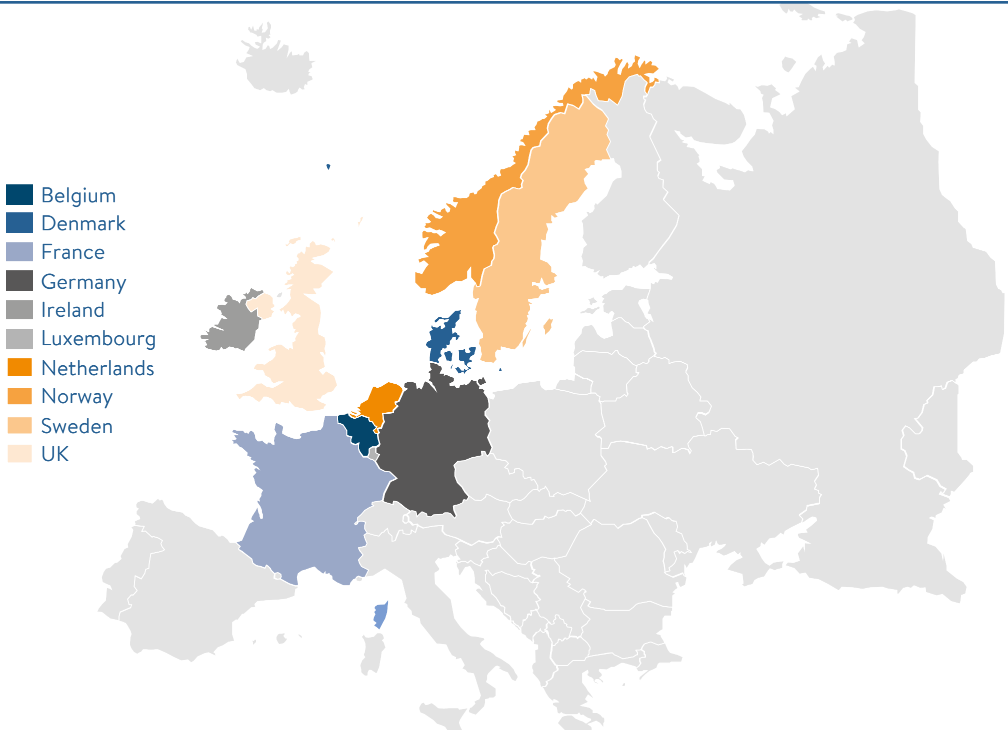
[1] The forming of the NSEC in 2016 was a further strengthening of the North Sea Countries' Offshore Grid Initiative (NSCOGI), which was established in 2009. The development of an offshore grid linking the ten countries in the North Seas region has been a long-standing energy policy priority for the European Commission. The region is considered by the EC to have great potential for offshore wind generation and linking these countries via energy infrastructure is expected to create jobs and economic growth throughout the region. A regional, cooperative approach is adopted to deliver these benefits in the most cost-efficient manner.

Figure 1: The ten countries covered by the report



- Also in line with the earlier studies, the decade until 2030 and the subsequent two decades until 2050 are taken as milestone episodes. Broadly speaking, the first decade is expected to see strong growth in green electricity generation, the kick-start of policy actions and the crossing of many economic valleys of death on the way to scaling up the production and use of carbon-free fuels. The period between 2030 and 2050 should see the realisation of actual massive further upscaling of green electricity and carbon-neutral fuels, and corresponding large-scale phasing out of fossil-based energy forms.

- In the lead-up to 2050, NWE's demographics – an ageing but highly prosperous population – and strong efficiency improvement targets will be major determinants of just how much energy will be needed on a household level for mobility, heating and running household appliances. Although it's always impossible to predict things with absolute certainty, the outlook for this general trend to 2050 seems quite straightforward.

- A large unknown factor is how much and what kind of energy will be required by industrial production. If Europe's explicit ambitions are to be fulfilled and NWE continues to be an attractive place for advanced energy-intensive industry in the decades to come, this industry will require vast amounts of green electricity as well as carbon-free fuels (hydrogen and other gases).

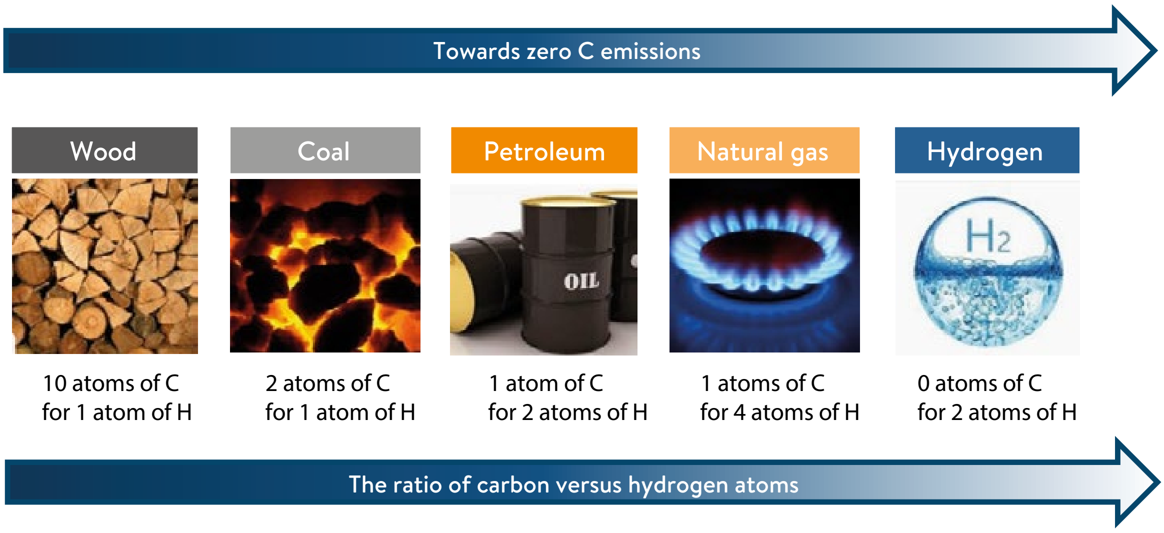
- Even if the most ambitious capacity-building targets in NWE are met, the capacity to generate green electricity and carbon-free fuels by NWE producers on their own is very likely to be insufficient. Much of the future energy will therefore still have to be imported. The gap in Europe between production and demand on a 100% electricity basis, for instance, is estimated to be some 18,000 TWh. The sheer size of this gap necessitates discussion about the affordability and security of supply on a European scale. Awareness of the gap will have a major impact on the choices for the energy production-mix and the infrastructure needs within Europe in both the medium and long term. Some fundamental technological as well as economic, policy and geo-strategic choices will inevitably have to be made.

- This study aims to assess and define an order of magnitude for these various challenges related to the 2030 and 2050 energy mix for NWE. The purpose of the study is to raise consciousness and insight for the energy sector itself, for policy makers and strategists, and for the general public.
- As was the case in all five preceding WEC NL reports, this report is the result of contributions from a number of companies and knowledge institutions specialised in at least one of the themes addressed. Under the editorship of PwC, contributions have been made by Shell, Vopak, New Energy Coalition, Rabobank, TNO, DNV GL, Port of Rotterdam Authority, EBN, ThyssenKrupp, Siemens, Nouryon and CIEP.

1.2 THE STORY

- Humankind has fuelled its astonishing economic development of the past three centuries by exploiting fossil reserves that took nature and geology hundreds of millions of years to produce. Burning fossil fuels has so far been the most efficient way of producing heat, power, gas and other energy feedstocks for all the needs of human societies. Seen on a timeline, it is clear that we have become ever more efficient in doing so in terms of the amount of carbon used to produce a given unit of energy.

Figure 2: Ratio of carbon and hydrogen in various fuel types



- This impressive improvement in carbon efficiency is dwarfed by the explosion in the volumes of energy demanded, however. No one now seriously contests that the intensity with which humankind uses carbon-based fuels to power its society and the environmental degradation this creates are unsustainable and, in fact, represent an existential threat to human development itself. Today's challenge could therefore be seen as simply a way to take the final steps in a longstanding carbon-efficiency process: that is, taking out the last atom of carbon from the energy system altogether.

- Despite the ongoing energy efficiency improvements in our systems, and the fact that an ageing, maturing or shrinking society needs less energy per Gross Domestic Product (GDP) or person, there is no question that NWE will still need a great deal of energy in the decades to come. A large proportion of that need will be driven by the wish to sustain a strong industrial position. Thankfully, large energy-intensive industries are clustered in an overseeable number of geographical centres in Europe, which strongly determine the energy requirements and flows. They are also conveniently interconnected via onshore and offshore grids for gases and power. As we demonstrate in this report, in this sense NWE is quite uniquely positioned to take the next steps towards decarbonising electricity and fuels.

- NWE's ultimate sustainable, dependable and affordable energy mix will in the long-term consist of carbon-free fuels and green electricity. Both will be indispensable. The electrification of our energy system will fulfil many of the future needs of households, most of our relatively service-oriented production sectors, and much of our mobility and industrial applications. It is likely, though, that substantial demand for green fuels will remain, for example for long-haul heavy mobility and as feedstocks for chemicals and energy-intensive industrial processes.

- NWE has not possessed the natural resources or technology to supply its own energy needs since the industrial revolution. This dependency on other regions in the world is expected to continue for at least the next three decades, even if we move from fossil-based to carbon-free forms of energy. Oil and gas are currently largely sourced from elsewhere, and Europe's own fields are past peak production. Likewise, technologies driving electrification, such as solar panels and batteries, are also largely sourced from other continents.

- At the same time, there is a very strong potential to generate significant amounts of affordable renewable electricity in the North Sea, as we have argued in earlier reports[2,3]. Its shallowness and proximity to rich end-user markets are among the characteristics that make the North Sea a unique asset. Next to this, there is also the rich heritage of a dense and highly reliable existing infrastructure for evacuating and transporting gas to user markets in NWE, both at the bottom of the North Sea and across the continent. Thanks to this established infrastructure, NWE has a strong starting position for transitioning to the production and application of carbon-free gases such as hydrogen.

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2 Bringing North Sea Energy Ashore Efficiently, WEC Netherlands, 2018
3 The North Sea Opportunity, WEC Netherlands, 2017

- NWE could well take a leading role in the world in the field of the hydrogen economy. Although NWE has some unique properties that can be difficult to reproduce elsewhere – a dense and affluent population, an advanced services industry, dense, flexible and reliable grids and other infrastructure, huge wind production potential, and a growing determination of governments to take on climate change – the lessons learned can serve as examples, and the solutions developed exported to other regions in the world.

1.3 KEY CONCLUSIONS

A SCENARIO FOR ACHIEVING A DECARBONISED ENERGY MIX FOR A PROSPEROUS NORTH-WESTERN EUROPE

- The first contribution of this report is a detailed map of the evolution of our mixture of energy carriers over the coming decades per country and per industry. The scenario presented in this report is the first to provide this degree of detail for NWE while describing how to:
  - Meet the Paris Agreement objectives by 2050;
  - Provide society with affordable and reliable energy; and
  - Sustain a substantial and competitive mature manufacturing sector.

- As meeting the Paris targets will require immense efforts, the scenario is built on a number of key assumptions that can be summarised as ‘all hands on deck’. Decarbonising the economy while maintaining our industrial position and providing secure and affordable energy will require:
  1. Efficiency improvements and the electrification of energy consumption;
  2. Generation of the required green electricity;
  3. Production and import of carbon-free fuels (for both fuel and feedstock purposes); and
  4. Optimal utilisation and integration of the electricity and gas networks.

- Efficiency improvements reduce the amount of energy required, lowering both emissions and capacity requirements for the energy infrastructure. Efficiency improvements across the board – or ‘decoupling’ energy use growth from economic growth – will need to proceed at the rate of more than 4% per annum. In combination with GDP growth projections, this dictates a decrease in overall energy demand of 1.3% per annum, which is quite bullish for a continent where industry, the transport sector as well as power production are already leading their peers. Without ongoing efficiency improvements, final energy demand in 2050 will be 230% of the level assumed by our Paris scenario. This would obviously have a massive impact on emission levels.

- Electrification of the economy means electricity will provide up to 50% of all final energy demand in 2050 compared to roughly 30% today. As electrified processes have lower heat losses, electrification is one of the drivers of efficiency improvements. Of course, actually lowering emissions would require sufficient green electricity to be provided. The NWE countries have excellent possibilities for generating green electricity using offshore wind power. Although the installed capacity is running behind national targets, there is a reasonably clear view and pathway towards large-scale utilisation of this valuable resource.

- Whereas plans and strategies for ensuring greener electricity are gradually taking shape, the decarbonisation of fuels has yet to get off the ground at all. The share of energy provided in the form of fuels – currently 70% of all energy – remains resolutely carbon-heavy. Although the share of fuels in the energy mix will fall over time, there will still certainly be high demand due to industrial needs for feedstock and high quantities of power. The enormous acceleration of the decarbonisation of fuels needed to meet the Paris Agreement objectives requires an immediate start to mixing biogas and hydrogen into the natural gas supply, for instance, for a rapid first-stage greening of feedstock. This ultimate demand for carbon-free fuels alone poses a major argument for the build-up of substantial hydrogen and power-to-gas (PtG) capacities.

- Chapter 2 gives a detailed description of the scenario, including motivations for the underlying crucial assumptions and a presentation of the model outcomes with respect to volumes and values, capacities and infrastructure challenges, as well as performance around security and dependency.

- Chapter 3 highlights the development of the demand for different energy carriers over the course of the transformation in the leadup to 2050, given the assumed rates of economic growth and taking into account the required rates of electrification, energy efficiency improvement and decarbonisation.

SHAPING UP THE ENERGY SUPPLY SIDE

- Chapter 4 outlines the roadmaps of the larger components of the supply side and summarises the findings in earlier WEC NL reports on the role of the North Sea as a source of offshore wind. Given the substantial inherited natural gas-based economy and infrastructure, the role of natural gas is shown to be a crucial stepping-stone towards the use of decarbonised gases – both in terms of experience with the provision and uses of gas as well as in terms of asset availability.

- In addition to the industrial requirement for carbon-free fuels, the systemic benefits of PtG in the electrical system are a further argument for its accelerated development. The application of carbon-free fuels in the form of hydrogen and PtG will lead to an optimal use of – and limitation of investments in – the electricity and gas grids. While the capacity and quality of our gas grids seem to be suitable for modification to accommodate vast amounts of low-carbon or carbon-free gases, the already congested power grids and storage capacity need to be expanded significantly, requiring huge investments.

EXPANDING OUR INFRASTRUCTURE

- In Chapter 5 we discuss the corresponding infrastructure challenges at four levels: the potential of the current and future infrastructure in the North Sea for production, transportation and storage; the role and challenges of transmission system operators (TSOs); the role of ports, of which NWE is endowed with quite a few; and the role and challenges of a decentralised infrastructure and distribution system operators (DSOs).

- A particular focus is given to the seasonal storage facilities for electricity of some 1,000-1,100 TWh that would be required annually to balance the system. The investments required to increase the electricity grid capacity would be much higher without the implementation of PtG. Furthermore, additional services for energy transport and grid balancing might be provided with the same technology. Carbon-free fuels from PtG will play a major role in such a system thanks to their compatibility with all sectors, high energy density, key role in the power system, and connection to the existing system for natural gas.

- The production of green electricity and carbon-free fuels within NWE will be largely provided by offshore wind power and PtG transformation solutions on the North Sea. The additionally required import volumes of carbon-free fuels can come from Norway and Russia. Other sources will be solar-based energy carriers from North Africa and the Middle East. Combining these options in a clever way holds the promise of affordable carbon-free fuels.

THE ROLE OF GOVERNMENT IN DRIVING DECARBONISATION WHILE SAFEGUARDING PUBLIC GOALS

- Chapter 6 describes the principal roles of governments with a focus on policy instruments supporting investment in renewables capacity. Financial and regulatory support is needed in the form of setting clear targets and standards, and precision funding of certain infant technologies while maintaining a technology-neutral principle. Governments will be crucial in ensuring that the subtle simultaneity of the development of end-user markets and viable earnings models goes hand in hand with the corresponding emergence of a reliable and increasingly decarbonised supply side, locally and on a macro-scale. This will inevitably require a certain degree of policy flexibility, which the private sectors will have to accept.

- Other aspects to which we draw attention are public goods such as the assurance of sufficient back-up capacity. Another important role is to formulate fair and adequate economic rules of the game, making sure that markets work well and playing fields are level both for regions and states.

- Alongside the financial, technological and policy design challenges, Europe's shifting but continuing import dependency also gives rise to geo-strategic questions. As our dependency on imported energy will remain high for the foreseeable future, the ambitions towards greening the economy should not lead to underinvestment in energy supply capacity. NWE will need to invest in its geopolitical relationships with energy suppliers to ensure security of supply. In terms of game theory, it makes sense to expect that our future energy providers – blue hydrogen from Russia and Norway, green electricity or decarbonised gas from North Africa and the Middle East, to name just a few obvious future suppliers – will take our energy transformation into account when mapping out their own long-term energy production strategies. It is important to realise that this is not a zero-sum game, and the best way to optimise the likelihood of achieving our targets is to seek cooperation and coordination.

1.4. RECOMMENDATIONS

- A socially optimal energy mix that meets the EU's triple energy policy targets will not be achieved overnight nor automatically. It will require a lasting, consistent and credible set of incentives for all stakeholders based on a range of policies and measures. In NWE this typically involves policy action at both the EU and national levels. Although the current set of EU and national policies and measures is promising, this report concludes that additional new policies will be needed to maximise the chances of reaching the EU energy policy goals, especially the 2050 emission reduction target.

- As a starting point, energy policy design should focus on the overall energy system as a whole rather than on its separate components. Deploying technologically neutral policies to stimulate the production of green electricity and carbon-free fuels – which can be converted into one another – should avoid point solutions and path dependency.

- There should be policies in place to ensure that fuels are both greener and contain less carbon. The key technologies to generate large volumes of carbon-free fuels are hydrogen production from natural gas, with the application of carbon capture, use and storage (CCUS), sometimes referred to as the blue hydrogen route, and PtG, i.e. turning green power into green fuels. Both technologies generate hydrogen as the principal energy carrier, and while neither is currently market-ready they should be made so as soon as possible.

- Natural gas and CCUS can be used to produce low-carbon hydrogen as a stepping-stone in the transformation. This combination will ultimately help us cross the valley of death and creep up the learning curve, leading to direct decarbonisation, whereas large-scale green hydrogen production first requires massive upscaling of green electricity production capacity by 2030.

- The acceleration of low-carbon hydrogen production to the required magnitudes will require creating momentum through the upscaling of current industrial applications in the decade ahead, while at the same time starting to lay the foundations for migrating towards fully carbon-free (green) hydrogen in the long term.

- The technologies for carbon-free hydrogen and PtG need broad financial support for substantial demonstration projects in the current decade. This, combined with a restriction on the use of grey hydrogen for industrial feedstocks in order to create demand, will allow these technologies to cross the valley of death before 2030.

- The positive upshot of the blue hydrogen route is that it may become feasible relatively soon, opening up the perspective of introducing carbon-neutral hydrogen to the market. The drawback can be that the carbon capture capacity and costs may at some stage result in bottlenecks to its long-term perspective, or that blue hydrogen will strongly benefit from learning and therefore ‘lock out’ the development of green hydrogen.

- PtG produces carbon-free fuels and serves as a balancing carrier. The positive upshot of PtG is that as well as undisputedly generating the green fuels needed for the optimal energy mix, it also contributes to dealing with two of the main challenges resulting from the massive introduction of intermittent renewables. These are the need for flexibility to balance the electricity grid and the requirement for back-up capacity for dark doldrums. The technological flexibility of PtG technologies can also result in flexibility for the power market. The gases produced can be transported cheaply via the existing gas grid, stored on a large scale against relatively low costs and converted back into power if needed. PtG can also contribute to solving back-up challenges for the same reasons. Finally, if Europe acts as a first mover with respect to innovative PtG technologies, it may develop a competitive edge in PtG technologies on the international market.

- Decarbonisation of the natural gas supply should also be stimulated in the current decade by policies prescribing the ‘admixing’ of renewable and carbon-neutral gases into the gas system. This will lead directly to emission reductions while also boosting demand for low-carbon fuels.

THE COMBINATION OF NATURAL GAS AND CCUS WILL ULTIMATELY HELP US CROSS THE VALLEY OF DEATH AND CREEP UP THE LEARNING CURVE, LEADING TO DIRECT DECARBONISATION, WHEREAS LARGE-SCALE GREEN HYDROGEN PRODUCTION FIRST REQUIRES MASSIVE UPSCALING OF GREEN ELECTRICITY PRODUCTION CAPACITY BY 2030.

- The existing gas storage infrastructure is in a class of its own and in a matching order of magnitude to cover the required developments discussed above. As a result of declining oil and gas production on the North Sea, the transport infrastructure will become available over time and should be used for the evacuation and transport of offshore-produced low-carbon fuels

- Dedicated policies and measures will therefore have to be put in place so that all these promises for an optimal future energy system and energy mix can be realised. We consider these the most important policy measures to be introduced as a first step in the current decade:
  1. Setting milestones and ultimate targets – continuing to make sure that the right intentions are in place;
  2. Managing the conditions for a simultaneous emergence of demand and supply;
  3. Upholding the principle of technology neutrality with respect to sources of renewable power and carbon-free fuels;
  4. Ensuring that markets function well and playing fields are level for all private parties;
  5. Admixing of carbon-neutral gases to stimulate their production and use and cross the fuels valley of death;
  6. Dedicated support scheme on an EU level to scale-up hydrogen and PtG production with the same purpose;
  7. Facilitating the uptake of hydrogen on the demand side by:
     - Introducing policies and measures to rule out the industrial use of grey hydrogen or comparable feedstock;
     - Incentivising the development of a fuelling infrastructure for hydrogen and other green fuels;
     - Tackling the greening of the aviation and shipping sectors.

- As the production of green electricity and fuels is nowhere near sufficient to cover demand, the import of energy will remain important, including in the longer term. The nature and risks associated with importing green fuels are different from those related to oil and gas. The likelihood of achieving our targets can be maximised by engaging with the potential long-term suppliers of carbon-free fuels and green electricity. Realising that efforts to green the planet are not a zero-sum game puts NWE in a unique position to coordinate and negotiate its way towards meeting the Paris Agreement ambitions.

- Being a first mover to act on a large scale in the introduction of low-carbon and carbon-free fuels can give NWE a technological advantage which benefits both the power and general (heavy) industry. With its combination of huge offshore wind potential, availability of gas infrastructure on the North Sea, excellent gas and power grids connecting the European mainland, and centrally clustered heavy industry, NWE is very well positioned to become a leader in the field of energy production and industrial use based on carbon-free fuels. If we miss out on this opportunity, other regions will pass us by and, over time, diminish the global role of NWE in the energy and industrial sectors. ■

2

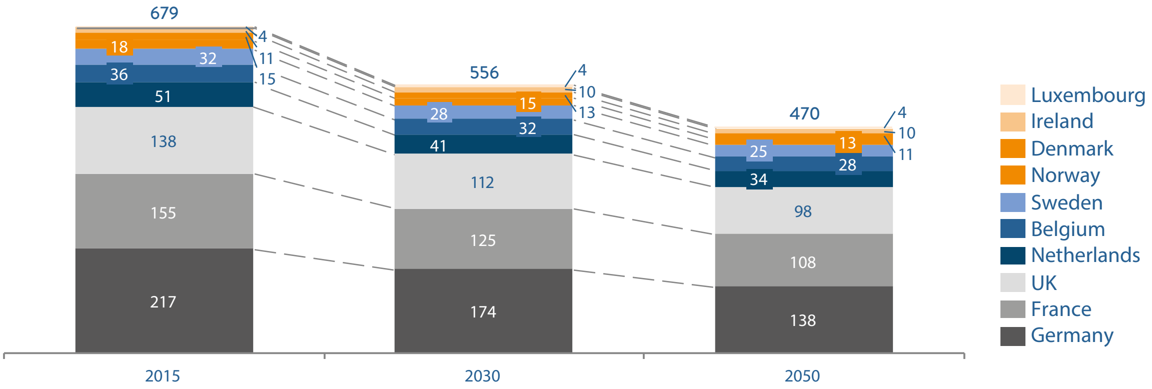
ENERGY SCENARIO

2.1. PATHWAY TO DECARBONISATION

A future energy scenario for the ten countries in scope was made for the purpose of this study[4]. This scenario is a normative trajectory, not a forecast. It shows the full extent of the changes in the NWE energy mix that are required to meet the deep decarbonisation targets of the Paris Agreement in 2050, under the premise of keeping the current level of industrial activity.

One of the key measures to decrease the level of greenhouse gas emissions is to limit the amount of energy used. This means that strong efficiency improvements are a first requirement. Measured in millions of tonnes of oil equivalent (Mtoe), the final energy demand should decrease by 31% over the period 2015-2050.

Figure 3: Final energy demand per NWE country in Mtoe



Over this same period, the gross domestic product (GDP) is expected to approximately double, mainly driven by an increase in GDP per capita as the overall population is expected to grow only slightly. As a result of this increasing GDP level, the energy intensity level (measured by gross inland energy consumption expressed over GDP) in NWE needs to fall even more, being over 60% during the period 2015-2050[5].

Driven by efficiency improvements and electrification, the lower final energy demand should translate into a fall of 36% in overall gross inland energy consumption between 2015 and 2050. This percentage is higher than the decrease in final energy demand of 31% mentioned earlier due to a lower level of losses during the production, conversion and storage of energy.

The fuel mix needs to change dramatically and become dominated by renewable energy forms. For NWE, these should consist mainly of carbon-free fuels (hydrogen) and green electricity, with the latter largely being generated by offshore wind farms located in the North Sea.

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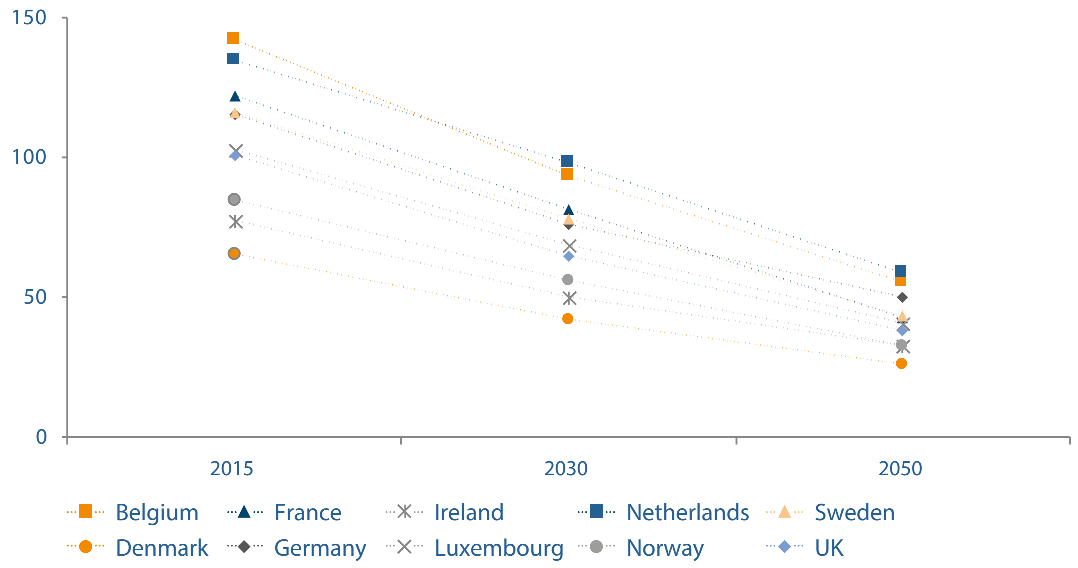
[4] In order to align with the goals of the European Union in general, we have based the scenario for the EU Member States (including the UK) on studies of the European Commission. For Norway, which is not a Member State and therefore was not included in these studies, we have constructed a scenario based on the extrapolation of historical data and other external sources. Please see appendix B for more details on the preparation of the scenario.

[5] The energy intensity level strongly varies among the individual countries due to the differing levels of industry, heating requirements, etc.

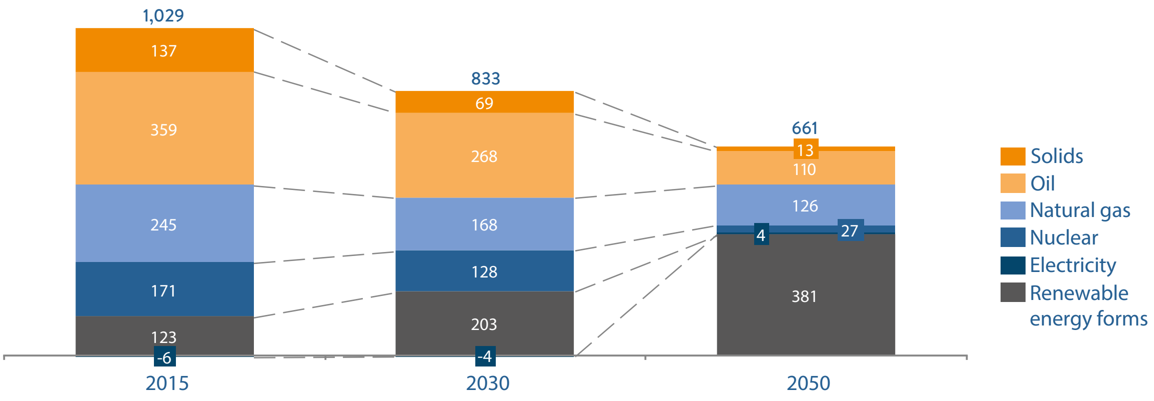
Figure 4: Energy intensity per country in NWE (gross inland consumption in Mtoe/GDP in EUR million)



The role of nuclear energy strongly diminishes after 2030 in our scenario. From a technical point of view, nuclear energy can certainly play a role in the decarbonisation of the energy supply in NWE; however, with the exception of France and the UK, the political and public debate is still quite negative with regard to the use of nuclear energy, as reflected among other things in the closure of the nuclear power plants in Germany. A larger role for nuclear energy has therefore not been further considered in this study.

The 72% share of fossil-fuel based energy observed in 2015 needs to decline to 37% in 2050. This remaining share of fossil fuels should contain almost no solids (coal). The share of oil should also be strongly reduced, mainly thanks to the electrification of transport. Natural gas may retain a relatively large share, mainly as a source for blue hydrogen.

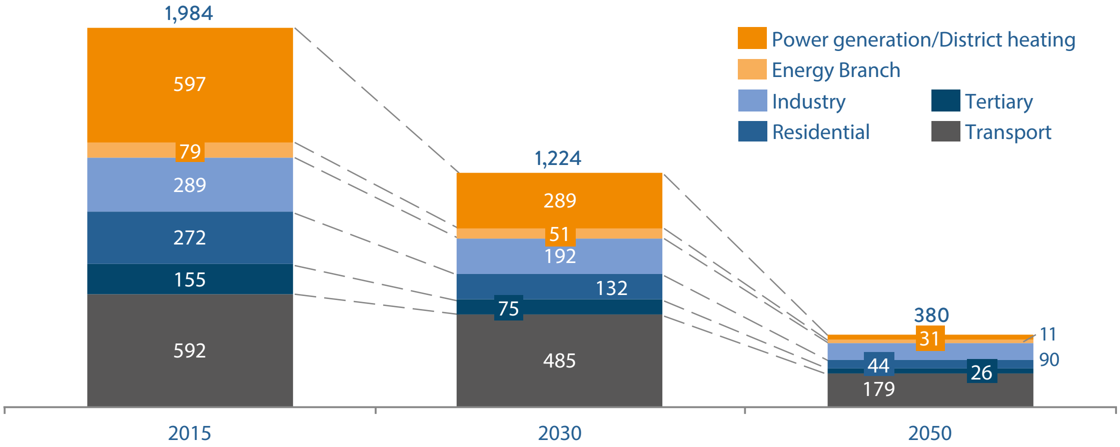
Figure 5: Gross inland energy consumption in NWE in Mtoe



2.2. EMISSION LEVELS OVER TIME

Efficiency improvements, electrification of power consumption, growth in renewable electricity generation and decarbonisation of fuel-based energy sources is expected to reduce CO_2 emissions by at least 80% compared to 2015.

Figure 6: CO_2 emissions in NWE (energy-related) in Mt[6]



The scenario is not to be considered as a static pathway, but rather as a broad guideline showing the main directions required to realise the goals of the Paris Agreement. Various ongoing developments will dictate further updates to these views over time. This is already reflected in the increase of the target for the reduction of greenhouse gas emissions specified in the European Green Deal put forward by the EC in December 2019 – the old target of a 40% reduction by 2030 (included in the scenario for this report) has been superseded by a substantially more ambitious new goal of 50-55%. Furthermore, the new plan aims for the EU to become climate-neutral by 2050, whereas the old target was for an 80-95% cut in emissions. To realise net zero emissions, either the energy mix will have to be fully decarbonised or the remaining CO_2 and other greenhouse gas emissions will have to be eliminated via CCUS and/or carbon sinks (forestation).

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[6] This graph excludes Norway, for which no data was available.

2.3. MAIN UNDERLYING DEVELOPMENTS

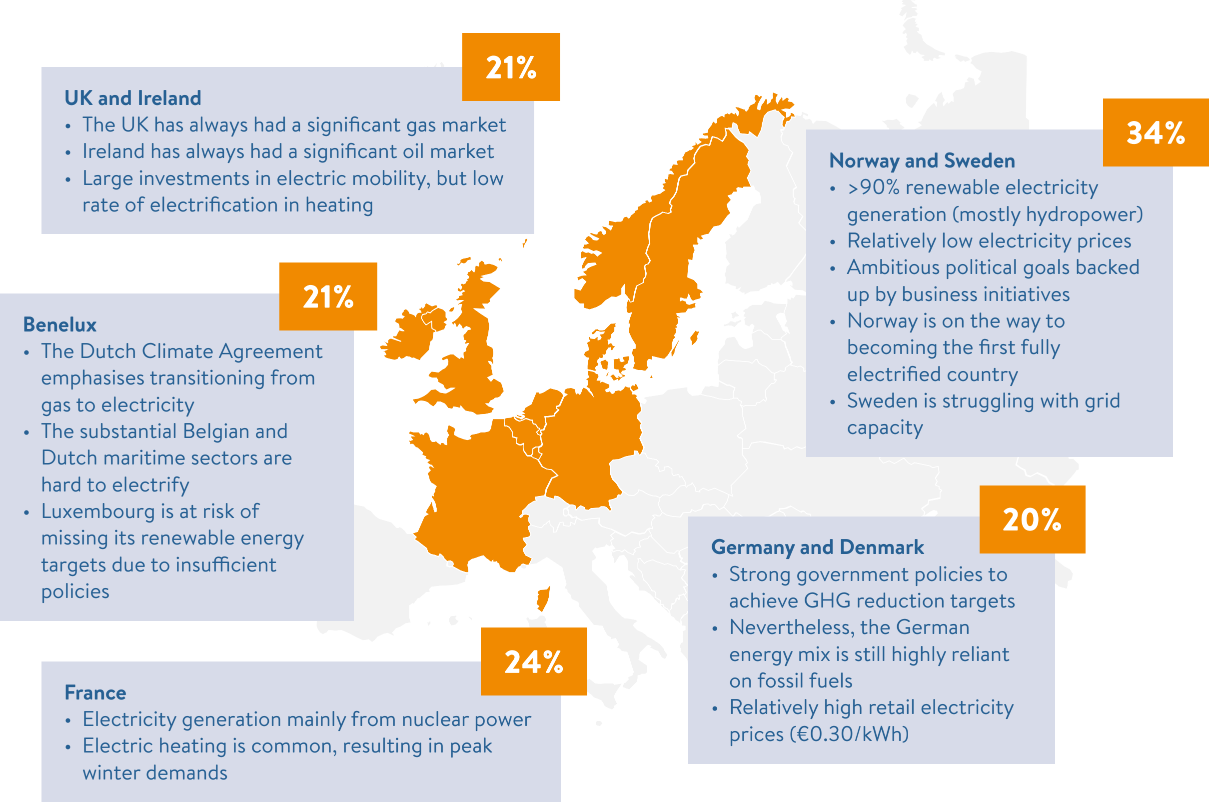
We expect that two main developments will underlie the radically changing energy mix in the leadup to 2050: the electrification of previously fuel-based energy processes and the decarbonisation of energy processes.

ELECTRIFICATION

The scenario used in this study presupposes a substantial increase in the use of electric power in all three major consumers of energy, namely industrial production, transport and the built environment. The electrification of energy demand is considered an important driver for decarbonisation. This will be achieved firstly by increasing the use of green electricity and secondly by increasing efficiency in the final energy use stage (electrical appliances generally lose relatively little power in the form of heat when converting between different types of energy). For instance, electric cars boast an efficiency of around 90%, while petrol cars have around 25%. It should be noted that this example only includes efficiency at the final conversion stage, however – electrification can lead to transmission and conversion losses (if the consumed electricity is temporarily stored first, for instance) that may lead to a less positive impact on the efficiency of the overall energy system.

The figure below describes the state of the electrification in each country.

Figure 7: Direct electrification rate in 2015 and background information



21%

UK and Ireland
- The UK has always had a significant gas market
- Ireland has always had a significant oil market
- Large investments in electric mobility, but low rate of electrification in heating

21%

Benelux
- The Dutch Climate Agreement emphasises transitioning from gas to electricity
- The substantial Belgian and Dutch maritime sectors are hard to electrify
- Luxembourg is at risk of missing its renewable energy targets due to insufficient policies

24%

France
- Electricity generation mainly from nuclear power
- Electric heating is common, resulting in peak winter demands

34%

Norway and Sweden
- >90% renewable electricity generation (mostly hydropower)
- Relatively low electricity prices
- Ambitious political goals backed up by business initiatives
- Norway is on the way to becoming the first fully electrified country
- Sweden is struggling with grid capacity

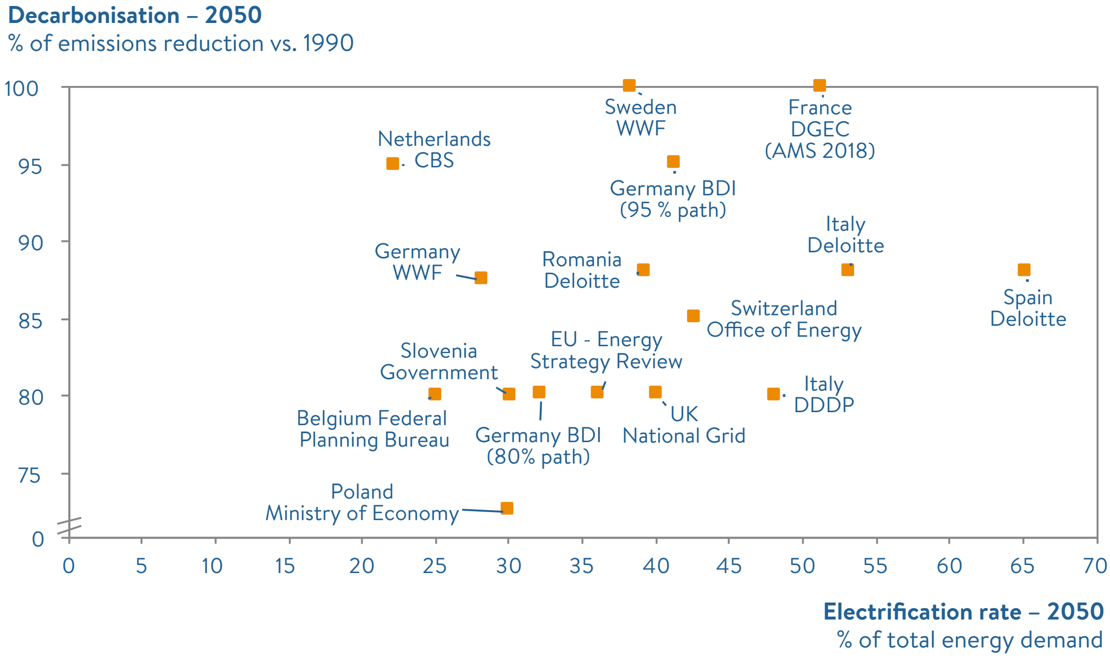
20%

Germany and Denmark
- Strong government policies to achieve GHG reduction targets
- Nevertheless, the German energy mix is still highly reliant on fossil fuels
- Relatively high retail electricity prices (€0.30/kWh)

The large share of renewable electricity (mainly from hydro) in Norway and Sweden has resulted in low electricity prices. This ameliorates the direct electrification business case. Especially Norway can be considered a leading country in the direct electrification trend.

Previous studies of various European countries have resulted in different approximations of the electrification rate as a percentage of the total energy demand. Figure 8 shows that the percentage of projected electrification in 2050 is not necessarily related to the projected emission reduction in 2050 versus 1990.[7]

Figure 8: Electrification versus decarbonisation



DECARBONISATION OF FUELS

The political and public debate on climate change mitigation has so far mainly focused on renewable electricity generation and a strongly increasing level of electrification. However, energy from fuels will remain a very large part of the future energy mix. Since there is no clear pathway yet on how to move to low-carbon or carbon-free fuels, it is very important to focus on this area in order to realise the CO_2 emission reduction targets.

Low-carbon fuels can be used to decarbonise the energy consumed by industrial production, transport and the built environment which would be technically difficult and/or costly to decarbonise through direct electrification. For instance, the demand for heating in buildings cannot be addressed by

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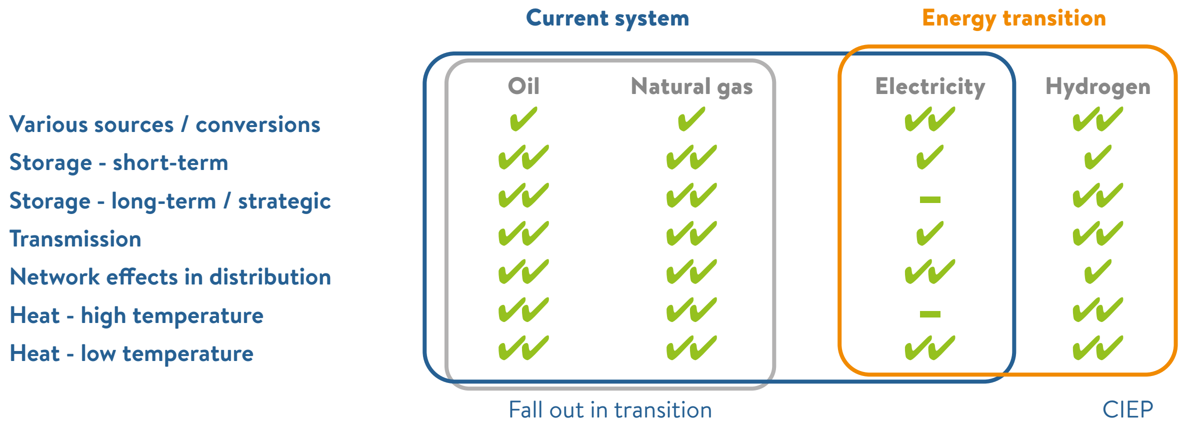
[7] Source for the figure: Decarbonisation pathways – full study results, Eurelectric, 2018

electrification alone. Meeting peak demand during cold periods would require capacity increases in the electrical grid which would be both technically challenging and very costly. In other words, it is strongly preferable to continue using physical fuels rather than electricity in certain cases.

The number of possible low-carbon fuels is limited. Hydrogen is the most promising option, although the business case for producing it is not yet viable without incentives. Given the decarbonisation targets and substantial required lead time, the large-scale deployment of a hydrogen economy would have to be prepared well in advance. Moreover, when the supply and demand of electricity do not match, as is often the case in a system with a large share of renewable electricity generation, a need for storage arises. The most viable solution for the longer-term storage of energy is in hydrogen-based energy carriers.

The graph below by CIEP displays a comparison of the system functions of the main energy carriers in the current system compared to a future system where hydrogen is the main physical energy carrier.[8]

Figure 9: System functions of energy carriers - current system and after transition



	Oil	Natural gas	Electricity	Hydrogen
Various sources / conversions	✓	✓	✓✓	✓✓
Storage - short-term	✓✓	✓✓	✓	✓
Storage - long-term / strategic	✓✓	✓✓	–	✓✓
Transmission	✓✓	✓✓	✓	✓✓
Network effects in distribution	✓✓	✓✓	✓✓	✓
Heat - high temperature	✓✓	✓✓	–	✓✓
Heat - low temperature	✓✓	✓✓	✓✓	✓✓

CIEP

✓✓ Well suitable
✓ Some limitations
– Limited

Each system role must be fulfilled to create a well-functioning energy system. Carriers with limitations in roles, but which complement each other, may be equivalent to a single well suited carrier for that role.

The most significant hydrogen applications so far have been deployed in the industrial sector, mainly for hydrocracking in refineries or as a feedstock for ammonia production. The most promising sector to kick-start the expansion in the use of hydrogen is also considered to be industrial production, for instance for high-temperature heating processes. Moreover, large-scale industrial implementation would ameliorate the business case for hydrogen in other sectors thanks to potential cost reductions enabled by concentrated large-scale production by a limited number of players (economies of scale).

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[8] Source: Van onzichtbare naar meer zichtbare hand? Waterstof en elektriciteit: Naar een nieuwe ruggengraat van het energiesysteem, CIEP, 2019

The methods for producing hydrogen are usually called grey, blue or green. The main form seen over the past decades is grey hydrogen production, which is based on the use of fossil fuels as feedstock (in NWE this is predominantly natural gas) and the steam methane reforming (SMR)[9] or autothermal reforming (ATR)[10] methods. These processes emit large amounts of CO_2. Blue hydrogen is produced in a similar manner; however, the carbon emissions are either eliminated through capture, utilisation or storage (CCUS)[11] or avoided by using bio-methane as the fuel source. Green hydrogen production is based on water electrolysis with renewable electricity or nuclear power as an energy source, and results in no direct carbon emissions. ■

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[9] SMR combines natural gas and pressurised steam to produce syngas, which is a blend of carbon monoxide and hydrogen

[10] ATR combines oxygen and natural gas to produce syngas. ATR technology is typically used for larger plants compared with SMR technology

[11] With SMR, about 60% of the total carbon can be captured directly by separating CO_2 from the hydrogen. The remaining CO_2 must be extracted from the exhaust gas, which is currently relatively expensive. Up to 90% of the CO_2 can be captured in total. ATR allows up to 95% of CO_2 emissions to be captured relatively easily.

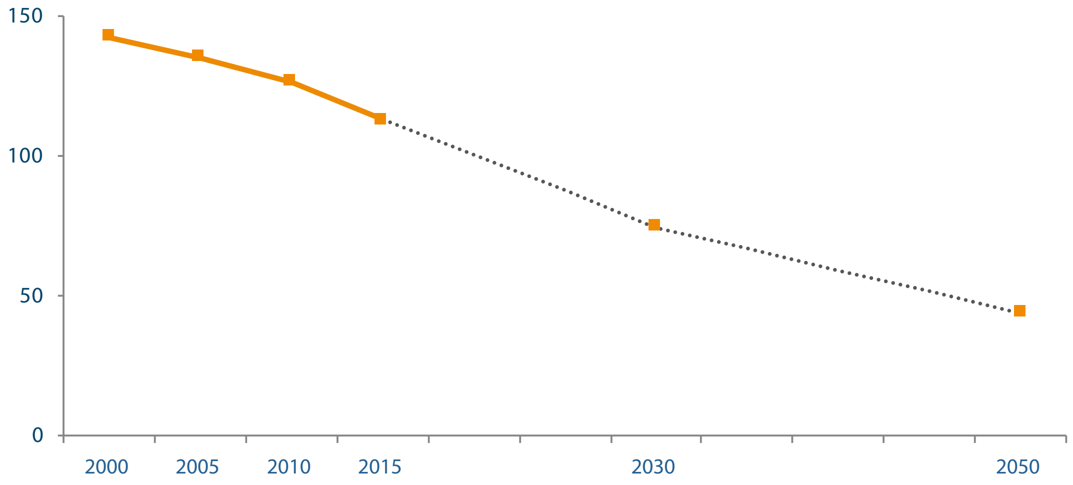
3

DEVELOPMENT OF DEMAND

3.1. EFFICIENCY IMPROVEMENTS

As discussed earlier, our scenario assumes that final energy demand in NWE will drop by 31%. To make sure that final energy demand decreases despite a growing GDP, it is important to ensure a continued decoupling between energy use and GDP growth. This will require a high level of electrification complemented by strong improvements in efficiency. While efficiency improvements are currently in the spotlight due to climate change mitigation, they have been important for NWE for a long time as the region has always been a net importer of fossil fuels.

Figure 10: Decoupling of energy demand from growth in NWE (gross inland consumption in Mtoe/GDP in EUR million)



The EC also considers efficiency improvements as one of the key developments required to realise the Paris goals. The EUCO 3232.5 forecast includes an efficiency improvement of 32.5% by 2030 compared to the baseline year of 2007[12]. Efficiency improvements have many effects and benefits. A higher level of efficiency leads to lower energy requirements and thus reduced emissions. The lower need for energy also leads to a drop in energy-related costs. Furthermore, there is less need for transport capacity for energy, which decreases the total costs in the energy system. An important issue to address, however, is that efficiency is a double-edged sword. The lower manufacturing costs and energy consumption of various appliances have been engines of economic growth throughout the 20th century, but have also led to increasing consumption of goods and energy[13].

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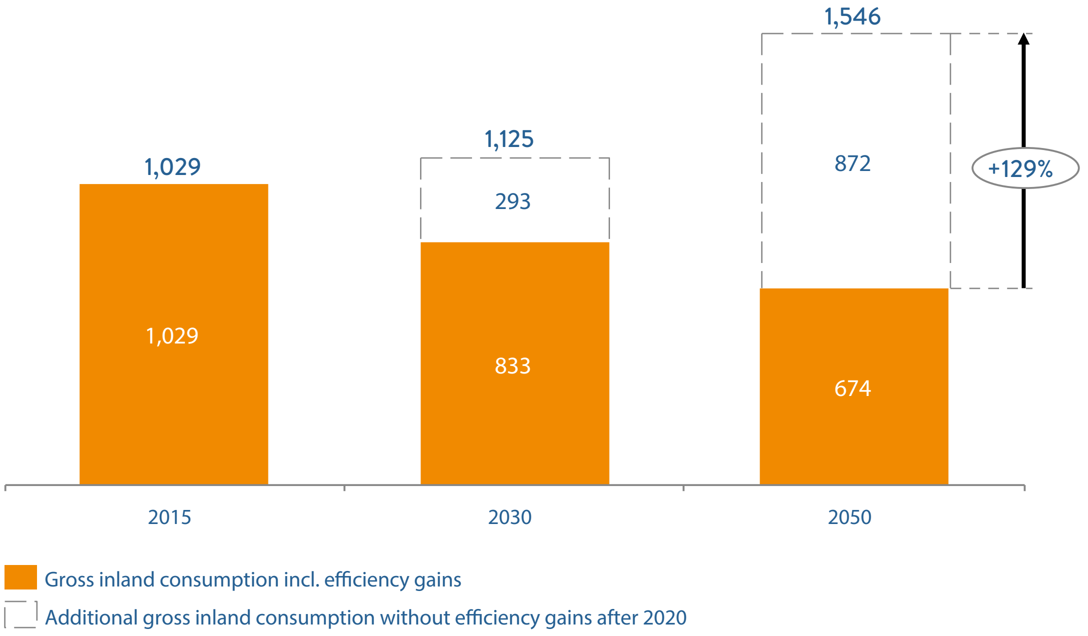
[12] See appendix B for more details on the EUCO 3232.5 scenario, which underlies our own scenario.

[13] Sky: meeting the goals of the Paris Agreement, 2018, Shell International B.V.

Figure 11 shows how energy demand would develop without any improvement in energy efficiency from 2020 onwards (gross energy consumption per GDP is assumed to be flat thereafter), indicating the critical importance of energy efficiency. Without any efficiency improvements, final energy demand in 2050 would be over 1,500 Mtoe, which is almost 230% of the demand resulting from our scenario. Realising efficiency targets is thus absolutely critical to realising the Paris Agreement goals. To ensure that enough renewable energy is produced to meet the demand specified in the scenario, including efficiency gains, it is generally assumed that all means must already be addressed. The most likely result of any increase in demand would therefore be that additional energy would have to come from high-carbon energy sources, which would have an enormous impact on CO_2 emissions.

Figure 11: Impact of energy efficiency gains in NWE on gross inland energy consumption in Mtoe

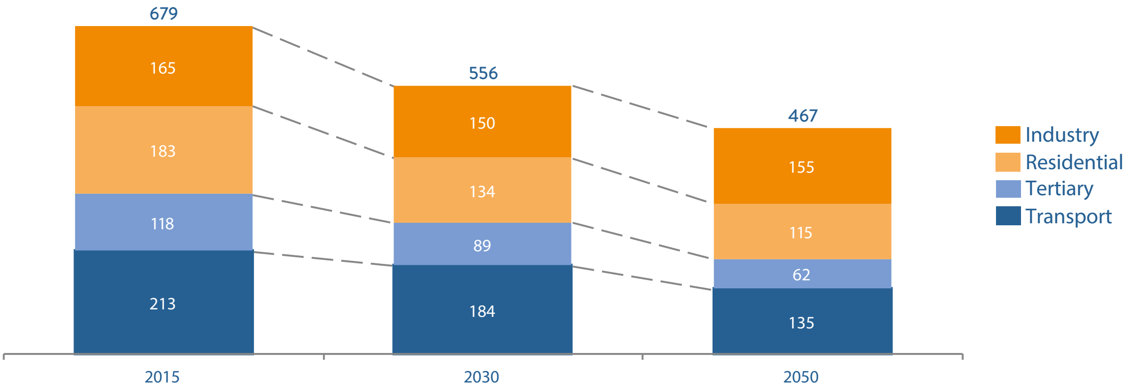


3.2. DEVELOPMENTS PER SECTOR

This section discusses the drivers behind the development of demand from industrial production, transport and the built environment (covering the residential and tertiary sector), while considering the required developments in electrification and efficiency improvements.

Figure 12 shows the development of final energy demand by sector over time.

Figure 12: Final energy demand in NWE per sector in Mtoe



The energy demand should decrease the most in the tertiary sector (49%), followed by the residential and transport sectors (both 37%). The fall in energy demand from industrial activities may be quite limited.

INDUSTRIAL ACTIVITIES

The decrease in energy demand from industrial production is expected to be limited due to the desire to maintain the current level of industrial activity and growth in GDP per capita. These developments, which will boost energy demand, will be partly offset by efficiency improvements in industrial processes. These will remain relatively limited, however, due to the relative lack of possibilities for a more energy-efficient electrification of processes. Low (below 100 °C) and medium-temperature (between 100 to 500 °C) processes can often be electrified (the first through heat pumps and the second through hybrid boilers, which accept both gas and electricity as fuel). The same cannot be said for heavy industry, which is one of the main users of energy in the form of high-grade heat (above 500 °C).[14]

The use of carbon-based feedstocks is another vital issue. Approximately 10% of the primary fossil fuel supply in NWE is currently used for non-energy purposes, almost exclusively in the form of coal, oil, and natural gas used as feedstock for industrial processes. As the demand for energy and feedstock in the industry is not expected to decrease, and electrification (and thus the use of green electricity) is not a realistic option for heavy and energy-intensive industries, it is crucial to have a strong focus on emission reductions specifically in this sector.

Although the possibilities for increasing energy efficiency are more limited in industrial applications than for the other sectors, this is still an important strategy for emission reduction. A higher level of automation is expected to lead to greater customisation and efficiency in the production of both base materials and finished goods. The evolution of the energy mix within industrial activities depends on technological innovation, resource availability and policy & economic incentives[15].

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[14] Decarbonization of industrial sectors: The next frontier, McKinsey, 2018

[15] Energy Transition Outlook (ETO), DNV GL, 2019

Where technically and economically feasible, industrial processes will be electrified to enable lower emissions. An important driver will be the cost of CO_2 and the need to reduce or prevent other harmful emissions. The evolution of investment costs and progress in the elaboration of new alternatives for industrial processes will also be important drivers of electrification and the greater uptake of (sustainably produced) fuel alternatives such as green gas, hydrogen and ammonia.

Next to efficiency improvements, the decarbonisation of energy carriers is a prime concern for industrial applications. As we discussed extensively in a previous report, we consider that the industrial sector in NWE is an ideal candidate for kick-starting the hydrogen economy[16]. The sector is already by far the largest producer and consumer of hydrogen, mainly in the form of feedstock in the ammonia/fertiliser industry and in refineries. The vast additional volumes of hydrogen needed to green industrial processes would enable the hydrogen economy to achieve a larger scale and reduce costs. Furthermore, heavy industry in NWE is strongly concentrated in a number of clusters, and emissions from industrial processes and product use are concentrated in just a few sub-sectors. The iron and steel industry generates the highest emissions from industrial energy use, followed by non-metallic minerals and the chemical sector. These three industries alone account for over 50% of all industrial energy emissions. While emissions are a major challenge, the fact that they are concentrated in so few industries makes it possible to effectively channel investments that foster the adoption of hydrogen.

The valley of death

A common characteristic of the evolution of new technology is that it passes a number of stages before reaching maturity, i.e. a technology readiness level (TRL) at which it can be considered commercially feasible. These stages are collectively commonly referred to as the valley of death as high risk and low returns initially provide few incentives for investors to step in. The typical components of the technology development cycle are the laboratory stage, the pilot stage and the demonstration stage. Each stage makes it possible to gain experience with the technology as costs decline towards maturity level. The drop in costs is due to learning (removing inefficiencies and achieving economies of scale as more devices can be produced and installed, which reduces their cost price, among others because fixed costs are divided over more units), upscaling (larger devices lead to cheaper production costs per unit of output) and, sometimes, international competition (e.g. competition from low-wage regions reduces monopoly margins that existed in earlier stages). As the valley of death is crossed, costs can come down considerably, sometimes within a very short period of time.

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[16] Hydrogen: Industry as catalyst. Accelerating the decarbonisation of our economy to 2030, World Energy Council Netherlands, 2019

Many hydrogen-related technologies are still in the early stages of technological maturity, in the sense that they have been technically proven and are being demonstrated on a relatively small scale. However, a roll-out on a much larger scale is required for them to operate in a cost-efficient manner. In other words, the technologies are in what economists call the valley of death of the technology curve. In Chapter 6 we propose a set of policy adjustments to stimulate the development and upscaling of hydrogen production and use, in order for hydrogen technologies to overcome this valley of death in the period leading up to 2030.

TRANSPORT

The main element in the decrease in energy demand in the transport sector is expected to be changes in the fuels used, with electrification of road vehicles as the largest factor. Furthermore, a steady further improvement in the efficiency of internal combustion engines should also boost efficiency improvements in road transport.

The widest adoption of electric vehicles (EVs) will be in the light-duty vehicle segment, which are best suited to direct electrification due to their generally short-distance trips and intermittent use, which allows for frequent charging between tasks. The development of self-driving mechanisms, which mitigate the impact of charging times (allowing cars to charge autonomously between rides), will further accelerate the adoption of electric mobility.

The growth of electric mobility is also essential for further electrification because electric mobility aids the integration of sustainable energy sources by helping balance the grid[17].

PASSENGER VEHICLES

The adoption of EVs in the passenger vehicle sector is expected to be fostered by public policies. The different categories are generally considered to be plugin-hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs) and fuel-cell electric vehicles (FCEVs). BEVs are more cost effective than internal combustion engine vehicles or PHEVs for most uses as they typically have a lower energy consumption and much lower maintenance costs.

Thanks to falling battery costs, overall cost parity is in sight. Further acceleration of the BEV uptake will, however, still require policy support in the near term; removing such support would reverse BEV uptake dynamics[18]. An example of a support measure is the recent EU vehicle carbon emissions reduction legislation, which stipulates severe penalties from 2020 onwards for car manufacturers if the average CO_2 emissions their vehicles produce in a given year are above 95 grams per kilometre driven. Producers of cars which emit less than 50 grams of CO_2 per kilometre driven will receive additional credits to encourage their use over cars with higher emissions. This will be a major incentive for vehicle

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[17] Electrification of the transport system, European Commission, 2017

[18] Testa and Bakken, A comparative, simulation supported study on the diffusion of battery electric vehicles in Norway and Sweden, 2018

manufacturers to offer electrical vehicles in the form of both PHEVs and BEVs. Over time, the latter are expected to become dominant. For instance, Volkswagen anticipates that 40% of its sales will come from BEVs in 2030[19].

Additionally, automated driving of passenger vehicles will contribute to increased asset utilisation. The number of vehicles will likely decrease strongly, but their utilisation rate will be much higher. As a result, asset lifetimes (in years) will decrease, leading to faster renewal of the fleet. This will further drive the uptake of emerging battery technologies and help reduce fuel consumption in all passenger vehicle segments.

FCEVs are not currently expected to reach a significant share of passenger vehicle road transport. This is mainly because the conversion of electricity to hydrogen results in significant efficiency losses and a lower drivetrain efficiency compared to BEVs. Furthermore, FCEVs require a more complicated propulsion technology, in addition to batteries that are still substantial (albeit smaller than those used by BEVs), further driving up the costs. The disadvantage of FCEVs with respect to BEVs will make the former less attractive in most segments, except for heavy and long-haul transport[20].

COMMERCIAL TRANSPORT

The uptake of electric commercial vehicles will take more time. There is a wide variety of vehicle characteristics in this segment, ranging from buses, which can be electrified relatively easily (relatively low weight, short distances, long stopping times), to long-distance heavy trucks, which are less well-suited to drivetrain electrification.

FCEVs for commercial transport uses are expected to reach the market in significant numbers after 2030. The distribution of hydrogen as vehicle fuel will probably mirror the use of hydrogen as heating fuel in the same regions, and having a distribution network in place will also enable FCEV uptake[21]. Another advantage is that the arrival and departure locations of this category of transport are often located around specific hubs, ensuring that the development of hydrogen infrastructure is more concentrated and likely more economical.

AVIATION

Aviation is often still ignored by climate change policies and emission targets. As the emissions in this sector are hard to reduce, aviation-related emissions may come to represent a much larger share of total emissions. More policies to decrease such emissions should therefore be enacted.

While it is theoretically possible to electrify aircraft, only a small share of short-haul flights are expected to ever become electrified, and only in the longer term. Biofuel blends, which include synthetic kerosene in which the carbon is sourced from biomass, are expected to make a more significant

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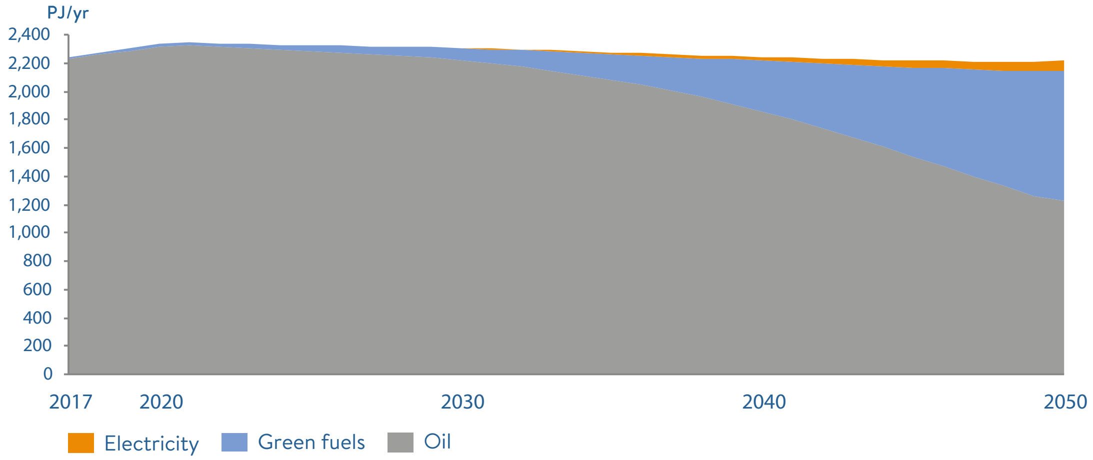
[19] https://zerauto.nl/volkswagen-ongeveer-70-elektrische-modellen-rond-2028/
[20] Energy Transition Outlook (ETO), DNV GL, 2019
[21] Energy Transition Outlook (ETO), DNV GL, 2019

contribution to the reduction of emissions in aviation. DNV GL estimates that the European fuel mix for aviation will contain over 40% green fuels by 2050, whereas electricity will only account for 5%, as shown in the figure below[22]. The strong growth in biofuels is expected to be driven by a combination of technological advances and successful decarbonisation policies.

Figure 13: European aviation energy demand



RAIL

The decarbonisation push will likely also give a boost to rail travel between the major cities in NWE, as this already-electric and efficient mode of transportation will be promoted to replace short-haul aviation trips covering up to several hundreds of kilometres. To facilitate this development, rail connections will have to be improved and upgraded to high-speed connections wherever possible. Another thing to consider is the fact that rail passenger transport offers space efficiency that is superior to that of other options, especially in urban areas[23]. The increasing level of urbanisation will therefore also boost rail passenger transport over other options.

SHIPPING

Electric propulsion offers important potential for the inland and short-sea transport distances typically encountered within NWE. Efficiency improvements can be achieved through a mixture of logistics and hull and engine efficiency measures. Switching from using only oil as a fuel, which is currently the case, to a mix of electricity, natural gas (mostly LNG) and hydrogen in 2050, should be encouraged by increasing carbon prices, as well as regionally imposed decarbonisation efforts[24]. The future fuel mix for the shipping industry in Europe as estimated by DNV GL is shown in figure 14[25].

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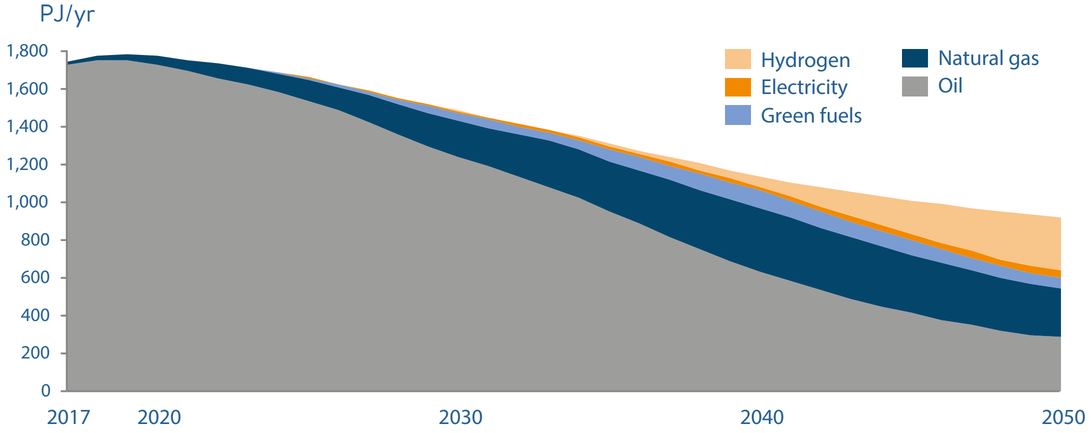
[22] Energy Transition Outlook (ETO), DNV GL, 2019
[23] Energy Transition Outlook (ETO), DNV GL, 2019
[24] Energy Transition Outlook (ETO), DNV GL, 2019
[25] Energy Transition Outlook (ETO), DNV GL, 2019

Figure 14: European maritime energy demand



BUILT ENVIRONMENT

The expected fall in energy demand from the built environment will be due both to lower energy use (thanks to developments like better isolation, more efficient appliances, etc.) and to electrification, as electric solutions in general suffer from much lower thermal losses and therefore have a higher level of efficiency.

The main use of energy by households in NWE is for residential heating. In Europe overall, heating constituted 64% of the final energy consumption in the residential sector in 2017[26]. The first topic to address in heating is better insulation as this directly reduces the amount of energy required for the same level of warmth and lowers emissions. Furthermore, a certain minimum level of insulation is often required for electric heating or the use of heat pumps, and insulation is also often among the most cost-effective measures.

Interior heating can use a range of energy sources: natural gas is the most common, accounting for 36% of the final energy consumption in the residential sector in Europe[27]. Other options include electric heating, solar water heating, district heating and geothermal energy.

In addition to electrification and district heating, natural gas in heating is expected to be replaced by hydrogen. There are a range of pilot projects on the use of hydrogen for residential heating currently underway in places like the Netherlands[28] and the UK[29]. Thanks to the existing natural gas distribution

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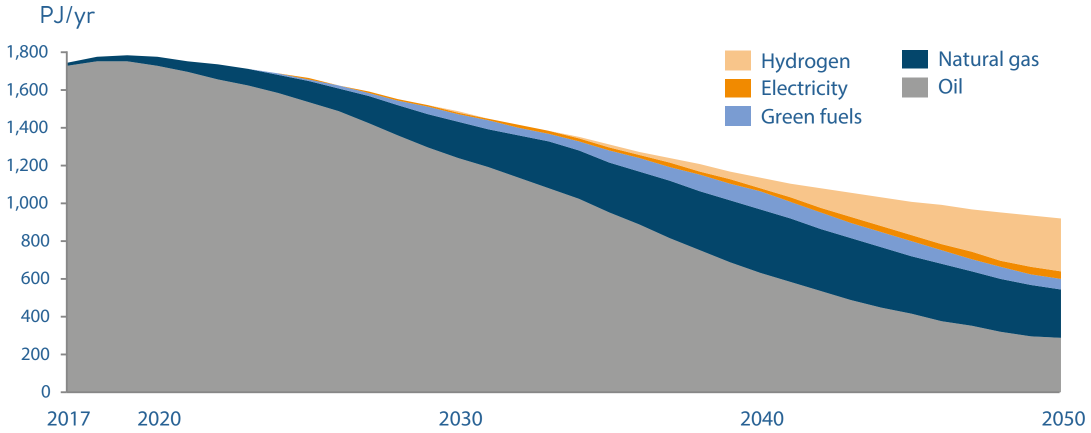
[26] Eurostat, May 2019: https://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_consumption_in_households
[27] Eurostat, May 2019: https://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_consumption_in_households
[28] See: https://fuelcellsworks.com/news/heating-with-hydrogen-worlds-first-hydrogen-powered-domestic-boiler-pilot-project-in-the-netherlands/
[29] http://www.climateaction.org/news/uks-first-grid-injected-hydrogen-pilot-gets-underway

networks in NWE, which can relatively easily be adapted to the use of other gases, the conversion to hydrogen is a viable alternative. Another advantage is the avoidance of the complexities related to installing hybrid heat pumps into old buildings. The figure below shows DNV GL's estimation of future hydrogen demand for the purposes of the built environment in Europe[30].

Figure 15: European hydrogen demand in buildings



The application of solar water heaters in individual buildings also has huge potential to make the provision of more sustainable low-temperature heat (up to 60-70 degrees Celsius) available to households and businesses. Rooftop solar thermal panels that can heat up water for residential use in NWE (particularly the Netherlands) have a heat production capacity of around 1.5 GJ/m^2. In addition to allowing them to generate electricity through solar PV, such rooftop installations enable households to meet part of their own heat demand, especially when combined with an extra heater for periods of low sunlight. Such solutions can even be scaled to entire neighbourhoods or towns by connecting all rooftop or ground-based resources, including a local heat buffer[31].

The main energy source for appliances and lighting in the built environment will continue to be electricity, mostly from grid-connected sources. For other appliances and end uses, electrification and lower use of natural gas are two obvious coming (large-scale) transitions. As alternative fuels become more available and affordable, there will be a switch from traditional water heating with natural gas towards a greater use of renewable energy sources, including green gas, biofuels, hydrogen and direct solar water heating.

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[30] Energy Transition Outlook (ETO), DNV GL, 2019

[31] See for example: https://stateofgreen.com/en/partners/ramboll/solutions/large-scale-solar-heating-and-seasonnal-heat-storage-pit-in-gram/. Another example can be found in the Prinsejagt neighbourhood in Eindhoven, the Netherlands.

The ongoing general digitalisation of societies will require more electricity to power both data centres and an increasing number of connected devices. On the one hand, the solutions offered by digital controls and communication systems will help improve the efficiency of processes and communication and reduce transportation needs (e.g. for meetings). On the other hand, the vast growth in IT infrastructures and use will increase the need for electricity.

3.3. FACTORS INFLUENCING HYDROGEN DEMAND

The decarbonisation of future energy systems will be achieved through the use of hydrogen in a wide variety of end markets. Even though there is a consensus that demand for hydrogen will increase, it is hard to estimate the level it will ultimately reach as that will depend on a range of external factors, such as the acceptance of alternative renewable energy options, the implementation of CCUS, and the political climate. A short overview of the most important factors influencing future hydrogen demand, based on the HyChain-I study conducted by ISPT[32], is given below.

AVAILABILITY AND ACCEPTANCE OF BIOMASS

The first important factor is the availability and social acceptance of biomass. Biomass is an attractive option for large-scale use as a feedstock (i.e. methanol, refineries) in industrial processes and for heating. However, it is not clear how much biomass can be made available for heating and as feedstock without affecting food production. The level of social acceptance related to this solution is also unclear. Then there is the issue of biomass being in competition with hydrogen for use as feedstock and heating. The large-scale availability of biomass will be a crucial factor in the future demand for hydrogen and there has been an ongoing debate on the use of biomass as a renewable energy source. The result of this debate, its political consequences and the resulting acceptance of biomass a as renewable energy source will have a direct influence on the use of low-carbon hydrogen within the industry.

LARGE-SCALE USE OF CCUS

A second important factor affecting future hydrogen demand is the availability and acceptance of CCUS options. Many observers are critical about the use of CCUS as a solution for decarbonisation. They argue that the use of CCUS can create a lock-in mechanism for the continued use of fossil fuels, limiting the development of green alternatives. On the other hand, large-scale acceptance and use of CCUS could also boost the use of hydrogen since CCUS can help facilitate a relatively low-cost transition from carbon-intensive to low-carbon hydrogen. The costs of producing hydrogen via electrolysis are currently still significantly higher than via SMR or ATR, so switching to low-carbon hydrogen via the deployment of CCUS can help develop the hydrogen market and reduce electrolysis production costs. The large-scale use and implementation of CCUS may therefore be an important factor to kickstart the low-carbon hydrogen economy.

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[32] HyChain I, Energy carriers and Hydrogen Supply Chain: Assessment of future trends in industrial hydrogen demand and infrastructure, ISPT, 2018.

POLICY FRAMEWORK

The third critical element influencing future hydrogen demand is the political framework around the energy system. This includes all government regulations and measures affecting the current fossil fuel-based energy market and the future renewable energy market, which determine the cost-competitiveness of fossil fuels compared to renewable energy. For example, the introduction and level of a local CO_2 tax in addition to the current EU-ETS system would influence the costs of fossil fuel-based energy production. However, if governments decide to embrace a renewable energy system, which they will be strongly encouraged to do by the European Green Deal, they will foster a renewable energy market and help further develop a comprehensive renewable energy system – for example by subsidising renewable energy production (lowering electricity prices) and encouraging the hydrogen market. Hydrogen demand will ultimately be affected by the political climate around renewable energy: the hydrogen market will thrive if governments, both local and European, facilitate its operation with subsidies and regulations aimed at developing a low-carbon energy system. Governments limiting their investments in renewable energy will have a direct adverse effect on final hydrogen demand in the future.

OTHER FACTORS INFLUENCING FINAL HYDROGEN DEMAND

The development of a large-scale hydrogen market will also be influenced by other factors, including technological developments throughout the hydrogen value chain, safety regulations on hydrogen use in different sectors, the state of the overall economy (low economic growth can limit investments) and investments in both the electricity and gas grid. ■

4

SUPPLY OF ENERGY CARRIERS

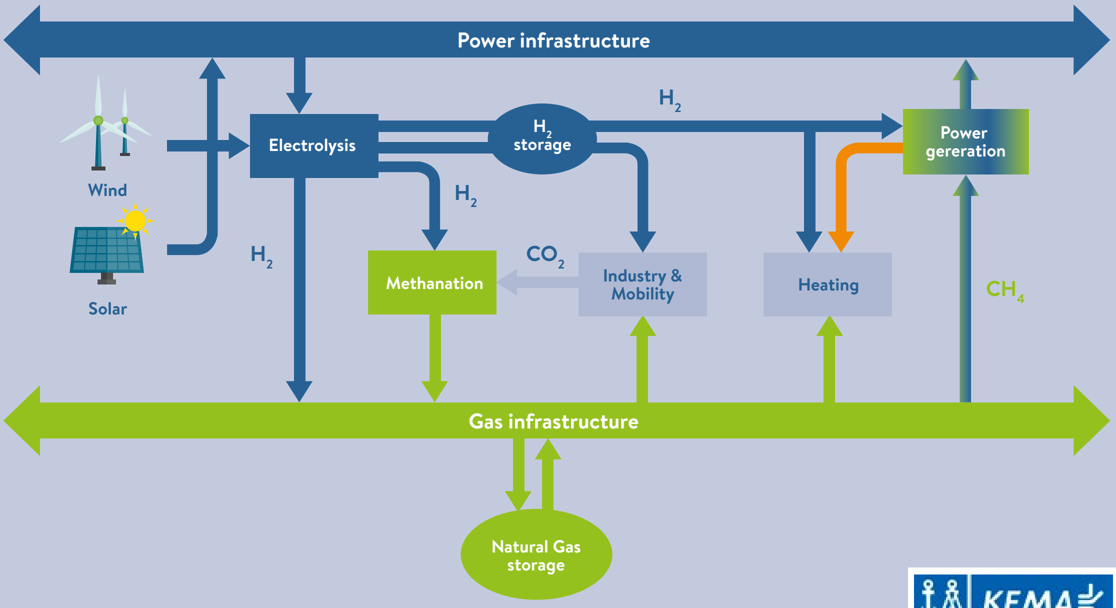
The most important factors affecting the supply of energy carriers required for the future energy mix will be the installation of renewable energy generation and the supply of low-carbon fuels. The limited natural resources in NWE means energy imports are expected to remain high.

With respect to renewable energy generation within NWE, offshore wind is seen as having the most potential. Among physical energy carriers, the options considered the most viable for the future are low-carbon hydrogen and other green gases produced through power-to-gas processes. Natural gas will also continue to play an important role for the foreseeable future, both in direct use and for conversion into carbon-free hydrogen.

POWER-TO-GAS (PTG)

The decarbonisation of both the electricity and gas sectors faces a range of challenges. Green electricity generation cannot always match demand and the electricity grid will be stretched to its limits as further intermittent renewable power generation is integrated. Decarbonisation plans have so far been relatively limited for the gas sector, hindering its possible role in a highly or even fully decarbonised energy system. PtG offers a possible solution to both challenges by allowing excess electricity to be converted into carbon-neutral hydrogen and/or methane, and the fact that it can be powered by dedicated renewable electricity sources. The figure below provides a schematic overview of PtG, showing its interlinking of power and gas infrastructures.

Figure 16: Schematic overview of PtG



Source: ENTSO-G, 2020 scenario methodology report

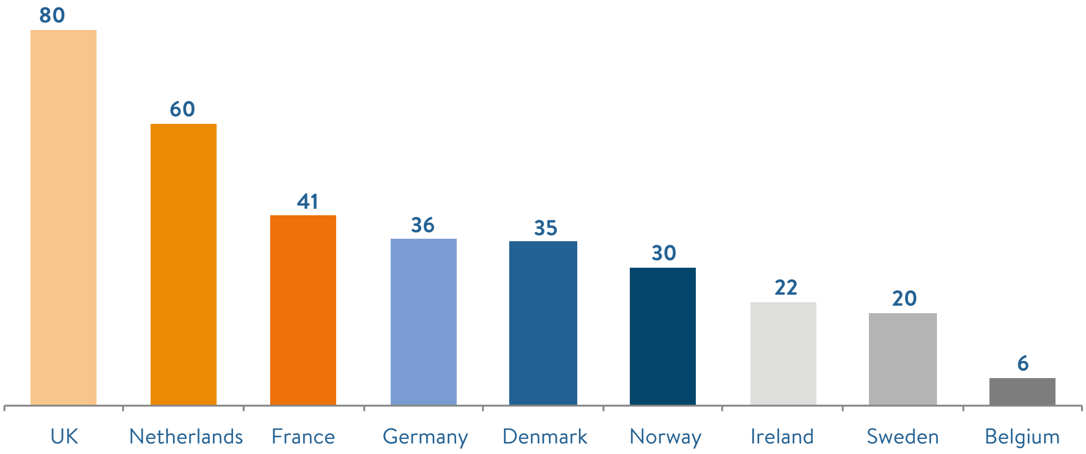
4.1. THE OFFSHORE WIND POTENTIAL OF THE NORTH SEA AS AN ENERGY HUB

The proximity of the North Sea provides NWE with excellent opportunities for the development of offshore wind – one of the crucial pillars in the future energy mix required to realise the Paris Agreement goals.

The expected total capacity installed by 2050 will range somewhere between 180 GW[33,34,35] and 212 GW[36], depending on how large an area is developed. Some 134 GW of capacity is also expected to be installed in the Atlantic Ocean, Baltic Sea and/or Mediterranean Sea for the electricity demands of NWE[37]. The total resulting capacity of around 346 GW would meet around 60% of NWE's electricity demand in 2050[38] (which will be 250% of its 2015 level due to electrification)[39].

Figure 17 provides an overview of wind capacity per country suggested by a Windeurope report[40]. This overview includes the North Sea, Baltic, Atlantic and Mediterranean.

Figure 17: Installed offshore wind power capacity in NWE by 2050 in GW



Some 60% of the offshore wind capacity that will be installed in NWE by 2050 will be developed in the North Sea, which has excellent wind resources and the lowest supply chain costs of all the seas bordering NWE thanks to its proximity to demand. Taking into account the current restrictions (e.g. environmentally protected areas), the average levelised cost of energy (LCOE) for offshore wind across

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[33] Cost Evaluation of North Sea Offshore Wind Post 2030, Witteveen+Bos, 2019

[34] Modular hub and spoke, North Sea Wind Power Hub, 2017

[35] Translate COP21: 2045 outlook and implications for offshore wind in the North Seas, Ecofys, 2017

[36] Our energy, our future: How offshore wind will help Europe go carbon-neutral, Windeurope, 2019

[37] Our energy, our future: How offshore wind will help Europe go carbon-neutral, Windeurope, 2019

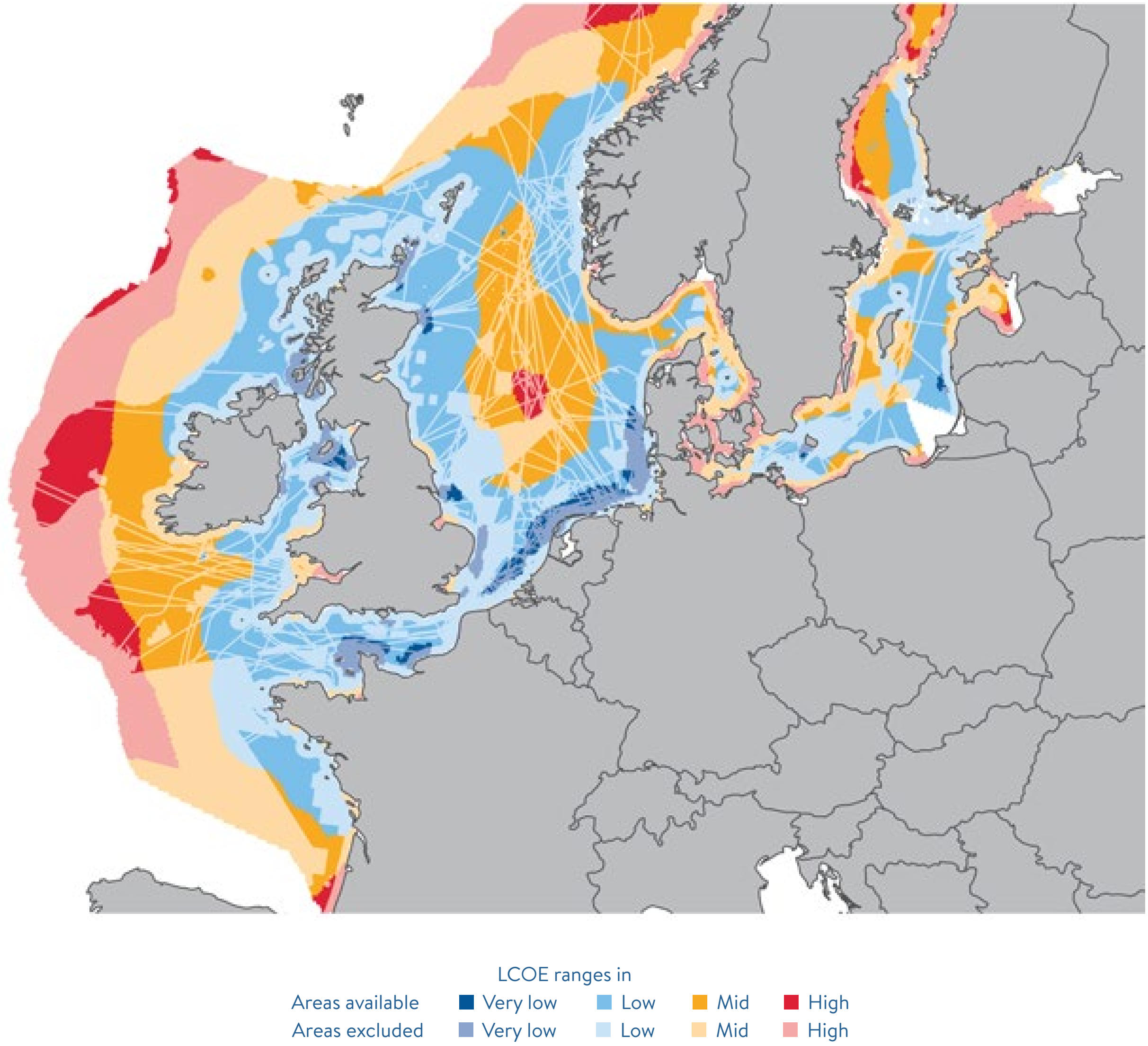
[38] The net generation capacity was calculated assuming 50% efficiency and 5,000 annual load hours.

[39] Note that electricity demand may include the demand for electricity for hydrogen production.

[40] Our energy, our future. How offshore wind will help Europe go carbon-neutral, Windeurope, 2019

NWE (including the Atlantic Ocean, Baltic Sea and Mediterranean Sea) is in the range of €50-55/MWh. Figure 18 from Windeurope indicates the LCOE and the resulting potential for offshore wind power expansion in the various areas[41]. LCOE estimates for the North Sea are within a lower bandwidth of about €40/MWh – although it is important to note that this includes areas currently closed to wind park development[42].

Figure 18: LCOE for offshore wind power generation in northern Europe (with spatial exclusions)



Source: WindEurope-Our-Energy-Our-Future report

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[41] Our energy, our future. How offshore wind will help Europe go carbon-neutral, Windeurope, 2019

[42] Cost Evaluation of North Sea Offshore Wind Post 2030, Witteveen+Bos, 2019

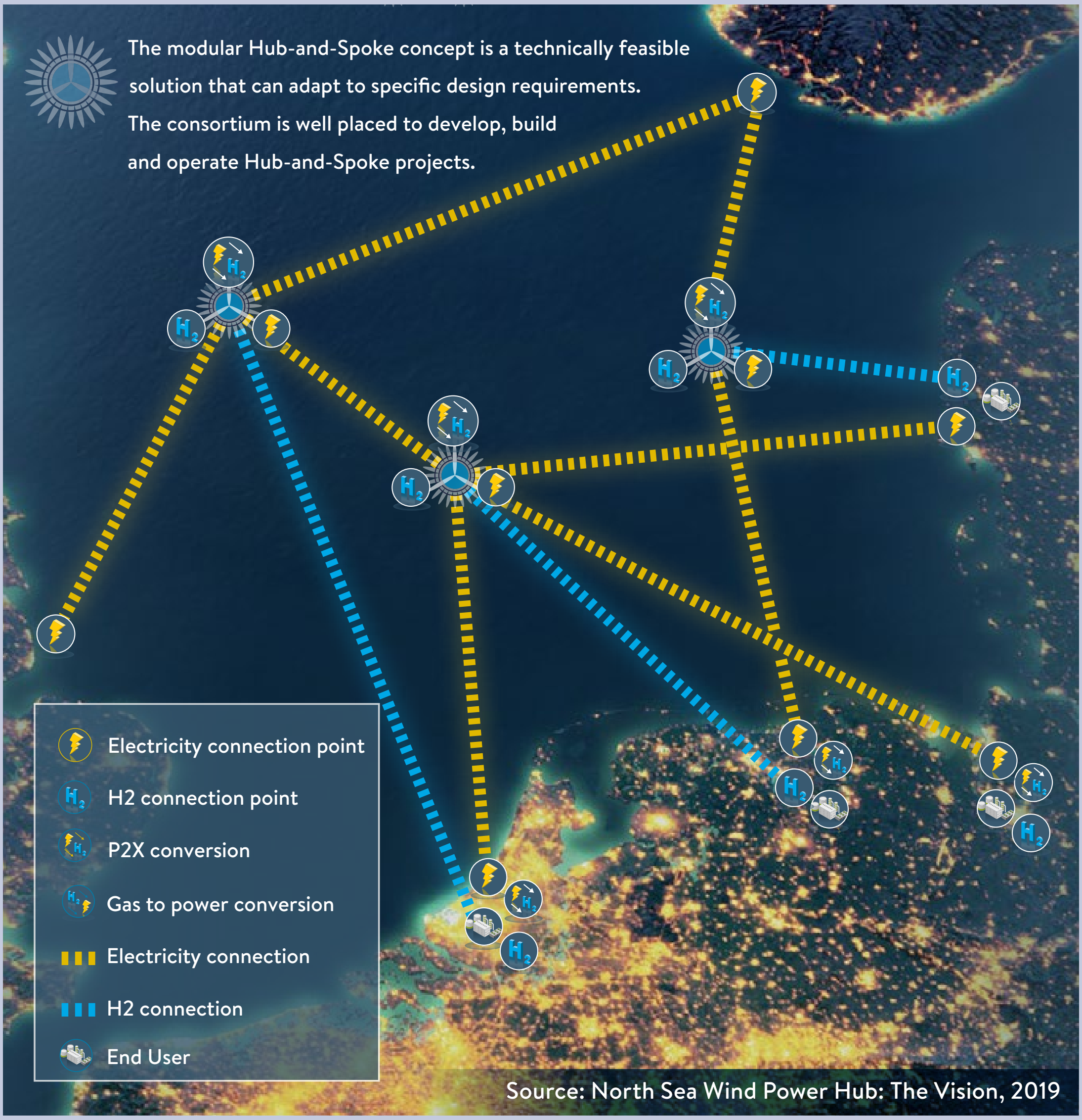
NORTH SEA WIND POWER HUB

A consortium consisting of the Port of Rotterdam Authority, Gasunie, TenneT and Energinet is working on a plan called the North Sea Wind Power Hub. This concept plans to make full use of the North Sea's potential through the realisation of a series of islands which will act as energy hubs where renewable electricity can be bundled, stored and – where required – converted into physical fuels via PtG. The consortium sees the modular hub-and-spoke concept as an important phase in the step-by-step integration of large shares of offshore wind energy into the wider regional energy system, as opposed to the current radial and incremental approach. The key benefits includes:

- Ensuring a cost-effective and timely ramp-up of offshore wind energy;
- Providing flexibility so as to adapt each project to location-specific needs; and
- Enabling offshore wind integration and ensuring the flexibility of the energy system through interconnections and sector coupling.

The image below shows an overview of pipeline routes that are expected to become feasible for the transport of hydrogen from far offshore wind farms after 2030.

Figure 19: Possible infrastructure for hydrogen and electricity



Source: North Sea Wind Power Hub: The Vision, 2019

4.2. NATURAL GAS PRODUCTION AND IMPORTS

In our scenario, natural gas demand in NWE is forecasted to gradually decrease by approximately 50% between 2015 and 2050. Natural gas production in NWE is currently largely dominated by Norway, which is the only net exporter of gas in the region. Natural gas is also produced elsewhere in the region, mainly in the UK and the Netherlands[43].

As a result of the fast decline in the Groningen field production, combined with the mature status of offshore gas production in the North Sea, natural gas production in NWE is expected to decrease. The net result of the fall in both demand and local production will mean that import needs for natural gas in NWE countries other than Norway will remain roughly unchanged as a percentage of total gas consumption in the period from now to 2030. From 2030 to 2050, NWE countries other than Norway are expected to import almost all the gas they consume. The supply of natural gas from Norway is expected to decrease steadily over time in parallel with the expected decline in the production levels of the Norwegian gas fields[44].

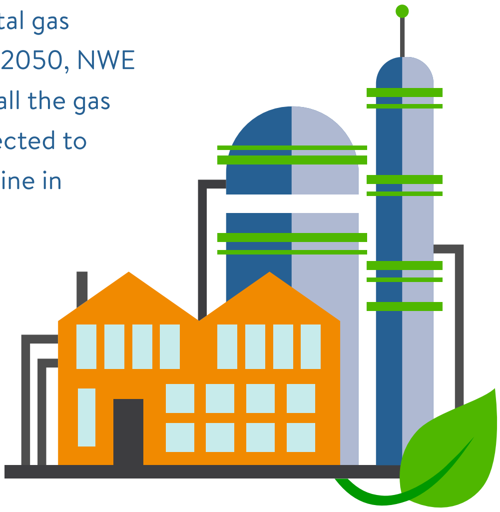
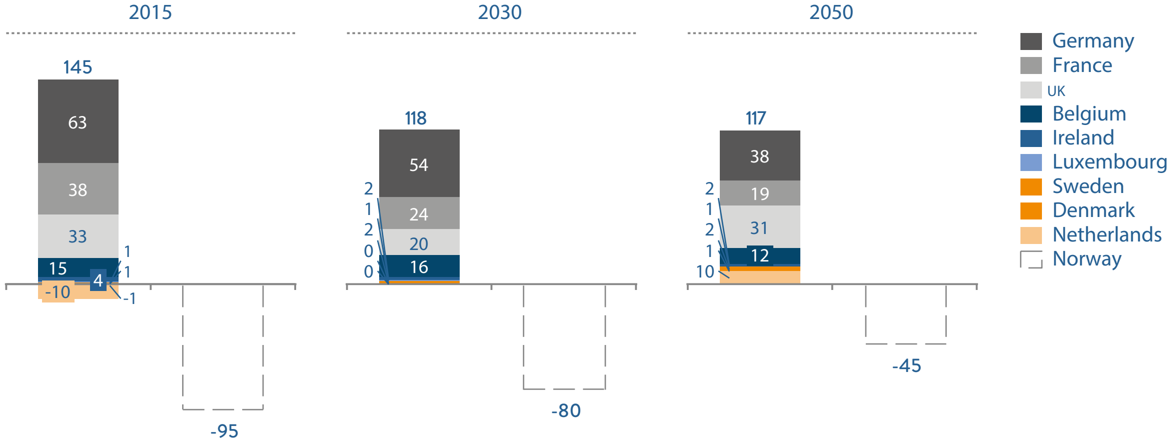


Figure 20: Net import of natural gas in Mtoe



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[43] BP statistical Review, CIEP, 2017

[44] 'Equinor expects the Norwegian oil and gas production to be less than half of the current levels by 2050', https://www.nsenergybusiness.com/news/equinor-greenhouse-gas-emissions/

Russian imports could fill the growing demand-supply gap. If Russian gas remains competitive compared to other sources of gas, EU-wide gas imports from Russia could rise to about 195 billion cubic meters (bcm) in 2020 before dropping to 170 bcm in 2025[45] – still some 35-60 bcm more than the 2015 level. Europe is, however, also trying to diversify its gas imports. This will lead to an increase in LNG shipments from overseas, which will be combined with new investment. For instance, Germany's Minister for the Economy and Energy Peter Altmaier has indicated that it is likely that at least two of the three proposed LNG terminals in Germany (Brunsbüttel, Stade and Wilhelmshaven) are likely to be built within the foreseeable future[46]. The creation of two LNG terminals would increase new import capacity by some 12-16 bcm[47].

The expected stability in gas demand does not, however, imply that the carbon content of gas will remain at a similar level. Biogas and hydrogen could be admixed to natural gas to increase the sustainability of NWE's gas consumption. A spatial analysis of biogas potential from manure in NWE indicates that up to around 10 bcm could realistically be produced per year[48].

4.3. RENEWABLE ENERGY IMPORT AND COSTS

Meeting the increasing demand for renewable energy in NWE in 2030 and 2050 will require substantial imports of renewable energy. This will take place via two routes:

- In the form of electricity via long electricity cables; or
- As physical fuels via pipelines or ships.

In general, the import of energy in the form of physical fuels is less expensive (considered in €/kW/km) and more efficient than via electricity cables. Furthermore, the gas grid has much more capacity than the electricity grid in NWE. This means that even if the import of electricity is more cost-efficient, mainly for short-distance transport, the electricity grid has limited capacity, which could only be expanded at the cost of major investments. This means that the import and use of physical fuels will remain a crucial part of the future energy mix in NWE.

Moreover, if the hydrogen economy in NWE is to develop strongly, the local production of low-carbon hydrogen may need to be supplemented by large-scale imports. The success of a hydrogen economy in NWE will encourage other countries to expand their exports of hydrogen to Europe.

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[45] Outlook for gas imports from new suppliers into the EU to 2025, CIEP, 2016

[46] https://www.reuters.com/article/germany-lng/update-1-germany-set-to-have-at-least-2-lng-terminals-minister-idUSL5N2072W1

[47] https://eurasianventures.com/liquefied-natural-gas-in-germany

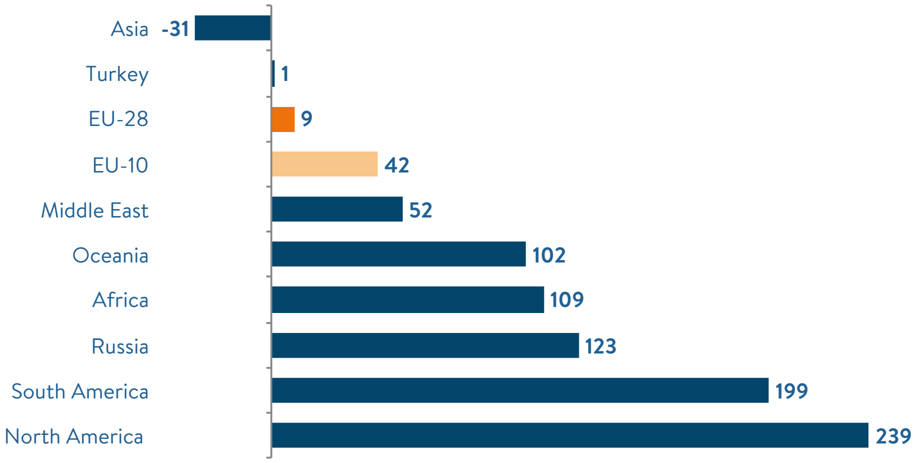
[48] Biogas: Developments and perspectives in Europe, Scarlat, Dallemand & Fahl, 2018

[49] Hydrohub HyChain 2: Cost implications of importing renewable electricity, hydrogen and hydrogen carriers into the Netherlands from a 2050 perspective, IPST, 2019

SUPPLYING COUNTRIES

There are several countries with excellent geographical conditions for becoming major producers, and net exporters, of renewable energy. As shown in the graph by ISPT below, the greatest export potential in terms of volume can be found in North and South America, and, closer at hand, in Russia and Africa[49].

Figure 21: Energy export potential by 2050 in PWh/year



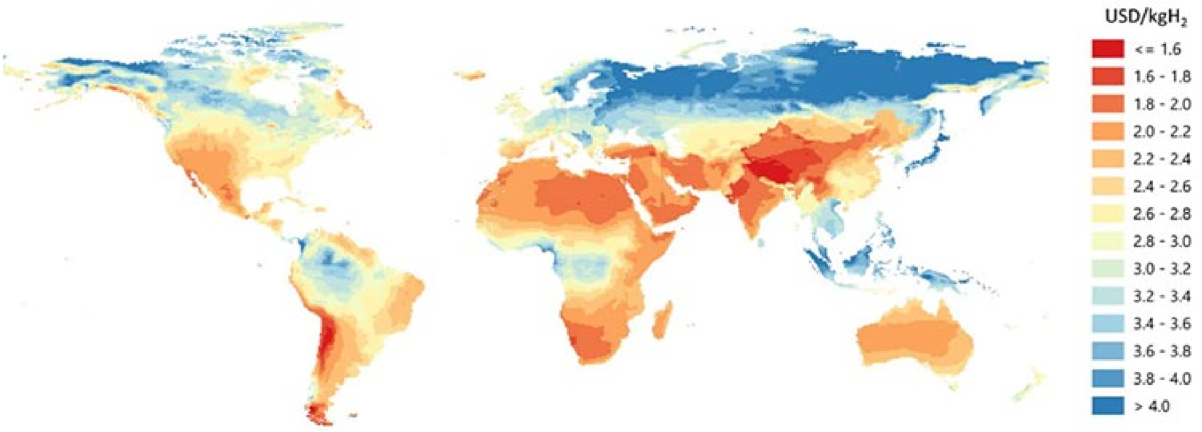
The export of electricity or fuel from other EU countries to NWE is expected to remain minor, although some is likely to originate in southern Europe (e.g. Spain & Portugal). Although Asia has a high potential for renewable energy production thanks to its excellent conditions for the production of solar power, its export potential is relatively small due to the immense growth in energy demand expected within the region itself.

Of course, production is not the only factor that determines the energy export potential of countries: the costs of transport to the final demand markets are of equal importance. The transport of energy to NWE can take multiple forms. At shorter distances, electricity can be transmitted via the high-voltage direct current grid, while greater distances mean that energy carriers like hydrogen, liquid organic hydrogen carriers (LOHCs), ammonia or methanol become more cost-efficient.

GREEN HYDROGEN PRODUCTION AND IMPORT COSTS

The costs per kg of green hydrogen strongly depend on access to cheap and reliable sources of green electricity, decreasing capital expenditure costs thanks to scaling and the learning effects of electrolysis technology, as well as the investment climate across countries[50]. The International Energy Agency (IEA) mapped the production costs for hydrogen from solar energy in several regions; the results are shown below[51].

Figure 22: Long-term costs of producing hydrogen with hybrid solar PV and onshore wind systems



Countries that benefit from high solar irradiance (North Africa, South Asia, Oceania, southern North America and southern South America) have potential access to a great deal of cheap electricity and could produce hydrogen for prices ranging between €1.4 and €1.8 per kg[52]. Similarly, regions that are abundant in high wind speeds (like NWE) could also produce green electricity at low cost.

The IEA indicates that the transmission and distribution of hydrogen gas by pipeline is cheaper than by ship for distances below approximately 1,500 km[53]. The transport of hydrogen via ship is possible if different carriers, such as LOHC and ammonia, are used: this may even lead to lower transport costs. Figure 23 by the IEA shows that energy carriers like LOHC and ammonia involve lower transportation costs[54].

The Hydrohub HyChain 2 study conducted by ISPT developed a high-level cost-based model which looks at different routes by which renewable energy can be imported into the port of Rotterdam by 2050[55]. The model includes the costs of the entire value chain of electricity production, conversion to hydrogen (or other hydrogen-based carriers[56]) and the transport of either electricity or physical fuels to Rotterdam. The total cost of import from individual countries is compared to the reference costs of producing hydrogen via electrolysis using renewable energy in the Netherlands in 2050, which are estimated to be approximately €3/kg hydrogen.

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[52] Based on an exchange rate of 0.9 USD/EUR.

[53] The Future of Hydrogen, IEA,2019.

[54] The Future of Hydrogen, IEA, 2019

[55] Hydrohub HyChain 2: Cost implications of importing renewable electricity, hydrogen and hydrogen carriers into the Netherlands from a 2050 perspective, IPST, 2019

[56] These include ammonia (NH3), formic acid (FA), methanol (MeOH), dibenzyltoluene (DBT), which is a liquid organic hydrogen carrier (LOHC), sodium hydrogen bromide (NaBH4), dimethylether (DME), oxymethylene ether (OME), liquid natural gas (LNG) and liquid H2 (LH2). The most cost-efficient options are ammonia, dibenzyltoluene (DBT) (a LOHC) or sodium hydrogen bromide (NaBH4). Ammonia and DBT are the most attractive options because a large part of the current infrastructure can be repurposed to transport them as hydrogen carriers. Sodium hydrogen bromide can be an attractive alternative to NH3 and/or DBT; however, technological development is required before it can be implemented on an industrial scale.

Figure 23: Comparison of transport costs for various energy carriers in USD/kg H_2

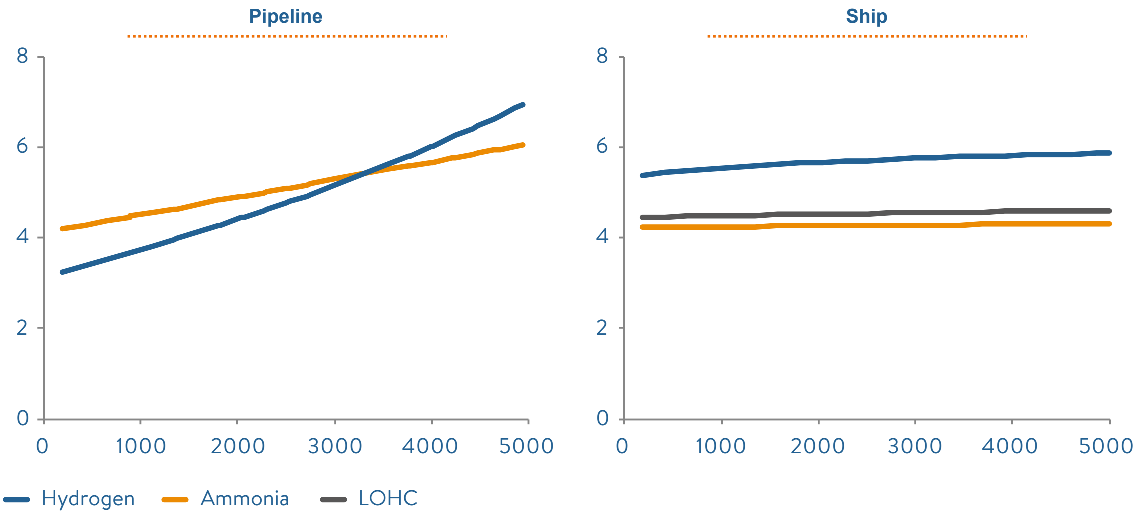
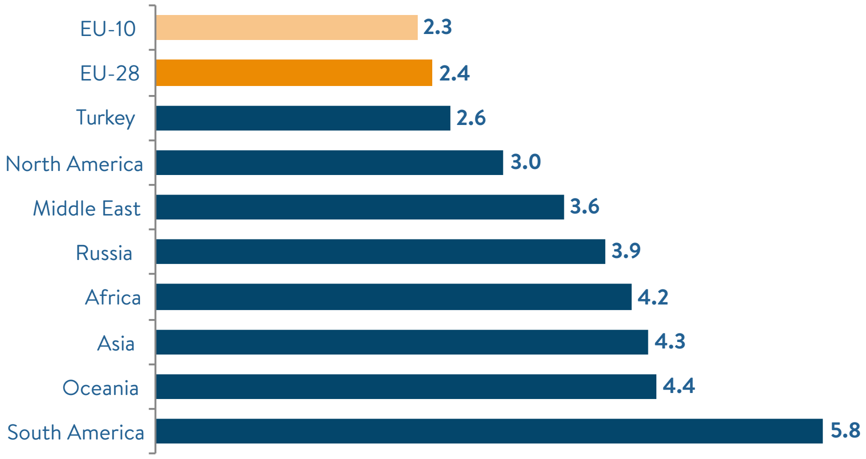


Figure 24 shows the average prices in the more than 150 countries included in the analysis. The main message is that, although electricity and hydrogen may be cheaper to produce in other regions, local production may be preferable in many cases when we take into account the price of transporting imports. This analysis suggests a regional green hydrogen price of €2.30 in NWE. The study also shows that the price of hydrogen per country within NWE varies between €2.1/kg (UK) and €2.9/kg (the Netherlands).

Given that domestic production within NWE may not be sufficient to cover all demand, hydrogen import is likely to be required at any rate. Among major potential sources of imports, North Africa and the Middle East are found to have the lowest costs (southern Europe and Turkey are less expensive still, but their expected export capacity is very limited, as shown in figure 21).

Figure 24: Costs of producing hydrogen and transporting it to Rotterdam in €/kg H_2



IT IS PARTLY TRUE THAT THE DEPENDENCY ON FUEL IMPORTS WILL FALL IN THE COMING YEARS, BUT THIS SHOULD NOT BE OVERESTIMATED: AS A PERCENTAGE OF TOTAL ENERGY CONSUMPTION, THE DEPENDENCY OVER TIME WILL REMAIN COMPARABLE TO CURRENT LEVELS.

It is important to note that the development of a large-scale dedicated hydrogen pipeline network within NWE will be a time-consuming process. The Netherlands is looking at converting one of its existing gas pipelines to a dedicated hydrogen backbone, although this is the only such initiative within NWE. The challenges facing the development of an integrated hydrogen pipeline network mean that the import of hydrogen via ship will have to account for a substantial share of the energy in a renewable energy system.

4.4. SECURITY OF SUPPLY CONSIDERATIONS

In its 2018 study on Europe's energy relations, the Clingendael International Energy Programme (CIEP) noted that European energy policy-making has often been a reaction to singular events, such as the 1973 oil crisis, the 2006 and 2009 Ukraine gas crises, and the 2011 Fukushima nuclear incident[57]. The authors also observed that energy policy is often shaped by legacies related to national endowments in natural resources and industrial assets and to long-standing political-economic relations. Since energy policies are often centred around the security of supply, which will be strongly impacted by the energy transition in many ways and over a long period, the countries in NWE should try to adopt a more stable, long-term and forward-looking approach to their energy policy.

Security of supply is an important goal of the EU's 2015 Energy Union Strategy, which aims to provide EU consumers with secure, sustainable, competitively priced and affordable energy. To do so, the strategy proposes to build five pillars, the first of which relates to security, solidarity and trust. It moreover stipulates that a focus on diversifying energy sources and ensuring energy security should be ensured through solidarity and cooperation between EU countries.

DEVELOPMENTS OVER TIME

NWE energy markets have undergone a large degree of liberalisation over the past decades. This process followed a period during which neoclassical economic thinking and politics were ascendant. The last years of the 20th century were also characterised by intensive globalisation and enduring cooperation between international political and economic institutions[58].

Since then, the world has seen the gradual formation of economic blocks which compete with each other for markets and resources. An example of this movement can be observed in the oil sector, which has transitioned from a globalised situation to one of strong supply connections between specific regions.

This higher level of international competition and its effects on the security of supply do not seem to be reflected in the political and public debate in Europe. Over the past years, this debate has mainly focused on greening our electricity system with local renewable generation and the issue of Russian gas.

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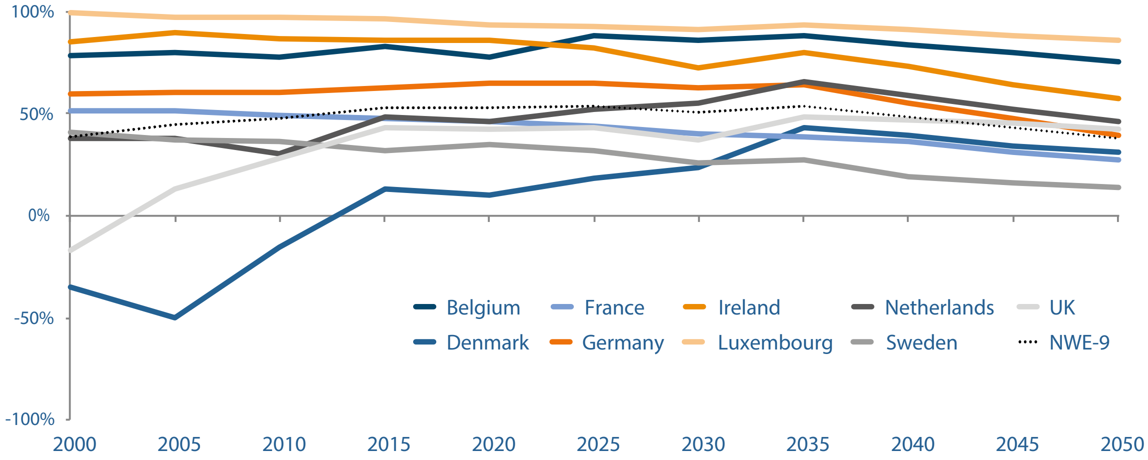
[57] Europe's Energy Relations: Between legacy and transformation, CIEP, 2018

[58] Europe's Energy Relations – Between legacy and transformation, CIEP, 2018

As a result, there seems to be a general impression that our dependency on fuel imports will somehow decrease and discussions around the security of supply – which is for the most part related to physical fuels – have become less prominent. This process has also been marked by a shift in the duration of contracts for energy imports in several countries in NWE, which have become more focused on spot markets instead of long-term contracts which provide more supply security over longer periods of time.

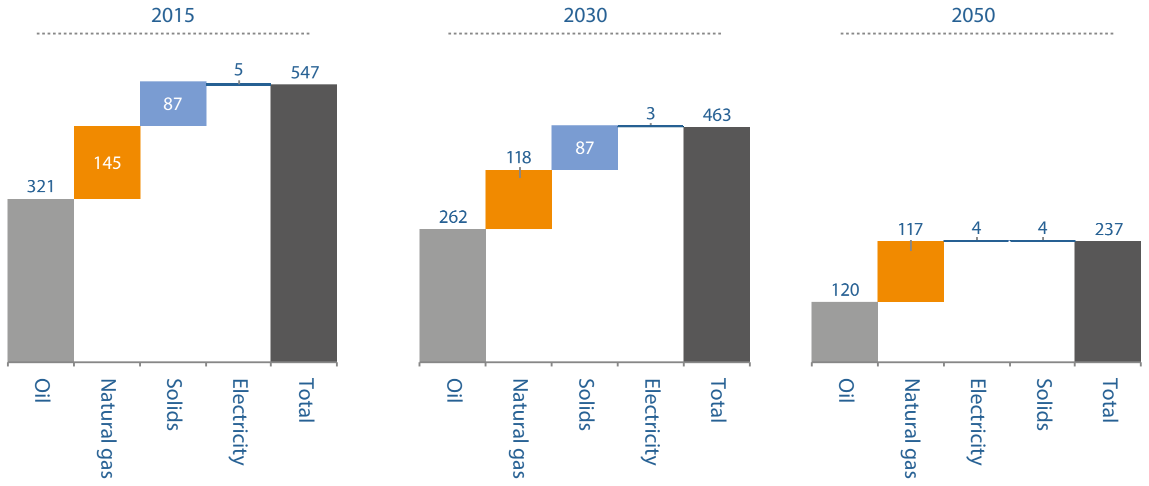
It is partly true that the dependency on fuel imports will fall in the coming years, but this should not be overestimated: as a percentage of total energy consumption, the dependency over time will remain comparable to current levels.

Figure 25: Import dependency (excluding Norway)



Thanks to projected efficiency improvements, the increasing level of electrification and more local production of green electricity, which will replace other domestic sources such as coal (in Germany) and natural gas (in the UK and the Netherlands), the actual amount of energy to be imported will in fact decline over time. In other words, in absolute terms the future energy mix may indeed feature less (imported) fuel than is currently the case; however, in the long-term imported fuel will continue to be a very large part of NWE's energy mix. The gradual decline of the absolute import dependency is shown in figure 26.

Figure 26: Net import by fuel in Mtoe (excluding Norway)



An increasing share of hydrogen in the future energy mix of NWE may replace some of the natural gas demand and imports. This substitution should reduce dependency on individual suppliers as hydrogen can be produced from many different sources and in many different regions. However, this development will take a considerable period.

There are also several factors which have the opposite effect and therefore call for a stronger focus on the security of supply. One important fact is that Europe has been investing relatively less effort in its relationships with energy suppliers due to its decreasing focus on the long-term supply of physical fuels. Given the strong increase in the importance of China and India as energy-importing countries, this may lead to a decline in the attention paid by energy-exporting countries to Europe. That in turn could result in lower investments in generation assets and transport infrastructure oriented towards Europe, negatively affecting the future security of supply and possibly increasing the future costs of energy import. Moreover, due to the diminishing significance of NWE as an energy-importing region and as an economic bloc in general, additional non-monetary costs may be imposed by countries before they agree to supply energy in the future.

In addition to the direct relationships NWE has with its suppliers, there are also indirect effects of these mechanisms. Southern Europe, for instance, is dependent on energy supply from Northern Africa, which suffers from a degree of political instability that poses a threat to the security of supply. Given inter-European solidarity agreements, this also implies risks for NWE. ■

5

INFRASTRUCTURE FOR THE TRANSPORTATION, CONVERSION AND STORAGE OF ENERGY

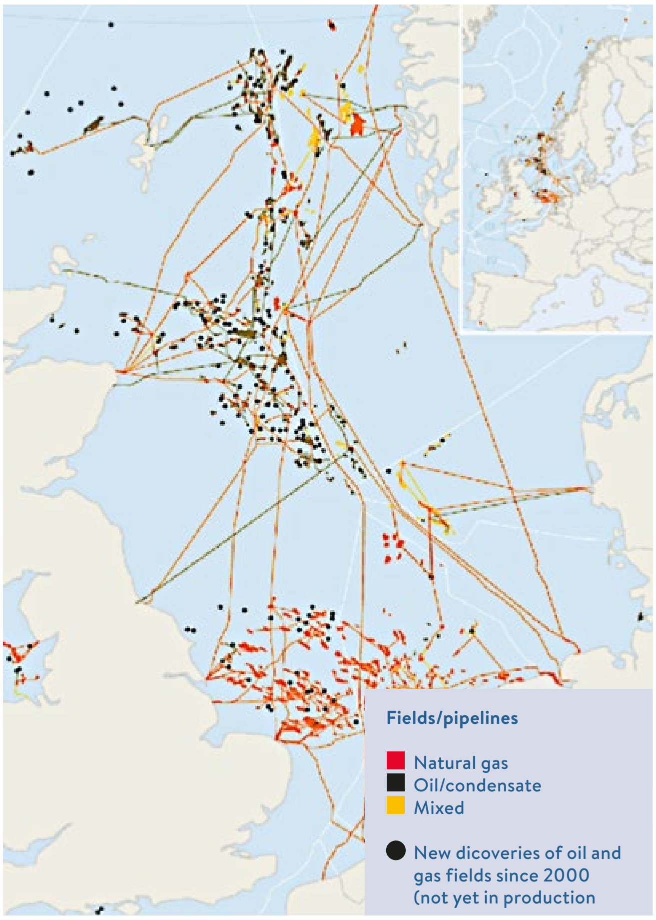
TSO and DSO networks are currently large technological systems with many stakeholders, governed through regulations and a few institutions with a large influence on and responsibility to society. This means that changes to the system must, by definition, be not only technical but also societal and economic.

The future energy mix will be more electric as well as having a greater dependence on decentralised assets. The current transmission and distribution systems have historically served a different purpose and not been designed to sustain the current increase in electricity demand, power fluctuations and number of power producers. This transition therefore requires large-scale adjustments to the energy infrastructure and, if not carefully executed, may result in an unstable grid and high societal costs.

5.1. INFRASTRUCTURE REQUIRED TO REALISE THE POTENTIAL OF THE NORTH SEA

The North Sea has been a major oil and gas producing basin since around 1970. A total of some 1,300 offshore infrastructures, fixed and floating platforms, and subsea installations have been installed over the intervening years. The oil and gas produced is transported to shore via a large-scale offshore pipeline network with a total length of 50,000 km. Of this network, about 3,500 km is located in the Netherlands and 20,000 km in the UK. Since oil and gas production in the Netherlands[59] and the UK is in steep decline, a significant portion of the capacity of the transport infrastructure can be expected to become available for new uses over the next decade.

Figure 27: European offshore pipeline grid and interconnections between countries surrounding the North Sea



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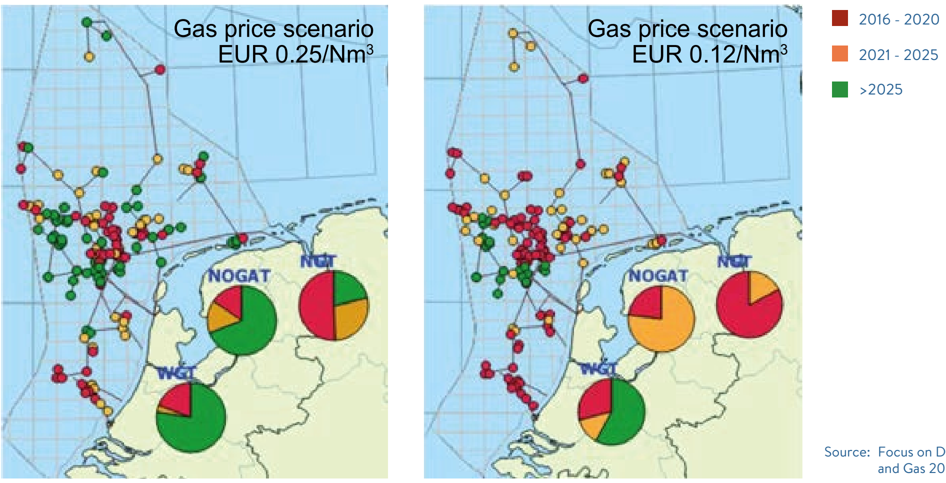
[59] The gas production in the Dutch part of the North Sea has dropped by more than half between 2004 and 2018, going from 29 BCM to 11.3 BCM. Source: FD.nl, 3 February 2020, “Not one gas field discovered in the North Sea in 2019”

Energie Beheer Nederland (EBN) has stated that a structurally low gas price of 12 ct per standard cubic metre would result in most of the existing gas fields becoming uneconomical. This would free up substantial pipeline capacity, including the main trunk lines in the Netherlands NOGAT (from Den Helder to the Doggerbank area), NGT (from Eemshaven to the K/L blocks) and WGT (from Den Helder to the UK border). In the UK, the first offshore pipeline systems in the southern North Sea area have already been taken out of service because gas production has ceased.

Figure 28: EBN estimation of decline in the used capacity of major trunk lines in the Dutch sector[60]

COP of infrastructure, best and worst case scenario



COP Based on reserves & cont/prosp resources

COP Based on reserves

Source: Focus on Dutch Oil and Gas 2016, EBN

Future wind parks in the UK and Dutch economic zones of the southern North Sea will be developed in locations where energy transport in the form of electricity would require significant investments in high-voltage direct-current grids in order to transfer the electricity to shore with minimum losses. There will also be free gas pipeline capacity available at that time, however, making it possible to connect new offshore wind developments to shore using existing infrastructure for the transport of physical fuels, preferably hydrogen produced through the offshore electrolysis of desalinated seawater.

The existing pipeline infrastructure has a great deal of capacity for the transport of energy in the form of hydrogen. Although hydrogen contains only one third as much energy per cubic metre as natural gas, the transport capacity of a trunk line is significantly larger than the production of a single wind park. An offshore wind park with a typical size of 700 MW will produce an average of about 10 PJ of energy per year. Transformed into hydrogen, this amount of energy can fit through a pipeline with a diameter of 15 inches and a pressure of 20 bar. Even the total production of offshore wind in the North Sea in 2030, expected to be some 12 GW, could – once transformed into hydrogen – in theory fit through a single trunk line with a diameter of 36 inches at elevated pressure.

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[60] Focus on Energy: The full potential of the Dutch subsurface, EBN, 2017

Figure 29: Offshore wind parks under development in the southern North Sea (NL and UK)

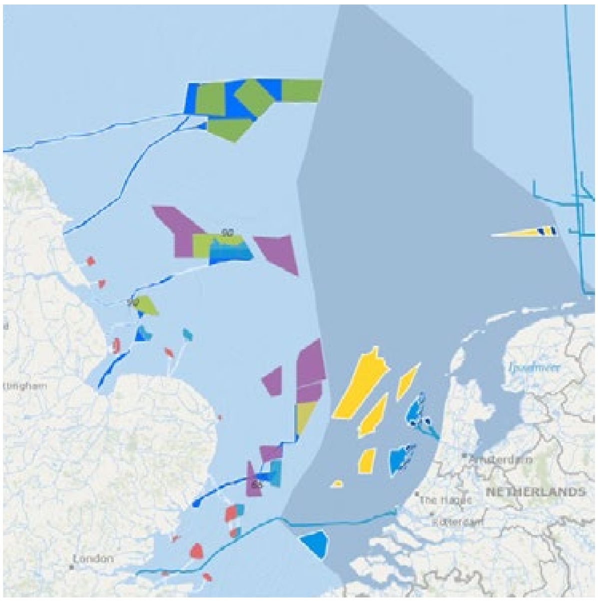
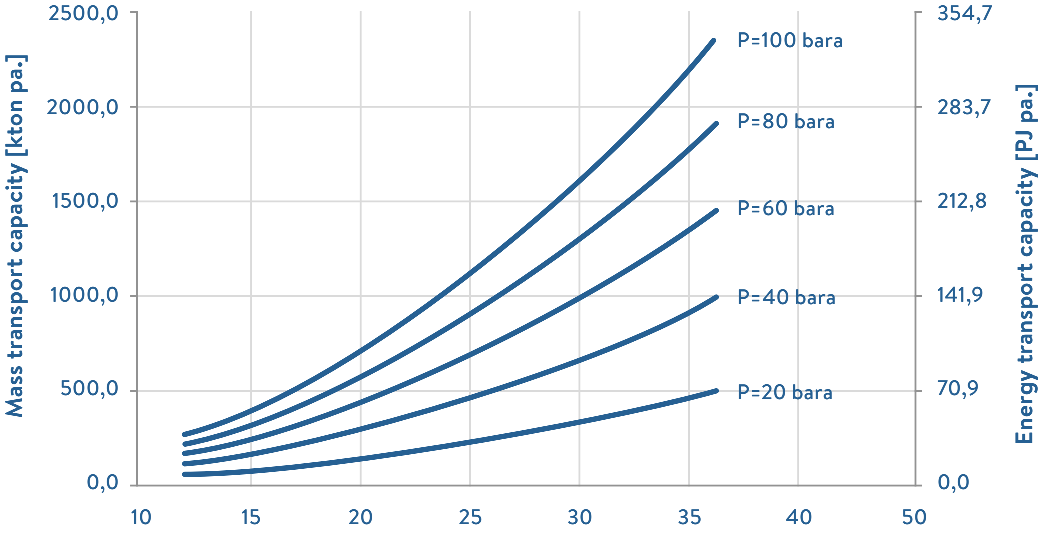


Figure 30: Existing pipeline infrastructure for oil and gas in the Netherlands

Figure 31: Hydrogen transport capacity of offshore pipelines, depending on pipe size and operating pressure[61]



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[61] Source: North Sea Energy (www.north-sea-energy.eu)

Figure 32: Overview of existing pipes and sizes

PIPE SEGMENT	OPERATOR	NPS [INCHES]	DUTY	FROM	TO
PL0099_PR	TAQA	26	Gas	P15-D	Maasvlakte
PL0223_PR	Neptune	8	Gas	Q16-FA-1	Maasvlakte
PL0138_PR	NAM	8	Gas	Q16-FA-1	P18-A
PL0106_PR	TAQA	16	Gas	P18-A	P15-D
PL0030_PR	NAM	24	Gas	K15-FB-1	LOCAL
PL0004_PR	Wintershall	36	Gas	K13-AP	WGT
PL0091_PR	Neptune	24	Gas	L2-FA-1	NOGAT
PL0061_PR	Wintershall	10.7	Gas	Q8-A	Ijmuiden
PL0218_PR	Wintershall	10	Gas	Q4-C	Q8-A
PL0003_PR	Noordgastransport	36	Gas	L10-AR	NGT
PL0142_PR	Noordgastransport	36	Gas	D15-FA-1	L10-AC

5.2. OTHER TSO INFRASTRUCTURE DEVELOPMENTS

Besides projected grid developments on the North Sea, the European electricity and gas transmission system will also need to be reinforced onshore so as to accommodate energy flows from production sites to load areas. Central planning for all reinforcements is overseen by the European Network of Transmission System Operators (ENTSO), which is subdivided into two organisations tasked with the power (ENTSO-E) and gas grid (ENTSOG), respectively. Their role is to facilitate and enhance the cooperation between national TSOs across Europe and ensure the development of pan-European transmission systems in line with European Union energy goals.

The Ten-Year Network Development Plans of ENTSO-E[62] and ENTSOG[63] contain projections for the networks in 2025, 2030 and 2040, under multiple scenarios. All scenarios foresee electricity grid expansions due to significant growth in peak electricity – up to a factor of 5 in the scenario with the highest electricity demand. For the gas grid, peak demand – typically occurring during a cold spell with very low temperatures – is expected to decrease because of a higher penetration of electrical heat pumps. In addition to the network developments, the scenarios assume new flexible thermal generation. This generation is not necessarily economically viable in an energy-only market, which is why the scenarios partly assume capacity-remuneration mechanisms.

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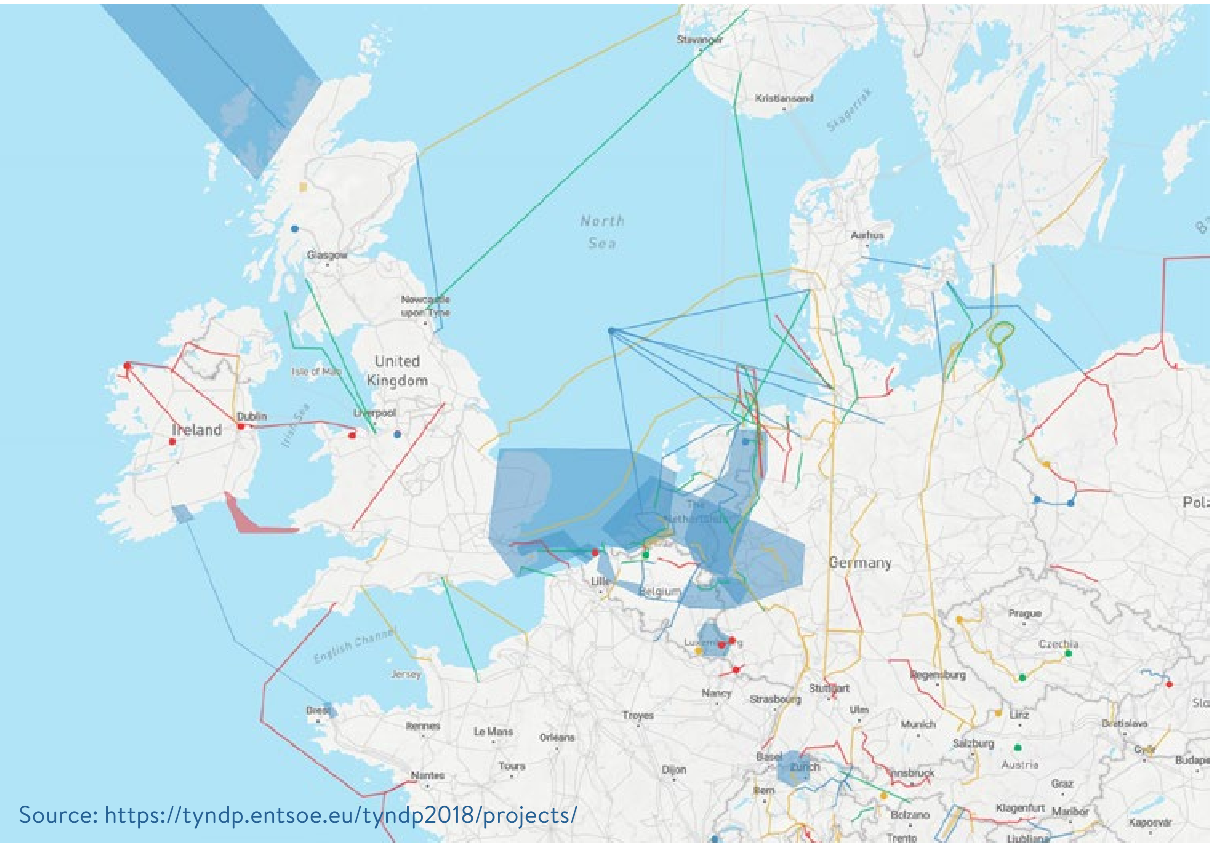
[62] See: https://tyndp.entsoe.eu/tyndp2018/

[63] See: https://www.entsog.eu/tyndp#entsog-ten-year-network-development-plan-2020

As shown in figure 33, most electricity grid reinforcements are centred around the North Sea, with lots of additional interconnection capacity being constructed, planned and/or studied[64]. Furthermore, there is a clear focus on strengthening north-south transmission capacity. These plans are needed to tackle grid congestion as the capacity is increasingly insufficient to transport all the power produced. This security of supply challenge mainly arises in periods of high electricity demand and low or variable renewable electricity production.

Figure 33: Grid reinforcements



Source: https://tyndp.entsoe.eu/tyndp2018/projects/

ENTSO-E's 2017 regional investment plan for the North Sea, which focuses specifically on NWE, foresees an expansion in of the electricity grid capacity of between 30 GW and 35 GW by 2040[65],[66]. Additionally, about 15 to 23 GW of grid capacity is required for the integration of the NWE electricity market with the rest of Europe. The price tag of such a massive expansion of the power grid would be enormous: based on the standard costs indicated by ENTSO-E and shown in figure 34, a very high-level estimation proposes a total cost of around €50 bn[67].

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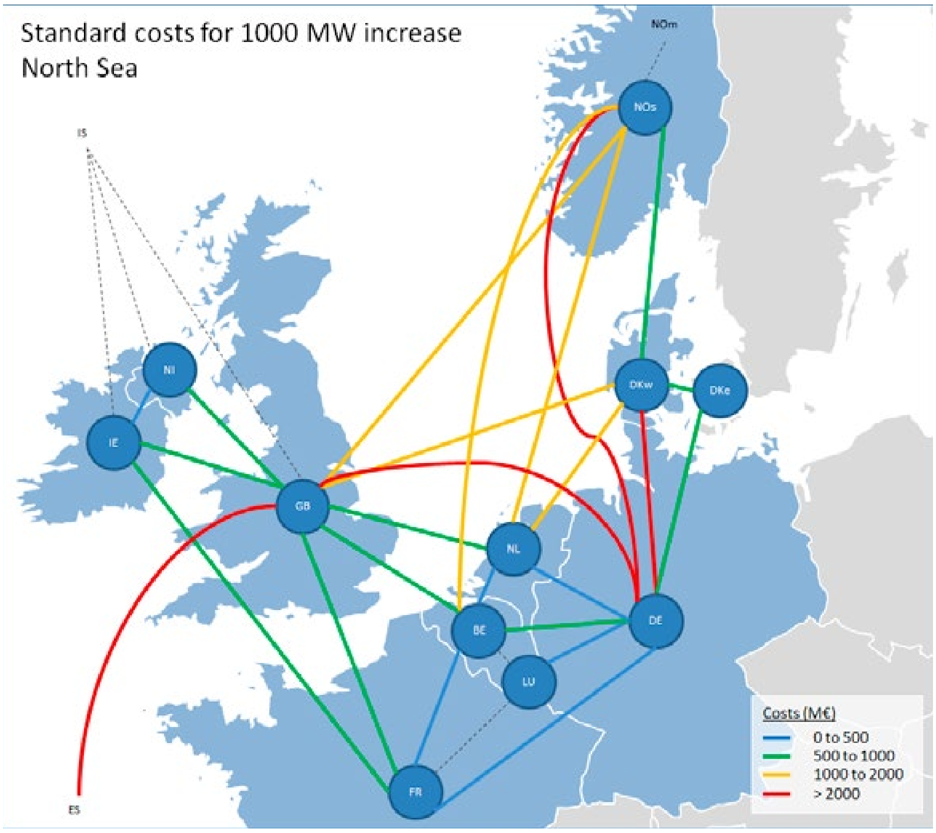
[64] ENTSOE TYNDP 2018
[65] https://docstore.entsoe.eu/Documents/TYNDP%20documents/TYNDP2018/rgip_NS_Full.pdf
[66] The regional investment plan for the North Sea does not include Sweden.
[67] Regional investment plan North Sea 2017, ENTSO-E, 2019

Figure 34: Standard costs for grid capacity increases in the North Sea



By increasing interconnection capacity, TSOs also facilitate further market coupling. In their role as market facilitators, TSOs also accommodate the market by auctioning ancillary services on a more frequent basis (from week/month contracts to daily/four-hourly block contracts). This ensures more flexible assets, contributing to grid stability. These developments are initiated by the EC and the Agency for the Cooperation of Energy Regulators (ACER) so as to encourage the completion of a single EU energy market for electricity and natural gas.

Another development which should be further encouraged is the cooperation between electricity and gas TSOs, as the energy system of the future needs integration of electricity, heat and gas systems. Cooperation between all TSOs would make it possible to greatly reduce the need for infrastructure expansion by introducing conversion technologies (like PtG installations) in the right locations[68]. Although electricity storage is expected to be widely available by 2050, only gas storage will provide a solution for seasonal storage in a system based on solar and wind power.

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[68] Infrastructure Outlook 2050, TenneT & Gasunie, 2019

5.3. INFRASTRUCTURE DEVELOPMENTS IN PORT AREAS

IMPORT NEED AND PORT ENERGY INFRASTRUCTURE

The major port areas in NWE are Rotterdam, Antwerp, Hamburg and Amsterdam. These ports are hubs which import, store and further distribute large amounts of energy via pipeline, truck and rail towards the rest of Europe. Figure 35 gives an overview of the throughput of energy products of the NWE ports, of which Rotterdam has the largest share[69].

Figure 35: Overview of throughput in NWE per commodity

Commodity	Total Throughput in NWE
Coal	70 million metric tonnes
Oil	150 million metric tonnes
Gas	8.9 million metric tonnes

FUTURE STORAGE OPTIONS

The current natural gas infrastructure in NWE is well connected and can be used in the future for the import of carbon-free fuels. The coming transition to a zero-emission renewable energy system means that import demand for renewable energy will increase as renewable energy production within NWE is limited by the production potential of solar and wind power.

Renewable energy can be imported from locations with a large production potential such as Africa, the Middle East, Australia and Chile, mainly by converting the renewable energy into hydrogen. The hydrogen can be imported into NWE via existing energy import routes – that is, by pipeline or via ship. While hydrogen can be imported via pipelines if the existing natural gas infrastructure is repurposed, that infrastructure will still be needed to transport natural gas within NWE for the foreseeable future, and converting it to a dedicated hydrogen system will take time. A more likely solution is to import hydrogen by ship to major industrial port areas like Rotterdam, Amsterdam and Hamburg.

Hydrogen can be transported and stored by ship in the form of ammonia (NH3) by using a liquid organic hydrogen carrier (LOHC) and in liquefied form (L-H2). Current infrastructure can be repurposed for ammonia and LOHC, which is a major advantage; hydrogen in liquefied form, on the other hand, would require investments to create an entirely new supply chain and infrastructure.

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[69] Based on facts and figures provided by Port of Rotterdam Authority.

PORT OF ROTTERDAM

The port of Rotterdam is the largest port of Europe. It saw the arrival or departure of around 8,800 PJ worth of energy carriers, which is around three times the yearly energy consumption of the Netherlands or 13% of that of the EU. The energy carriers consist mostly of oil and oil products. About a third are processed into oil and chemical products, biofuels, electricity and heat in the Rotterdam area, while the remainder are sent on to other destinations unrefined.

Some five per cent (430 PJ) of the energy carriers are used within the port area, which produced 18% of the total CO_2 emissions of the Netherlands in 2018. The industrial sector in Rotterdam is working on a series of projects which can achieve a total of 25% of the Dutch CO_2 reduction target for 2030. Hydrogen is one of the main pillars in these projects. Hydrogen production in the area was around 40 PJ in 2018 and is expected to triple by 2030. For the future expansion in hydrogen production and use, a common carrier network with a significantly higher capacity than the currently existing private hydrogen network is planned.

There are several initiatives under development that will contribute to decarbonising the production of hydrogen. A CCUS facility is being developed under the Port of Rotterdam CO_2 Transport Hub and Offshore Storage (Porthos) project, where the CO_2 is to be stored in depleted offshore gas fields under the North Sea. This facility allows the current hydrogen production to be decarbonised. A consortium of several companies active in the port area is working on another project called H-Vision, which explores additional production of hydrogen based on ATR and CCUS and also uses the Porthos facility.

Figure 36: CCUS network project in Port of Rotterdam

Source: Port of Rotterdam Authority

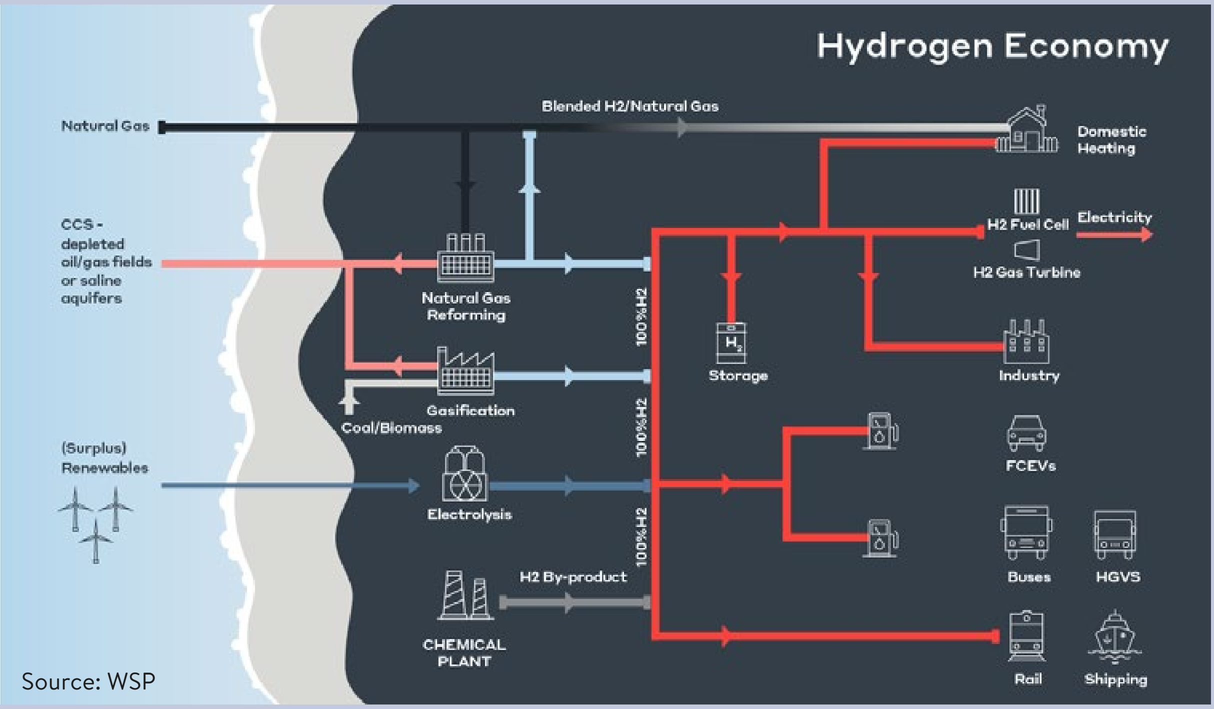
One of the strengths of hydrogen as an energy carrier is that it converts electrical energy into chemical energy and vice-versa, enabling it to connect different sectors. The large number of stakeholders involved in hydrogen projects can, however, also lead to complexities. For the Porthos project, the main stakeholders are industrial companies supplying the CO_2, the consortium partners EBN, Gasunie and the Port of Rotterdam Authority, and the owners of the depleted gas fields. An important point of discussion with the government relates to the long-term ownership of the CO_2.

There are also several initiatives in large-scale electrolysis being explored in the port area. This includes a 250 MW facility by Nouryon and BP, which is the largest electrolyser in Europe.

A centralised PtG conversion park with a total capacity of 2 GW is planned for the port area. Centralisation is required as the transport and delivery of the required electricity through the port area to local initiatives require extensive high-voltage power lines and stations throughout the area, which would be both very costly to build from scratch and is anyway precluded by spatial requirements. An extensive expansion of the power grid is, however, still required, as the use of electric power in the port area is expected to triple by 2030.

An example of the various possible elements of the planned hydrogen infrastructure is shown here.

Figure 37: Hydrogen infrastructure



Source: WSP

The heat produced by the thermal losses during the electrolysis process is planned to be used in the extensive heat networks in the area, increasing overall system efficiency.

As the local production of hydrogen is not expected to cover all needs, and the Port of Rotterdam is also an energy hub for the European hinterland, the port will need to import large quantities of hydrogen.

5.4. LOCAL INFRASTRUCTURE REQUIREMENTS DUE TO DECENTRALISATION

ELECTRICITY

In most countries, TSOs and DSOs have an obligation to connect any requesting party to the power grid. While this is usually understood to also include redundancy, connecting decentralised electricity generation assets (solar and wind farms) can be a lot more expensive than connecting central power plants. It might therefore make sense from a societal point of view to remedy by changing current regulations. For instance, grid connections should not be located in places with limited network capacity but in places where flexibility developments (conversion and/or storage) exist or are planned, since the full capacity requirement in that case does not also need to be realised for the connection with the national power grid.

Cost savings can also be realised by so-called cable pooling, where a grid connection is established for a combination of solar and wind farms. Because those two types of power production do best in different weather, a grid connection linked to both at the same time can make do with a lower capacity than two individual connections. Regulation has already been implemented in Germany in this respect. In exceptional cases, a small part of the load may be curtailed by the network operator if the social costs of the required network expansion or reinforcement are too high.

Under some circumstances, more decentralised systems can, however, also present advantages compared to a centralised system. These range from a more cost-efficient transmission system to an increased reliance of the system[70]. Interconnection of the decentralised infrastructure is essential to keep the balance between load and demand. Besides ensuring that the physical constraints of the grid are met, the system should not result in significantly increased costs of electricity.

In the traditional system, the grid operator used to run centralised algorithms with limited input variables (dispatchable assets). The centralised algorithms are not suitable for the more complex decentralised grid, however. The solution is to implement decentralised optimisation algorithms with the capacity to process all the data. These still have several obstacles to overcome, however: for instance, decentralised optimisation algorithms do not by and of themselves provide protection against cyber-attacks or guarantee privacy. These algorithms therefore need to be run on a blockchain platform that uses smart contracts for coordination. This enables the system to allot electricity in the most cost-efficient manner while adhering to the relevant physical and safety constraints[71].

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[70] R.E.H. Sims, R.N. Schock, A. Adegbululgbe, J. Fenhann, I. Konstantinaviciute, W. Moomaw, H.B. Nimir, B. Schlamadinger, J. Torres-Martínez, C. Turner, Y. Uchiyama, S.J.V. Vuori, N. Wamukonya, X. Zhang, 2007: Energy supply. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[71] Munsing, E., Mather, J., & Moura, S. (2017). Blockchains for Decentralized Optimization of Energy Resources in Microgrid Networks. UC Berkeley: Energy, Controls, and Applications Lab. Retrieved from https://escholarship.org/uc/item/80g5s6df

HEAT

Hard to transport over a long distance with high efficiency, heat is traditionally often generated on site. The scale of decentralised heat may, however, shift. There are three main methods with which low-carbon heat may be supplied in the future.

- Electrical heating systems are being installed in many new buildings. Due to the high energy requirement for heating, large-scale adoption of electrical heating will lead to high demands for green electricity generation capacity and may a potentially large burden on electricity grid capacity.
- Another option is to use the existing gas grid and change the content. Although possibilities include the use of biomass and waste gasification, these feedstocks cannot be expanded to the required amount. The use of hydrogen seems more promising for most countries. Initially this can be integrated by adding up to 20% hydrogen to the natural gas, while gradually transforming the system until it is fully operational on hydrogen. This would require minor adjustments to the grid and presents opportunities for the installation of fuel cells for various uses.
- District heating via low-carbon sources is another important alternative. This technology has been around for a long time and has a clear proof of concept. District heating has the best business case when there is a significant and dense heat load nearby (e.g., geothermal energy, heat recovered from industrial sites, etc.). Nevertheless, this is not a prerequisite for implementation. ■

EXAMPLES ILLUSTRATING THE POSSIBILITIES OF DECENTRALISED HEAT SOLUTIONS

The city of Freiburg in Germany has the ambition to decouple its energy infrastructure from the national grid. The next milestone is 2030, when the city aims to have reduced its carbon emission by 60%. The energy consumed by Freiburg comes mainly from solar power and a combined heat and power plant powered by biomass.

A fourth-generation district heating system has been built in Stockholm with a total annual capacity of 12 TWh. The system consists of combined heat and power plants, 660 MW of heat pumps and 300 MW of electric boilers. Moreover, storage is incorporated in the district heating and cooling network. The system makes it possible to balance intermittent renewable energy generation.

The municipality of Heerlen in the Netherlands has successfully executed a fifth-generation district heating project called Mijnwater.

The small town of Vojens in Denmark has a relatively new solar thermal power plant which is used to provide seasonal heat storage through pit storage technology. The system meets approximately half of the heating needs of the 2000 houses in the town. While this does not meet the whole heating demand, it demonstrates how major improvements can be made locally.

6

THE ENERGY MIX AND REQUIRED POLICIES AND MEASURES

6.1. INTRODUCTION

The European Union has traditionally distinguished between three main energy policy targets: a decarbonised energy system, a high degree of security of supply and the provision of competitive & affordable energy. One of the main policy challenges is to achieve all those targets at once while maintaining a competitive internal energy market and keeping possible trade-offs between the three targets in balance. This has led to an impressive set of EU policies and measures, which have resulted in a range of rules and incentives[72] for the many stakeholders involved[73]. Clear recent examples are the Fourth State of the Union Report of 2019, which outlines progress towards an Energy Union, and the European Green Deal announced in December 2019 which aims to show the way forward to a sustainable green transition for Europe while maintaining its global competitive position. The European Green Deal contains a package of measures, including a European 'Climate Law' to be drafted by March 2020.

To assess the policies and measures needed to realise the optimal future energy mix for NWE, which is the focus of this report, we need to account for the three above-mentioned targets of European energy policy. Our analysis also accounts for existing policies and measures. In this section we argue that new and additional policies and measures, and possibly a shift of focus, will be needed to achieve those three goals as well. An increasingly accepted perspective on the energy system is the notion that successfully achieving and reconciling energy policy targets requires the energy system to be treated as an integrated whole rather than as a set of separate markets for different energy carriers and related stakeholders. In other words, traditional distinctions in policy making between steering and regulating stakeholders – related to power, physical fuels, heat, energy feedstock, energy for mobility, built environment, industry, etc. – need to be replaced by policy frameworks that deal with energy and feedstock markets as a whole. This means that, in the process leading to a carbon-neutral energy system, it is important to optimise the overall energy mix of green power, various carbon-free fuels and green heat, and recognise that energy conversion, transport and storage will become an integral part of finding the socially optimal energy mix.

From this perspective, a few key challenges are likely to shape the cornerstones of the energy research and policy agenda of the future:
1. How can we stimulate investments in renewable electricity generation?
2. Which energy mix provides the optimal balance between green electricity and carbon-free physical fuels?
3. How can we secure the flexibility required to balance the power grid and provide the back-up capacity needed to guarantee affordability and security of supply?
4. Which new EU and national policies and measures are required to make the above happen?

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[72] See Appendix A for an overview.

[73] We consider the supply side of the energy sector to encompass actors in the field of energy generators, such as utilities, owners/operators of wind and solar parks etc.; parties responsible for the transmission and distribution grid, i.e. TSOs and DSOs; energy suppliers; and regulators. On the demand side, we distinguish between households and industrial consumers.

In the following sections we will address these issues with a specific focus on the need for energy policies and measures.

6.2. FACTORS HOLDING BACK INVESTMENTS IN RENEWABLE ELECTRICITY GENERATION

Supplying the required amounts of green electricity will entail serious investments in renewable electricity generation. Over the past years, these investments have been slower than desired in NWE, however[74], meaning that several Member States may miss their individual 2020 targets for renewable electricity production. Below we discuss some of the main factors holding back investments in this area.

SUPPORT MECHANISMS

Mandatory renewable energy objectives have been set at the EU level for some time now in order to encourage a faster energy transition. These objectives are unlikely to be met if one relies on market forces alone, however, as renewable energy generation technologies have been, or continue to be, insufficiently competitive. This is why many Member States have introduced public support measures for renewable energy generation, such as feed-in tariffs and other types of subsidies. The need for such stimulation mechanisms was already acknowledged in the Renewable Energy Directive from 2009.
In many NWE countries, the subsidies for specific types of renewable energy are being significantly reduced over time or shifted between technologies. These developments are motivated by EU regulations, which prescribe that state aid should be temporary and only prolonged in case of clear and specific need. From an economic point of view, it can also be argued that novel technologies for the generation of renewable electricity should only be subsidised until they are competitive with fossil fuel-based technologies.

There are indeed limitations to the period over which subsidies should be provided. However, what often seems to be lacking is sufficient visibility on the roll-forward or future adjustments for subsidies after their initial term ends. This results in major uncertainty with respect to the expected returns on investment in renewable electricity generation, both for large-scale investors and small-scale investments, such as those carried out by individual households. An example are the subsidies for solar energy in Spain. At the beginning of this century, owners of solar farms in Spain were guaranteed a fixed feed-in tariff. However, as the installed capacity grew to be approximately ten times higher than anticipated, the system became too expensive and the fixed feed-in tariff was ended. The growth of installed capacity halted when taxation on the production of solar electricity was eventually introduced. and the public sentiment around solar energy became very negative[75].

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[74] Eurostat, 12 February 2019, ‘Share of renewable energy in the EU up to 17.5% in 2017’
[75] NRC, 13 January 2020, ‘Krijgt de Spaanse premier Sánchez nu zijn daken vol met zonnepanelen?’

Investments in renewable electricity generation are exposed to longer-term policy uncertainty and growing market price risk. This increases financial risk, reducing the ability to attract debt financing and increasing the cost of capital for such projects. Although support schemes need to adapt to changing circumstances in order to remain efficient, abrupt and unpredictable changes to support schemes can be counterproductive. Support schemes are therefore most effective when flexibility measures are predefined, providing predictability as well as the ability to react to changing circumstances[76].

In addition to the predictability of individual subsidy schemes at the level of Member States, it is important to ensure uniformity at that level to stimulate investments in renewable electricity generation. Not having uniform support mechanisms may, for instance, cause administrative burdens and financial risks for companies which are planning to invest in either individual assets in multiple countries or in large-scale projects which cross borders (for instance investments related to renewable electricity generation in the North Sea).

PROFITABILITY PARADOX

Another issue for investments in renewable energy is the profitability paradox. Thanks to increases in scale and technological improvements, the costs of the production of renewable energy have declined significantly over time, and are expected to drop further for many technologies[77,78]. Although these developments foster the expansion of renewable electricity over time, the capacity does not automatically match supply to demand. Renewable electricity supply is intermittent while demand is stable and inflexible. This leads to an oversupply of renewable electricity on days with a great deal of wind and/or sunshine and, conversely, a shortfall on days when there is little wind and/or sun. Prices decline on days of plenty and rise when power is scarce – but renewable energy producers cannot profit from the price peaks. The ever-growing supply of renewable electricity means that this effect will increase over time: as a result, the profitability of (renewable) electricity generation will fall, making it less attractive to invest[79].

PUBLIC RESISTANCE

Another important issue holding back or delaying investments in renewable electricity generation onshore in NWE is the ‘not in my backyard’ (NIMBY) attitude of some of the public. The available locations for renewable electricity production in more open spaces and industrial areas, where public resistance is relatively low, are developed first, and as a result become scarcer over time. Renewable electricity production on land therefore increasingly needs to be located in more densely populated areas, and public resistance can be expected to increase accordingly. Renewable electricity generation is now increasingly planned offshore in the North Sea, where public resistance is relatively low. This may, however, create new challenges to realising new investments within the set timeframes, or with respect to the availability of transmission infrastructure.

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[76] Hogg, K. and R. O’Regan, Renewable energy support mechanisms: an overview (New York: PricewaterhouseCoopers LLP, 2010)

[77] EIA (2019): “Cost and performance characteristics of new generating technologies”, in Annual Energy Outlook 2019, January 2019

[78] Fraunhofer (2018): “Levelised costs of electricity renewable energy technologies”, Fraunhofer Institute for Solar Energy Systems ISE, March 2018

[79] Blazquez, et al. (2017): “The renewable energy policy Paradox”, Renewable and Sustainable Energy Reviews, 82-1, p.1-5

GRID CONNECTION

The NWE power grid was developed over time for the centralised distribution of power from a limited number of facilities to end consumers. A mix of baseload and peak power plants made it possible to maintain a stable and secure power grid at all times. Nowadays we are seeing a decentralisation of electricity production and an increasing share of renewable intermittent electricity, however, and this is placing much more strain on the electricity grid. Making the most of this new situation requires large investments in the NWE electricity grid, but there are multiple factors limiting the level of such investments:

- The regulation policies in place often do not include enough incentives to invest proactively. Investments may be disincentivised by regulatory mechanisms which ensure the efficiency of TSOs, such as the application of benchmark approaches to determine the appropriate level of investment expenses for grid operators or efficiency targets for certain expenses.
- Due to the steady nature of their operations in the past, grid operators are not used to making long-term plans which include radical changes.
- Time-consuming permit approval processes slow down investments. This means that, in areas where large increases in renewable electricity generation are foreseen, such as rural areas for onshore wind farms and solar power farms, it is not possible or financially viable for the distribution system operators to invest upfront in the required capacity increases in the electricity grid.
- Another factor slowing down investments related to the transmission system is their sheer size. As these need to be financed upfront, additional shareholder capital is required in order to attract further debt financing while maintaining the required debt and interest-coverage ratios. The shareholders, which are often governmental bodies, must be both willing and able to provide this additional capital, but the international expansion of TSOs may lead to governments being reluctant to provide financing which will not contribute directly to the national energy grid in their own country[80].

6.3. PROVIDING THE OPTIMAL BALANCE BETWEEN ELECTRICITY AND PHYSICAL FUELS

Despite the slower than desired uptake of renewable electricity generation discussed in the previous section, statistics show that progress towards the greening of the power system in NWE has on the whole been considerable. The share of renewables in NWE gross electricity generation by 2020 is about 30%, which is comparable to the EU average. If biomass and nuclear, which are also carbon-neutral, were included in the figure as well, this share would be some 67% (WEC energy scenarios, 2019). According to the WEC NWE scenarios, by 2030 these percentages are expected to increase to 46% and 80%, respectively. For the EU as a whole, the share of electrification in final-demand projections for 2050 typically ranges between 40% and 60% in the literature (including the EU roadmap for 2050).

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[80] https://fd.nl/achtergrond/1317106/duitse-expansie-van-tennet-dwingt-nederland-tot-lastige-keuze

WHY PHYSICAL FUELS WILL REMAIN A SIGNIFICANT PART OF THE ENERGY SYSTEM

Electric current – energy in form of a flow of electrons – cannot take over as the main energy carrier in all sectors without major extra costs for society compared to an optimised hybrid system. The extra costs for all EU taxpayers in an all-electric scenario could be over €200 billion per year compared to a hybrid scenario based on physical fuels playing a significantly larger role by combining the existing gas grid with power-to-gas technologies (ERIG – European Research Institute for Gas and Energy Innovation, 2018) (Navigant, March 2019) (RWTH Aachen University & Frontier Economics, 2019). This hybrid scenario already includes a substantial build-up of the required capacities for biomethane and blue hydrogen production and, especially, power-to-gas conversion. It also allows for extensive sector coupling – meaning the integration of all energy-consuming segments with the power generation sector.

The level and trend in the greening of the NWE power system contrasts quite strongly with the level and speed at which low-carbon or carbon-free physical energy carriers are introduced. While renewable electricity production is becoming more and more competitive, the production of low-carbon fuels is instead lagging behind and still relatively costly due to expensive feedstocks, often still immature technologies, and lack of economies of scale. Although precise data on the greening of energy and feedstock fuels in NWE is lacking, it seems fair to assume that this share will not be too different from the EU average i.e. no more than two to five per cent. Given the current share of physical energy carriers in the final energy consumption in NWE and given that their share is expected to still amount to around 40 to 60% of the final energy demand projected for 2050, a focus on incentives for the production of low-carbon fuels is and will remain key. Or, to put things somewhat more dramatically: if, given usual lead times, there is a lack of serious progress towards introducing lower-carbon fuels during the current decade, it is hard to see how the EU can reach its 2050 target to achieve a green energy system by then.

There are in fact only a limited number of technologies available to generate carbon-neutral fuels: biomass can be turned into green liquid fuels and gases via digestion or gasification; fossil gases and liquids can be decarbonised with the help of various technologies to capture the carbon and store or re-use in such a way that it will not enter the atmosphere; or carbon-neutral power can be converted into carbon-neutral hydrogen that can either be used directly or converted further into green chemical composites such as methanol, methane or ammonia.

Although all these technologies are expected to become deployable on a large scale in the future to generate much-needed volumes of low-carbon fuels, the truth is that, even in NWE, actual deployment of technologies to generate low-carbon energy fuels is still very limited – apart from some rural biomass digestion generating about five per cent, or about 20 bcm, of the EU-wide gaseous energy uptake. In fact, many of the technologies are still in their infancy and there are only a limited number of pilots.

THE VAST ADDITIONAL VOLUMES OF HYDROGEN NEEDED TO GREEN INDUSTRIAL PROCESSES WOULD ENABLE THE HYDROGEN ECONOMY TO ACHIEVE A LARGER SCALE AND REDUCE COSTS.

It is unclear why progress towards using more low-carbon fuels has so far remained so slow, while the production of green electricity has expanded significantly. The possible reasons include:

- The decarbonisation of fuels for mobility – the EU's prime focus point for generating green fuels – slowed down once it became clear that the sheer volume of biomass required would disturb world agriculture and possibly result in increasing food prices, major deforestation and land degradation in (the mostly poor) countries supplying the biomass[81];
- Producing biogas from agricultural waste turned out to sometimes meet local resistance and was not always easy to turn into gas that would be green (i.e. acceptable for public grid injection) without considerable costs;
- (Onshore) CCS initiatives faced considerable public opposition, which hampered their rollout and further technological development;
- Power-to-gas technologies have only recently received public and policy attention and typically still remain in their pilot stage;
- EU policy and measures seem to have been focused primarily on greening the electricity sector, with less attention for greening liquid and gas fuels.

Attention from investors, policy makers and even the public at large has recently seemed to be shifting to the issue of using more low-carbon fuels, the question of which technologies should be deployed for this purpose, and the issue of which policies and measures will be required to get these technologies off the ground at considerable scale and speed. The recent developments and projections for the North Sea region, as a central energy region within NWE and a potential energy transition hotspot, seem to have contributed to this shift in focus. The projected formidable offshore wind capacity, in combination with the presence of an extensive oil and gas infrastructure, may give rise to a range of different energy-system-coupling initiatives between electricity and physical fuels. These may involve power-to-gas conversion, the implementation of carbon-neutral hydrogen and offshore carbon storage. Together, these initiatives promise to optimise the overall energy system.

System coupling not only involves creating the right balance between fuels and electricity, but may also enhance the economics of energy transportation and distribution, power-grid balancing and providing back-up and energy storage. PtG technologies, for instance, make it possible for the existing gas network to store and transport very large amounts of electrical energy in the form of gas (hydrogen or methane) generated from wind and solar, rather than requiring relatively costly, time-intensive, and often societally complex investments in the expansion of the European power grid. This would largely make it possible to avoid the construction through Europe of large-scale high-voltage power lines, which could have faced serious public resistance. The existing gas network can instead absorb very large volumes of renewable energy without the need to expand.

Moreover, any expansion of the natural gas network, should it prove necessary, would also require much less topographical intervention than an expansion of the electricity grid, leading to clear

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[81] IEA, Tracking Transport, 2019

cost advantages. Contrary to an electricity grid expansion, PtG units can be designed and scaled in accordance with a wide range of requirements. In the low-voltage range, PtG can relieve the entire distribution grid and, by acting both as a balancing and an energy-transfer device, reduce the necessary electricity grid expansion across all voltage levels[82].

6.4. FLEXIBILITY FOR POWER GRID BALANCING AND BACKUP CAPACITY FOR SECURITY OF SUPPLY

BALANCING AND FLEXIBILITY

In a traditional power generation concept, with vast amounts of controllable generation in the form of coal, gas, nuclear or hydro power stations, keeping the entire system balanced was a rather straightforward task: ensuring that the amount of power generated corresponded to the amount of power demanded at a given moment simply required ramping generation from one or more plants up or down. In such a traditional centralised power system, there was no need to store or buffer power for use in times of scarcity.

Given the expansion of renewable generation sources, however, there is a growing need to ensure that electricity is used in an efficient way so as to bridge any excess or scarcity in electricity generation and avoid shortages and curtailing. This requires grid balancing, energy price stability and even security of supply, which can all be achieved by increasing flexibility. Generally speaking, flexibility can come from supply, demand or energy storage.

Market incentives can play a role: price effects in times of energy scarcity or excess availability can be an important driver for both consumers and investors to develop different kinds of flexibility. It seems increasingly unlikely, however, that such spontaneous, market-driven measures will be sufficient to solve the balancing issue in a future in which energy generation is dominated by intermittent, weather-dependent sources. This holds true even if flexibility in the power system can also be increased through better connections between different parts of the system, e.g. through cross-border interconnections that help to more efficiently balance out energy scarcity and abundance by providing flexibility via the connection of larger geographical regions.

As far as supply and demand flexibility is concerned, part of the solution will come from distributed energy resources (DER) such as small hydro, biomass, biogas, solar power, wind and geothermal power coming from so-called ‘prosumers’, i.e. small and medium-sized agents that both consume and produce electricity via, for instance, demand response (DR) services. DR refers to the changes in consumption by end consumers in response to changes in the electricity price over time, or to incentive schemes or payments designed to induce lower electricity use at time of high wholesale market prices or

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[82] Electrolyser systems usually function at a low voltage as well, reducing the need for voltage management and leading to additional savings.

when system reliability is in danger. DR includes vehicle-to-grid electric automobiles, home batteries and 'smart' devices. So-called aggregators enter these markets contracting demand and supply of electricity for various types of consumers, aggregating the prosumers' ability to adjust their energy demand or supply, and offering flexibility as a service to the market[83]. Next to DER and DR at the small and medium-sized level, flexibility in the direct electricity consumption of industrial processes can be an important source of flexibility in times of scarcity and the resulting high electricity prices.

More and better data, advanced data analytics, greater connectivity and automation will also contribute to improving ways of balancing supply and demand in an increasingly weather-dependent energy system. Specifically, artificial intelligence (AI) and machine learning will open new business and value creation models for a greater number of players, including aggregators and prosumers. This will help increase the availability of required flexibility (e.g. of small-scale sources, such as single EVs, in aggregated form) from small-scale actors such as households, that would normally not make such sources of flexibility available to the wholesale power market. Options in the built environment include smart controls[84] of household appliances and the smart charging of electric vehicles.

The abovementioned price effects in times of scarcity or excess supply of energy also mean that larger industry players will be better able to provide flexibility in available assets and processes through external service providers that take away any concerns about providing flexibility to energy markets without affecting core processes. Examples of such flexibility in industrial production include:

- Smarter use of buffering options in industrial plants or specific processes. This allows a plant or process to temporarily curtail energy consumption in times of scarce availability and consequent high prices. Examples include cooling houses that can postpone their cooling demand by one or more hours without affecting the quality of the stored goods, or glass production that can be more flexible in its energy consumption for heating without affecting the quality of the produced glass.
- Increasing flexibility in the self-production of energy, e.g. through hybrid boilers for heating. These are boilers that can use electricity and/or gas for heat production and can switch between these inputs depending on availability and prices. Self-generation capacity can also provide flexibility: large industrial plants typically have their own sources of power generation. Part of their output can be made available to energy markets in case of scarcity and high market prices. The latter is already common practice among industrial producers and sites in NWE.
- In case of foreseen, prolonged periods of scarce availability – think of a period with little wind and grey skies during wintertime, when the availability of solar and wind power is much lower[85] – industries can also plan production stops for maintenance during such periods, rather than the more traditional summer holidays.

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[83] Competition Policy and an Internal Energy Market. Study for the Directorate-General for Internal Policies, Policy Department A: Economic and Scientific Policy at the European Parliament, Ecorys, 2017

[84] Electricity demand of equipment tuned to price and/or grid frequency signals, particularly by temporarily lowering demand for power.

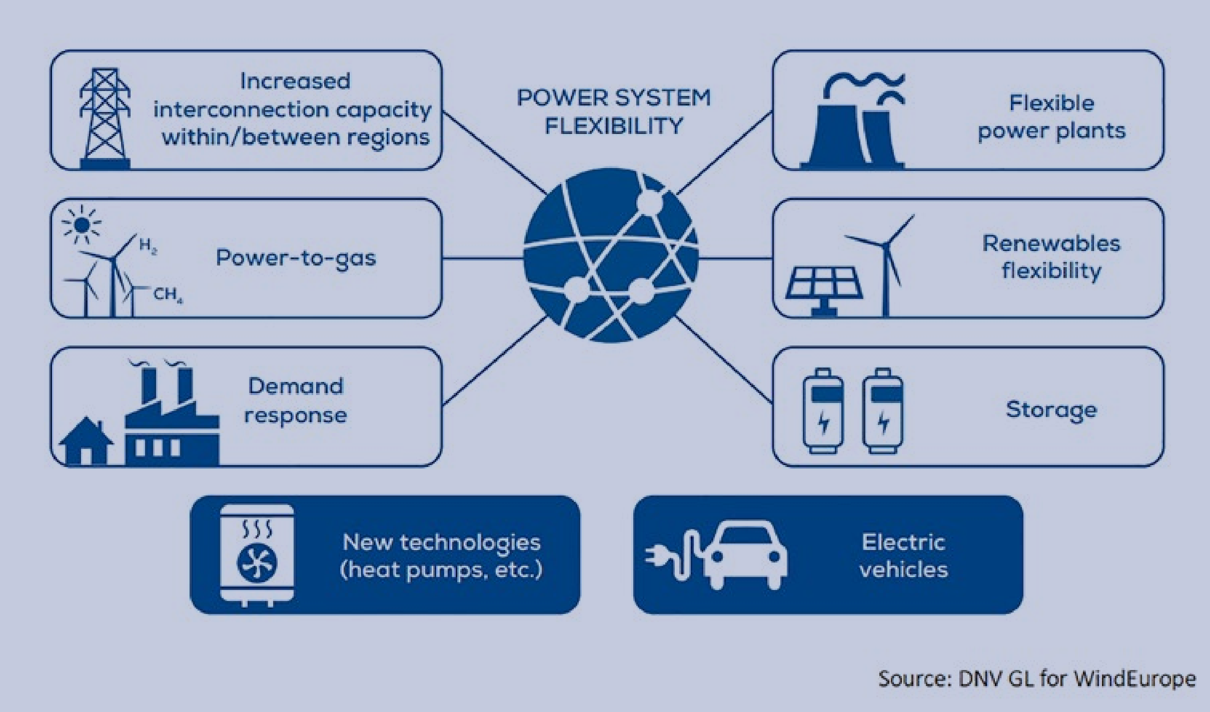
[85] Also referred to with the German term 'Dunkelflaute'. Under the normal weather patterns in NWE, these periods can last for up to about 20 days in extreme cases.

- In case of excess energy availability and resulting lower prices, industries can also choose to develop flexibility in the form of storage and/or conversion options, such as electrolysis or battery storage options.

The combination of demand-side response options described in the examples above can help develop the flexibility that the integrated, decarbonised energy system of the future needs to continuously balance the supply of and demand for energy. However, for these options to be developed, they will need to represent sufficient economic revenue potential for developers. Consider for example, a glass manufacturer that increases flexibility in its power demand by investing in (increased) heat buffering capacity in its primary production process. It cannot be expected to invest in increasing this flexibility unless there is sufficient return on this investment from the electricity market.

Alternatively, flexibility can be unlocked by external parties, such as aggregators, which create flexibility by managing different companies and prosumers without significantly impeding upon the primary processes or service offerings of the flexible capacity supplier. The primary focus of such potential flexibility suppliers will generally not be the supply of flexibility to the energy system, unless there is sufficient additional revenue potential and/or they do not need to worry about making the flexibility available without obstructing their core processes. As mentioned above, the latter can be enabled by external parties, such as aggregators, that make use of advances in digital technology to align market prices/needs with the dispatch of available flexibility from various demand-response sources.

Figure 38: Different forms of power system flexibility



Source: DNV GL for WindEurope

BACK-UP

In times of high demand and low renewable power generation, especially in the case of so-called dark doldrums – e.g. in winter when low renewable electricity generation is confronted with high demand – importing energy from other areas may not be sufficient to meet energy demand. As NWE has considerable underground storage capacities in both salt caverns and depleted gas fields, viable backup services could be provided in such cases via long-term storage solutions based on natural gas storage, hydrogen storage or pumped hydro. The major advantage of storage in gas is that renewable energy can be stored and released locally in the short as well as the long term. This makes it possible to tap the full potential of intermittent renewable sources like wind and solar by storing energy in times of surplus production and feeding it back into the grid after converting gas back to electricity when wind and solar cannot meet the demand.

Using gas as a long-term storage method for intermittent renewable electricity could be a very promising solution for the future. Physical fuels (in this case green gas) have higher energy densities and easier and cheaper storage options than electricity, which makes it possible to store them in large quantities for long periods of time at very low costs. While batteries, pumped hydro, flywheels and other technologies are also useful storage options, none offer seasonal storage like PtG can[86]. Although battery costs are expected to decrease in the next decades, even if they fall to €60/kWh by 2050, they will still be far more expensive to use for the seasonal storage of surplus renewable electricity compared to fuels based on PtG[87].

Previous calculations of how much energy needs to be stored seasonally in order to have a stable energy system vary, with the required amount estimated to be around 10% of the average demand in power capacity . The 1131 TWh of gas storage capacity available in the EU and the UK as a percentage of annual gas consumption is currently slightly higher (about 15%); in fact, current gas storage facilities – projected to grow somewhat during the next decades – can already deliver up to 22 TWh of natural gas a day[89].

The 2018 Ten-Year Network Development Plan includes an analysis that determines the total EU gas demand in high-demand cases (peak day and two-week cold case) for 2040[90]. According to this analysis, the gas demand in a 'two-week cold case' is between 25 and 28 TWh/day, with a maximum peak demand of 35 TWh/day[91]. Because our scenario suggests that the overall annual demand for gaseous energy carriers in NWE will remain relatively stable even in 2050, we assume that the current seasonal storage capacity, or slightly higher levels, will be broadly sufficient to store enough energy for the 'dark doldrums'.

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[86] European Power to Gas: Power-to-Gas in a Decarbonised European Energy System Based on Renewable Energy Sources, DNV GL

[87] Gas for Climate – The Optimal Role for Gas in a Net-Zero Emissions Energy System, Navigant, March 2019

[88] Blanco, H. & Faaij, A., August 2017. A review of the role of storage in energy systems with a focus on power-to-gas and long-term storage, Elsevier

[89] Gas Infrastructure Europe, 2018. Gas Infrastructure Europe - Storage Database

[90] TYNDP 2018, published by ENTSO-E and ENTSO-G

[91] An important factor to be considered for storage and security of supply is the difference between average or annual demand and peak demand. For industrial producers, grid reliability is of major importance in decisions on where to establish new business or to move existing business. Grid reliability is more affected by peak demand/low production situations than averages.

6.5. REQUIRED EU AND NATIONAL POLICIES AND MEASURES

The above sections discussed four of the main challenges facing the future NWE energy system: stimulating investments in renewable electricity generation; finding and creating an optimal balance between greening electricity and decarbonising fuels; guaranteeing the required flexibility to balance the energy system; and creating a sufficiently viable and secure back-up system. Addressing these challenges is crucial to generating a sustainable future energy system that achieves the main energy policy targets in a way that is optimal for European societies. As it is questionable whether the EU's policy regime is sufficient for this today or will be in the near future, here are a number of recommendations for each challenge to stimulate further discussion.

STIMULATION OF INVESTMENTS IN RENEWABLE ELECTRICITY GENERATION

The dominant market model in most EU Member States today is the energy-only model, under which a producer only receives compensation for the actual generation and sale of energy. This model can be problematic for producers of both renewable and fossil fuel-based electricity. The profitability paradox means that renewable electricity producers can expect low returns in the future, limiting the willingness of investors to expand renewable energy production. The predictability of the earnings of fossil fuel-based plants will fall further, with captured prices high just when there is less sun and wind, and demand for fossil fuel-based energy thus at its highest. At the same time, the fact that their role in providing baseload power will diminish strongly will decrease their level of operations and increase their risk profile.

- These issues could be addressed through a system that compensates for the availability of capacity. Rather than being compensated solely for the energy they produce, power producers would also be remunerated for the capacity they make available in the market. This capacity remuneration mechanism (CRM) is already in place in European countries such as France, Germany, Ireland and the UK, and will soon be implemented in Belgium. The EU is, however, critical of such a system as it is thought to distort electricity markets. In 2015, the EC expressed its concerns that CRMs are introduced in an uncoordinated manner and risk being inefficient and materially distorting cross-border trade and competition within the European internal energy market[92]. A 2016 study on this topic concluded that many Member States have failed to adequately assess the need for a capacity mechanism before introducing one[93]. Furthermore, many Member States have yet to implement the market reforms that are indispensable to delivering on issues regarding security of supply. The proposed reforms include the removal of low electricity price caps, enabling the participation of demand response in the market and matching bidding zones to network congestion. Only once these market reforms have been carried out should CRMs be considered, and if they are considered, the mechanisms should be made fit for purpose and open to all capacity providers.

- Market prices in the countries that do have CRMs tend to stay well below the value of lost load (VoLL),

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[92] Competition Policy and an Internal Energy Market, study for the ECON Committee, 2017
[93] Final Report of the Sector Inquiry on Capacity Mechanisms, European Commission, 2016

the price level at which demand shuts off. If prices are allowed to spike to these levels, investments in power generation with very few operating hours become profitable. However, the market takes a significant time to respond by bringing new capacity online, so such price spikes do not directly lead to the required additional capacity. They may, on the other hand, help unlock more DR capacity that can be made available much faster. The significant risk here is that the time lag between very high price spikes and increased DR or generation capacity causes a prolonged period of blackout risk or actual blackouts in the system.

- A study commissioned by TenneT and carried out by Ecorys on the topic of future energy market design concluded that adequate investment incentives can be provided in a 100% renewables market even without government subsidies[94]. While the model they envisage is in many ways more an evolution than a revolutionary change, interventions such as the establishment of CRMs may be required in the transition towards a 100% renewables market. The key reason is that the degree of uncertainty is far higher during a transition than after it.

- To address the financial risks related to the current variety of support mechanisms in NWE, these mechanisms should be harmonised on a European level. Determining long-term support mechanisms at an EU level can address both the inconsistency between individual country policies and the longer-term policy uncertainty of the national policies.

- The required investments in grid connections for newly built renewable energy generation should be facilitated by regulation which supports upfront investments. Furthermore, a multinational view and cooperation should be established with respect to TSOs in order to increase the willingness of their shareholders to invest in foreign markets.

- Renewable generation assets are typically built in regions with the lowest land costs, where network capacities can be limited. Research should be conducted into the optimal mix between renewable electricity generation in more expensive areas with sufficient network capacity and in areas with lower ground costs but less network capacity, which would thus include the costs for the required additional network capacity. The outcome of this research could help in the formulation of policies to discourage the connecting of renewable energy generation in regions with limited network capacity.

- Cost savings can also be realised through cable pooling, where a grid connection is built for a combination of solar and wind farms. Because the two types of connected generation facilities have different production profiles in a given weather profile, combined grid connections can have a lower capacity than two equivalent individual connections.

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[94] Investments in a renewables-only market, ECORYS, 2017

THE MAIN ENERGY SOURCE FOR APPLIANCES AND LIGHTING IN THE BUILT ENVIRONMENT WILL CONTINUE TO BE ELECTRICITY, MOSTLY FROM GRID-CONNECTED SOURCES. FOR OTHER APPLIANCES AND END USES, ELECTRIFICATION AND LOWER USE OF NATURAL GAS ARE TWO OBVIOUS COMING (LARGE-SCALE) TRANSITIONS.

OPTIMAL BALANCE BETWEEN GREENING ELECTRICITY AND DECARBONISING FUELS

To realise the best possible balance for renewable power storage and transmission, we suggest a set of incentives to speed up the production of low-carbon fuels.

- First, it is paramount that, in order to resolve the valley-of-death issue, a number of substantial regional demonstration projects in NWE covering the complete hydrogen (and derived products) value chain and related triple helix stakeholder collaboration be set up at short notice, collectively covering the feasible technology ranges of PtG. This will require a dedicated support scheme at the EU level of several billion euros, assuming at least ten demos/demo regions are needed, each requiring hundreds of millions in public support. Methanation, SMR and ATR including CCUS, green methanol production and related green chemicals, along with the implementation of hydrogen in mobility, the built environment and industrial production (as energy carrier and feedstock), should all be included in this set of demos, each of which would ideally cover the low-carbon gas value chain as completely as possible.

- New rules and regulations are required for the adaptation of/investment in gas transmission and distribution infrastructure for low-carbon fuels.

- A range of harmonisation and standardisation policies and measures need to be initiated to enable the large-scale adoption throughout the EU of biofuels, carbon-neutral hydrogen and derived products as energy carriers: in heavy mobility (including shipping, and aviation), in the built environment and in industrial production. This can be done through the introduction of standardised and harmonised rules with respect to health, security and environmental issues, guarantees of origin and other factors affecting the uptake of low-carbon gases.

- It is important to reassure potential investors in low-carbon gas production and conversion that there will be a serious market for renewable and carbon-neutral gases and derived products both in the feedstock and energy market. The industrial hydrogen feedstock market could be the first segment to get this moving, especially as it is so far still almost completely dominated by the uptake of grey hydrogen and grey carbon, both of which have a considerable carbon footprint. Policies and measures to rule out the industrial use of grey hydrogen or comparable feedstocks for these purposes within a clear timeframe would give an immediate boost to the expected demand for carbon-neutral gases and potentially speed up investment and support the learning curve. Large-scale adoption of CCUS would be one of the requirements for quickly ramping up the production required to fulfil the created demand.

- Another option with immediate impact would be the creation of a market for renewable and carbon-neutral gases for energy purposes. Policies that prescribe the admixing of these gases to the EU gas system could be adopted in an approach similar to that with regard to fuels for mobility. Such gases could be based on biomass or consist of low-carbon hydrogen up to a certain (20%, say[95]) share to be gradually reached, starting with 5% by 2025, for instance. The system could be based on guarantees of origin so that physical admixing in the grid would not be necessary. Imported gases into the EU would need to be subject to the same admixing procedures either inside or outside the EU for such policies to be effective.

- Next to these policies and measures, which would create incentives for investors to start up large-scale PtG activity, there is need for a significant research programme into PtG to assess the issues and obstacles that will need to be addressed to avoid unnecessarily slowing down the process of adopting lower-carbon fuels.

FLEXIBILITY REQUIRED TO BALANCE THE ENERGY SYSTEM

To facilitate the unlocking of flexible capacity to aid the balancing of the energy system, and the power system in particular, price formation in the electricity market needs to reflect system requirements: low or very low prices in case of overproduction and high or very high prices in case of scarcity. Such price setting will particularly stimulate large consumers to consider flexibility in their offtake and ways to better manage their energy consumption (and production) profiles.

To deal with grid congestion, greater flexibility from demand-side resources can also be more forcefully developed/incentivised by limiting the obligations of network development and operation parties (TSOs and DSOs) to fully (and redundantly) connect all developments of distributed generation. If not all power can always be fed back to the grid for energy sales to parties located outside the congested area. Parties within the congested area will be forced to look at alternative ways of using it, opening up more potential for options such as local conversion and/or storage.

As with the digitalisation of the rest of our society, the tools required to unlock flexibility from the demand side through digital solutions should respect the privacy and information rights of all connected and involved parties. Foundations for a smart energy system that connects the involved stakeholders while respecting the basic rights of each party can be found in the Universal Smart Energy Framework (USEF), for example[96].

To guarantee a sufficient level of flexibility to balance the energy system, we suggest the following measures:

- Set up demonstration projects covering the various flexibility options in various energy systems settings (prosumers, industry mobility).

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[95] Development of Business Cases for Fuel Cells and Hydrogen Applications for Regions and Cities, FCH, 2017

[96] Further information is available on https://www.usef.energy/.

- Organise the co-financing of projects of common interest (PCIs), enhancing flexibility and system integration. This includes installing gas and electric interconnectors within NWE and between NWE and the rest of Europe or stimulating the installation of offshore cross-border facilities like sandy or platform-based energy islands.
- Put in place harmonised regulations and rules regarding DER, prosumers and aggregators among EU member states to facilitate a level playing field.
- Make households and businesses more responsible for flexibility via the regulation or economic incentives such as supporting the introduction of smart metering and the use of smart meter data by parties like aggregators.

CREATING A SUFFICIENTLY VIABLE AND SECURE BACK-UP SYSTEM

Energy backup systems are often expensive, in part because they are only used occasionally in periods when there is no renewable energy production. The key policy question therefore is whether sufficient financial incentives are provided by the market for spontaneous investments in such systems up to the socially desirable security of supply levels. As the market cannot guarantee this, policies and measures to remedy the situation may be considered. This means:

- Supporting demonstration projects covering the various back-up applications.
- Clarity on regulatory and ownership roles with respect to backup systems, including energy storage, transport and production.
- Clarity in the Member States on the role and mandate of TSOs and other potential actors to take up backup service responsibilities or provide backup services, such as DSOs.
- A clear framework describing the potential role of the import of back-up services provided from one Member State to the other, and also from non-EU partners to EU Member States.
- Resolution of the current lack of financial incentives to invest in large-scale green energy backup capacity and service provision. This can be done through measures like introducing capacity remuneration mechanisms and guaranteeing sufficient securities for banks and other financial institutions to fund such backup capacity.
- A common framework of rules on how to prevent, prepare for and manage electricity crises, and how to strengthen the coordination of regulation, including on the role of ACER.

SECURITY OF SUPPLY AND ENERGY IMPORTS

- To ensure the security of energy supply during the energy transition, the topic of energy imports should be higher on the political agenda in NWE. International relationships should be strengthened in order to keep the focus of energy-exporting countries on Europe and to ensure a sufficient level of investments. The use of existing assets should be optimised in order to make the energy transition affordable.

- More integrated plans considering various alternatives should be developed. As stressed by the IPCC, only the implementation of a very extensive combination of all available low-carbon technologies will allow us to keep global warming to 1.5-2.0 degrees Celsius. Due to the many claims on green electricity, the generation capacity for renewable electricity currently being developed may not be enough to supply all envisaged uses. Other forms of low-carbon electricity generation may be needed if the emissions targets are to be met. With respect to physical fuels, policy should target both green and low-carbon solutions. Large-scale adoption of CCUS will allow Norway to monetise its natural gas resources and support the security of supply for NWE.

- To retain the current level of industrial production in NWE, the decarbonisation ideas brought forward by industry stakeholders themselves should be taken into account. Only by making cooperative agreements and ensuring a level playing field for productive industries and the entire EU economy can their competitive position be maintained. This should also be factored into the implementation of local initiatives on carbon pricing in addition to the ETS system, in order to prevent carbon leaks resulting from heavy industries moving to lower-taxed regions outside NWE. EU-wide policies to level the playing field such as the carbon border adjustment mechanism mentioned in the European Green Deal could also help.

- Finally, to limit the possibility of sudden energy crises, strategic, long-term energy supplies should also be maintained.

6.6. CONCLUSIONS

A socially optimal energy mix that achieves the EU's triple energy policy targets will not be reached overnight nor automatically. It will require a lasting, consistent and credible set of incentives for all stakeholders involved based on clear policies and measures. In NWE this will typically involve policy action at the EU and national levels.

To balance the energy targets, energy policy design should focus on the energy system as a whole, rather than on separate components. Energy can take various forms and carriers, but smartly designed conversion, transport and storage infrastructure facilitates an energy mix in which the social and other costs of the energy system can be minimised, affordability supported, greening secured, and acceptable levels of security of supply and demand guaranteed.

This report concludes that, although the current set of EU and national policies and measures is promising, additional new policies will still be needed to maximise the chances of achieving the EU's energy policy targets in general and the 2050 emissions reduction target in particular. A specific point of concern with respect to the energy mix development is the fact that, unlike the greening of power – which seems to be broadly on track – the introduction of more low-carbon fuels is still strongly lagging behind, with little perspective on a catch-up in the foreseeable future. This is a major concern as fuels are the backbone of the NWE energy system today and likely to remain so as we move towards 2050. Achieving the EU's 2050 target will therefore require switching to lower-carbon fuels to be a prime policy priority in the current decade.

The key technologies for generating large volumes of carbon-free fuels are hydrogen production from natural gas with CCUS (sometimes referred to as the blue hydrogen route) and PtG, i.e. turning green power into green fuels. Both technologies generate hydrogen as the main energy carrier and both technologies are on the whole still not market-ready (and in fact in the valley of death) – but should become so as soon as possible.

The positive thing about the blue hydrogen route is that it may become feasible relatively soon, opening up a perspective for introducing carbon-neutral hydrogen to the market. The drawback is that the carbon capture capacity and costs may at some stage come to represent bottlenecks in the long-term perspective, or that blue hydrogen strongly benefits from learning effects and locks out the development of green hydrogen.

The positive characteristic of PtG is that it not only undisputedly generates the green fuels needed for an optimal energy mix, but also contributes to dealing with two of the main challenges resulting from the massive introduction of intermittent renewables: the need for flexibility to balance the electricity grid and backup capacity for dark doldrums. The technological flexibility of PtG technologies means they can also generate flexibility for the power market, the more so because the gases produced can be transported cheaply via the existing gas grid, stored at large scale at relatively low costs and converted back into power whenever needed. PtG can also contribute to backup challenges for the same reasons. Finally, if Europe acts as a first mover with respect to the innovative PtG technologies, it may benefit from a P2G technology-competitive edge on the international market.

Dedicated policies and measures will have to be put in place to ensure that all these promises for the optimal future energy system and optimal energy mix can be realised. We consider these the most important policy measures to be introduced as a first step:

1. Setting **milestones** and ultimate targets – continuing to make sure that the right intentions are in place;
2. Managing the conditions for a **simultaneous emergence** of demand and supply;
3. Upholding the principle of **technology neutrality** with respect to sources of renewable power and carbon-free fuels;
4. Ensuring that **markets** function well and playing fields are level for all private parties;
5. **Admixing** carbon-neutral gases to stimulate their production & use and cross the fuels valley of death;
6. Dedicated support scheme on an EU level to scale-up **hydrogen and PtG** production with the same purpose;
7. Facilitating the **uptake of hydrogen on the demand side** by:
    - Introducing policies and measures to rule out the industrial use of grey hydrogen or comparable feedstock;
    - Incentivising the development of a fuelling infrastructure for hydrogen and other green fuels;
    - Tackling the greening of the aviation and shipping sectors. ■

Appendices

A. EU ENERGY POLICY FRAMEWORK AND RECENT EU ENERGY POLICIES

The goal of the EU Energy Union Strategy, published in 2015, is to build an energy union which gives EU consumers **secure, sustainable, competitive and affordable energy**. This is to be done by building on five pillars:

1. Security, solidarity and trust – a focus on the diversification of energy sources and ensuring energy security through solidarity and cooperation between EU countries;
2. A fully integrated internal energy market – a focus on building the EU energy infrastructure and removing technical or regulatory barriers;
3. Energy efficiency;
4. Climate action, decarbonising the economy – a focus on the Paris Agreement climate goals and on renewable energy; and
5. Research, innovation and competitiveness – a focus on R&D and R&I to foster the energy transition.

The progress made in the transition towards the Energy Union is laid out in progress reports, with the latest, the Fourth State of the Energy Union report, published in April 2019.

An important step towards the implementation of the Energy Union Strategy is the Clean energy for all Europeans package published in November 2016. This package updates the EU's energy policy framework to help deliver on the EU's Paris Agreement commitments and enhance the energy transition. The eight legislative proposals included in the package were agreed upon in 2018 and early 2019 and are to be transposed into Member State law in the coming one to two years.

The measures from the package aim to provide a new market design which better addresses new challenges via greater coordination of legislation, planning, guidelines and new institutions. The Regulation on the governance of the Energy Union and climate action establishes a regulatory framework for the governance of the Energy Union. It includes measures which streamline and integrate the planning, reporting and monitoring requirements in the energy and climate fields, and which define a political process between the Member States and the Commission, also involving other EU institutions, with the aim of achieving the Energy Union objectives. Each Member State is required to draft an integrated ten-year national energy and climate plan (NECP) for the period 2021 to 2030. The NECPs outline how EU countries plan to achieve their respective targets on all dimensions of the Energy Union, including a longer-term view towards 2050. The Governance Regulation (EU(2018)1999) has been in force since December 2018, and all Member States submitted their draft NECPs by early 2019. The Commission published an analysis of each draft plan with recommendations to be taken into account by the EU countries, which need to finalise the NECPs by the end of 2019.

The Directive on the promotion of the use of energy from renewable sources lays out the principles of an updated renewable energy framework. It sets a binding target of 32% for renewable energy sources in the EU's energy mix by 2030.

The design of the internal market for electricity is shaped by four dossiers: the Regulation on the internal market for electricity[97], the Directive on common rules for the internal market for electricity, the Regulation on risk-preparedness in the electricity sector and the Regulation establishing a European Union Agency for the Cooperation of Energy Regulators. The goal is to establish a modern design for the EU electricity market – one which has greater flexibility, is more market-oriented and is better placed to integrate a larger share of renewables. The measures establish key principles for electricity trading rules, measures to reinforce existing consumer rights and to introduce new rights, and a common framework of rules on how to prevent, prepare for and manage electricity crises. They also strengthen the role of ACER[98].

Announced in December 2019, the European Green Deal is a package of measures that should lead Europe into a sustainable green transition. The Commission has, for instance, announced that it will propose a European 'Climate Law' by March 2020 which will place the 2050 climate-neutrality objective into legislation, as well as a carbon border-adjustment mechanism.

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[97] The 'Regulation on the internal market for electricity' sets out the key principles for national energy legislation to allow for a functioning internal electricity market and for electricity trading rules within different timeframes (balancing, intraday, day-ahead and forward markets).

[98] ACER is the Agency for the Cooperation of Energy Regulators and was established to ensure that the single European market in gas and electricity functions properly. It assists national regulatory authorities in performing their regulatory function at the European level and, where necessary, coordinates their work.

B. ENERGY SCENARIO:

For the years up to 2030, the scenario applied for the nine EU Member States is based on the projections in the EUCO3232.5 scenario of the EC, which was presented in 2019.

The EUCO3232.5 scenario is part of a group of EUCO scenarios used in EU energy and climate policy development that have been derived from the EU Reference 2016 scenario. These scenarios were the basis for a number of impact assessments and the negotiations of the legislative acts proposed under the EU 2030 energy and climate policies.

The EUCO3232.5 scenario is based on the legislation introduced under the EC's Clean Energy for All Europeans package. This package established policies and targets for the European energy policy for 2030, including a share of at least 32% renewable energy in the EU energy mix and an improvement in energy efficiency of at least 32.5% at EU level. These complemented the 2030 greenhouse gas target of a reduction of domestic emissions by at least 40%.

From 2030 to 2050, the scenario for the nine EU Member States is based on the scenario underlying the EU Energy Roadmap 2050. This roadmap explores various routes which should lead to the overall goal of an 80-95% emission reduction by 2050.

For Norway, the scenario is based on an extrapolation of historical trends. With respect to the estimated oil and gas production and export levels, forecast data from the Norwegian Petroleum Directorate and Equinor has been taken into account.

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