# Getting fit for 55 and set for 2050

## Electrifying Europe with wind energy

June 2021

ETIP Wind
EUROPEAN TECHNOLOGY & INNOVATION PLATFORM ON WIND ENERGY

WindEurope

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ETIPWind®, the European Technology and Innovation Platform on Wind Energy, connects Europe's wind energy research community. Key stakeholders involved in the platform include the wind energy industry, political stakeholders, and research institutions. ETIPWind was established in 2016 to inform Research & Innovation policy at European and national level. ETIPWind provides a public platform to wind energy stakeholders to identify common Research & Innovation priorities and to foster breakthrough innovations in the sector.

WindEurope is the voice of the wind industry, actively promoting wind power in Europe and worldwide. It has over 400 members with headquarters in more than 35 countries, including the leading wind turbine manufacturers, component suppliers, research institutes, national wind energy associations, developers, contractors, electricity providers, financial institutions, insurance companies and consultants. This combined strength makes WindEurope Europe's largest and most powerful wind energy network.

### METHODOLOGY AND REFERENCES:

DNV has been contracted by ETIPWind to provide supporting analysis, in particular analysis the trends presented in the EC COVID MIX scenario. It is referred as **DNV for ETIPWind, March 21**

The report makes many references to the modelling work done by PRIMES for the European commission as part of the 2030 Impact assessment, published in September 2020. It is simply referred as **European Commission Impact assessment, COVID MIX scenario, 2020**, the full reference is the following: European Commission (2020). Impact assessment in support of the Commission Communication COM (2020) 562 final. Stepping up Europe's 2030 climate ambition – Investing in a climate-neutral future for the benefit of our people.

The electrification of industry analysis is based on recent academic work that gathers extensive evidence, based on 49 scientific publication. It is referred as **Madeddu et al 2020**. The full reference is: Madeddu et al 2020 Environ. Res. Lett. 15 124004


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# Executive Summary

The EU has committed to cut greenhouse gas emission by 55% compared to 1990 by 2030, a key milestone in reaching climate neutrality in 2050. The European Commission's analysis shows that direct electrification, complemented with the indirect electrification of hard-to-abate sectors, is the most cost-effective and energy efficient way to cut energy sector emissions to net-zero by 2050.

This report shows that deep decarbonisation of the economy is possible. In fact, it will cost no more as a share of GDP than our energy system costs today. And it will dramatically reduce external costs, notably of air pollution, not accounted for today. The technologies that will deliver the bulk of decarbonisation are already available or in development today but need the right market signals to be deployed at scale.

The EU can deliver on climate neutrality by rigorously prioritising the deployment of future-proof technologies, investments in infrastructure and the development of the right business models. And at the same time it can fully reap the economic and societal benefits of renewables-based electrification.

## Electrification is the most cost-effective path to climate neutrality

- The European Commission's scenarios show renewables-based electrification will be central to delivering climate neutrality by 2050. They show that more than three quarters of the final energy demand will be electrified. Electricity will directly cover 57% of final energy uses while providing another 18% indirectly through hydrogen and its derivatives.
- According to the Commission's scenarios, this will require the electricity system to grow to 6,800 TWh from less than 3,000 TWh today.
- And it will require wind to be 50% of the EU's electricity mix with renewables representing 81%.
- Delivering a climate-neutral economy will not lead to higher costs for society. The energy system cost relative to GDP will be similar to 2015 levels - 10.6% of GDP.
- Wind energy will become the no. 1 source of electricity in Europe shortly after 2025 and by 2030 it will provide 25% of the EU's electricity needs.

## Wind energy will sustain cost reductions and meet growing demand from business and society

- The costs of wind energy will continue to decline significantly over the next 30 years thanks to rising turbine size and capacity factors and optimised ways of installing and operating wind farms.
- Onshore wind will continue to be among the most cost-efficient forms of power generation across Europe. Onshore wind energy will fall another 28% to 2030 to 33€/MWh.
- Offshore wind will also see significant cost reductions by 2030. Bottom-fixed offshore wind costs will fall by 44% to 48€/MWh and floating offshore wind costs will fall by 65% to 64€/MWh.
- Offshore wind turbine size will double in the next ten years and multi-GW offshore wind farms connected to multiple countries will provide bulk power and crucial grid services to the transmission grid.
- Industrialising floating offshore wind will allow us to tap into massive wind resources in areas with a water depth beyond 60 metres notably in the Mediterranean and Atlantic Ocean.
- Repowering will be a key driver in delivering a net-zero economy. Repowered wind farms typically have 1/3 fewer turbines and three times the output as the initial project.
- Innovations that further reduce noise, mitigate collisions of birds and bats and reduce the visual impact of onshore wind turbines will ensure seamless integration into the onshore environment.
- Recycling existing materials and designing fully circular wind turbines will also further minimise wind's environmental footprint.

## Electrification can drive the decarbonisation of Industry, Buildings and Transport

- Industry could directly electrify 76% of its power and heating consumption with technologies that are commercially available. We will need to scale up the supply chain of these technologies, such as electric arc furnaces and infrared heaters to meet growing industry needs.
- Industry could electrify even more of its power and heat consumption with the development of emerging technologies including thermal plasma heating, electrolytic reduction of iron ore (electrowinning) and electric steam crackers and reformers.
- Reaching net-zero emissions in industry will also require the substitution of fossil-fuel feedstocks with renewable hydrogen and derivatives in steel, cement, chemicals, and refineries.
- The passenger vehicles market will be fully electric by 2050. Battery electric vehicles are six times more efficient than conventional cars which will help decrease total sector demand.
- Battery electric vehicles will soon reach cost parity with internal combustion engine vehicles, but their deployment depends largely on the currently lagging expansion of charging infrastructure.
- Short-distance maritime transport can technically be electrified, but investments in ports is still needed to provide robust infrastructure. For deep-sea transport, renewable-based ammonia appears one of the most promising technology along with renewable hydrogen.
- Heat pumps will drive the decarbonisation of heating and cooling in buildings, by almost tripling electrification rates in residential buildings.

## The power grid will remain the backbone of a climate-neutral energy system

- Boosting electricity grids investments is indispensable to delivering climate neutrality, system-wide planning will allow Europe to leverage indirect electrification notably via hydrogen valleys.
- Grid investments need to double from the current €40bn a year by 2025 at the latest. And by 2030 Europe needs an additional 85 GW of interconnector capacity on top of today's 50 GW.
- One in three grid infrastructure investments have been delayed or rescheduled. The upcoming Ten-Year Network Development Plan (TYNDP22) must address this by including all the infrastructure investments needed to deliver on Europe's 55% climate target.
- The EU needs to deploy an optimised offshore grid to deliver on its objective of 300 GW of offshore wind by 2050. Sea basin planning, speeding up permitting, and new market arrangements ensuring offshore hybrid projects are pre-conditions to having an optimised offshore grid.
- The investment framework for TSOs and DSOs should reward anticipatory investments and investments that deliver the most TOTEX benefits, rather than focusing exclusively on lowering the CAPEX.

## A climate neutral and resilient energy system requires investment in flexibility solutions

- Managing the energy system will become more complex as increased electricity demand and variable renewable energy sources will increase variability – notably in the daily time frame.
- With the right price signals, road transport, heating and cooling and hydrogen production can provide most of the demand-side flexibility needed to manage a renewables-based energy system.
- Grid interconnections play a crucial role in leveraging flexibility from neighbouring countries to alleviate technical constraints such as congestion and peak load.
- Daily flexibility needs can be provided by State-of-the-art variable renewables, demand response from industry and heat pumps in buildings and battery storage – stationary and vehicle-to-grid.
- Weekly and seasonal flexibility needs can be met by hydropower and pumped hydro-electric storage, power-to-hydrogen and the limited use of dispatchable power plants e.g. bioenergy combined with CCS.

# Policy recommendations

Wind energy will be the cornerstone of a resilient, cost effective and climate neutral energy system by 2050. By ruthlessly prioritising future-proof technologies, investments in infrastructure and the development of the right business models, the EU can deliver on this while fully reaping the economic and societal benefits of renewables-based electrification. To deliver on our 2030 climate and energy targets and set the course for climate neutrality we call on the EU to:

## 1. Unlock a massive supply of competitive renewable electricity by:

1) Supporting National Governments in simplifying permitting of wind projects, and ensuring authorities have the necessary resources to consent enough wind sites.
2) Ensuring EU State aid rules to 2030 help unlock wind investments thanks to Contracts for Difference and technology-specific auctions.
3) Ensuring spatial planning mainstreams climate targets and helps accelerate wind deployment.

## 2. Plan for and accelerate buildout of the infrastructure needed for a net-zero energy system by:

1) Doubling the rate of investments in electricity grids supporting anticipatory investments to address growing industry demand for electricity, notably through the Recovery and Resilience Plans.
2) Coordinating buildout of electricity grids with renewable hydrogen infrastructure.
3) Urgently addressing regulatory barriers for investments in an optimised offshore grid notably in hybrid offshore power plants.
4) Avoiding public spending in infrastructure incompatible with a renewable electricity-based energy system.
5) Setting national binding targets for e-charging and $H_2$ refuelling infrastructure.
6) Adapting the investment framework for grids to account for TOTEX and not just CAPEX savings.

## 3. Focus Research & Innovation funding on the technologies that will deliver climate neutrality by prioritising:

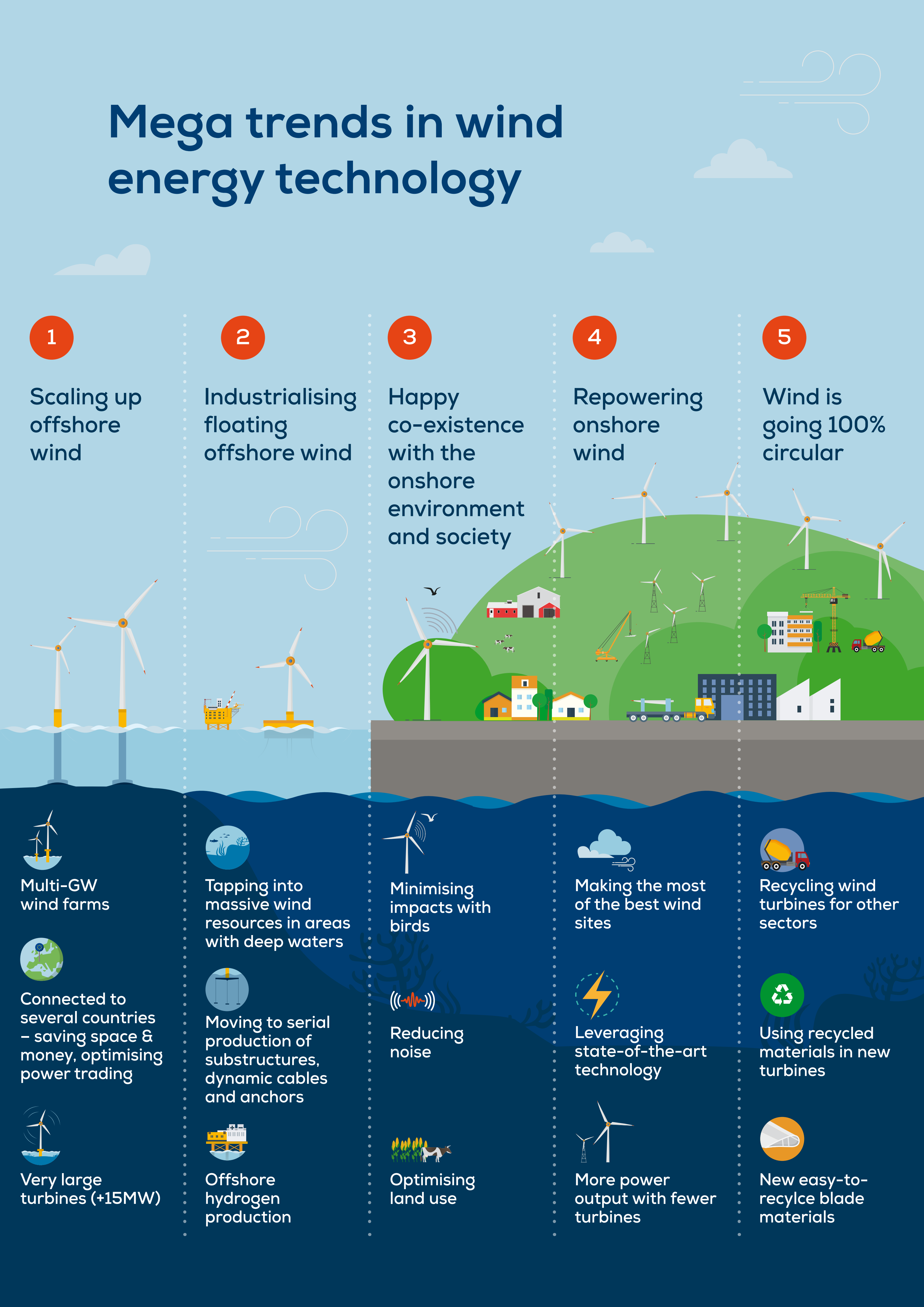
1) Incremental improvements in mature technologies notably onshore wind – digitalised operation and maintenance and robotics.
2) Grid integration and optimisation including interoperable HVDC infrastructure.
3) Bottom-fixed offshore wind balance of plant – e.g. dynamic, smart and lead-free cables - and floating offshore wind design suited for industrialisation.
4) Sustainable materials towards fully recyclable wind turbines.
5) Grants for fundamental research and mobility schemes for early stage researchers.

## 4. Send a carbon price signal and adapt taxation to shift away from fossil fuel consumption by:

1) Aligning the ETS with the EU's new climate target and setting up adjacent carbon pricing mechanisms for mobility and buildings.
2) Reflecting carbon intensity in energy taxes and levies as part of the Energy Taxation Directive.

## 5. Drive demand for renewables by:

1) Accelerating the uptake of corporate renewable PPAs through allowing all renewable electricity to be underpinned by Guarantees of Origin.
2) Closing the cost gap between fossil and renewable hydrogen, while accelerating the scaling up of electrolysers.
3) Setting targets for renewable energy consumption in hard to abate sectors and minimum target to 2030 for renewable hydrogen as a share of overall hydrogen consumption.
4) Strengthening the $CO_2$ emission performance standards for cars and vans by setting a reduction target of at least 50% and moving it forward to 2027.
5) Increasing requirements for renewable and efficient heating in buildings through targets for new and refurbished buildings.



Mega trends in wind energy technology
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Scaling up offshore wind
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Industrialising floating offshore wind
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Happy co-existence with the onshore environment and society
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Repowering onshore wind
5
Wind is going 100% circular
Multi-GW wind farms
Connected to several countries – saving space & money, optimising power trading
Very large turbines (+15MW)
Tapping into massive wind resources in areas with deep waters
Moving to serial production of substructures, dynamic cables and anchors
Offshore hydrogen production
Minimising impacts with birds
Reducing noise
Optimising land use
Making the most of the best wind sites
Leveraging state-of-the-art technology
More power output with fewer turbines
Recycling wind turbines for other sectors
Using recycled materials in new turbines
New easy-to-recycle blade materials

# Introduction

This report looks at how the electrification of the economy, directly and indirectly through the use of renewable feedstocks, gases and fuels, is the most efficient and affordable strategy to decarbonise Europe.

**Chapter 1 summarises the 2050 decarbonisation scenarios of the European Commission.** It explains the role of electrification in reducing final energy demand and emissions. It explains the implications of this for the power sector and considers the wider economic impact.

**Chapter 2 explores the role of wind energy in decarbonising the energy sector**. The technological trends that are bringing down the cost of wind energy. And other cost considerations beyond the cost of electricity.

**Chapter 3 explains why most energy consumers will opt for direct electrification with renewables.** For those facing significant obstacles to decarbonisation (the so-called harder-to-abate sectors), we look at how the indirect use of renewable electricity to produce hydrogen and its derivatives will play a crucial role.

**Chapter 4 presents the system infrastructure needed** to make the decarbonisation of the economy possible. We look at the pace required to expand the power grid. And priorities to maximise energy system resilience to cope with increasing extreme weather effects and other risks.

**Chapter 5 dives into the enabling technologies that must accompany renewable energy sources** on the path towards decarbonising of the energy system. We focus on the technologies that will help facilitate flexibility needs in the power sector driven by new users of electricity and larger shares of variable renewables.

**Chapter 6 gives recommendations to enable faster deployment** of wind energy and renewable-based electrification. What enabling policies will foster market uptake and technological innovation both in the supply and demand sides?

# 1

# The path towards net-zero $CO_2$ emissions

The EU has pledged to reach net-zero carbon emissions by 2050. It will need to abate the 3.5 Giga tonnes of $CO_2$ equivalent[1] it emits per year today. Energy use is responsible for three quarters of these emissions. Transport, buildings, and industry are each responsible for approximately 30% of energy-related $CO_2$ emissions. Decarbonising these sectors is vital to reach the net-zero target.

The EU has no time to lose in aiming for climate-neutrality. Frontloading emissions reduction over the next decade is possible and would be beneficial for the climate and the economy. By 2030 the EU already pledges to reduce its emissions by 55% compared to 1990 levels. To this end, the share of renewable energy in final demand will need to double from 20% today to 38-40% by 2030.

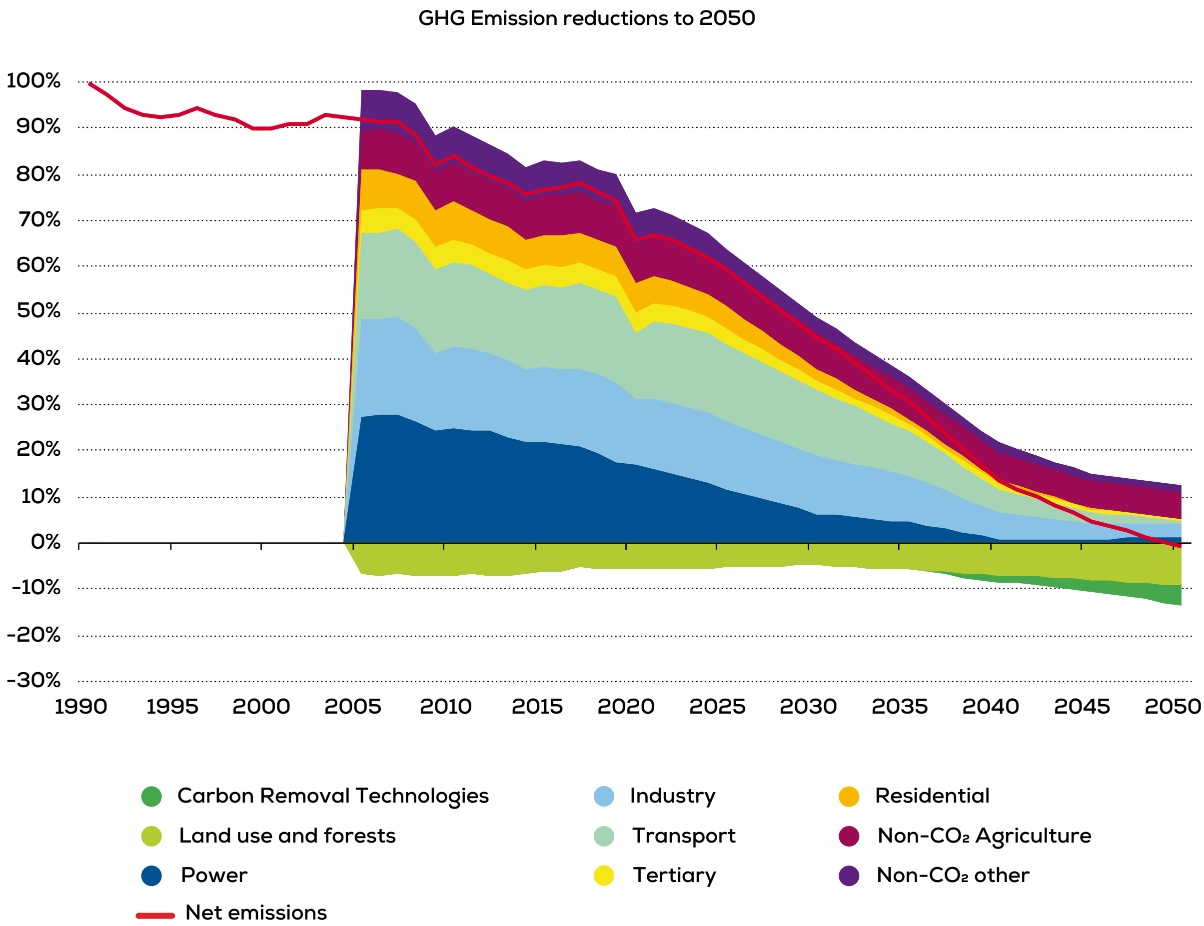



**Figure 1.** EU-27 GHG emissions reductions to 2050 compared with 1990 levels. Source: European Commission Impact Assessment, 2020.

The European Commission has made it clear that in order to become the first net-zero emissions continent, we have to see increased renewables-based electrification in Europe. This expansion of clean electricity will supply energy across all sectors of the economy and rapidly decrease final energy demand as well.

As it stands electricity accounts for only 25% of the energy consumed by industry, transport, and buildings. The European Commission says electricity should cover at least 30% of final energy demand by 2030 and at least 57% by 2050. This is more than double today's electricity share in the energy mix.

Total electricity production will double from 2,760 TWh today to 6,800 TWh by 2050. And most of this will be renewable electricity. The European Commission expects renewables to provide at least 81% of electricity in 2050. Wind energy will be the main electricity source after 2025, supplying 25% of the EU's electricity needs. By 2050 it will supply 50% of the EU electricity mix; onshore and offshore wind representing 33% and 17% respectively.

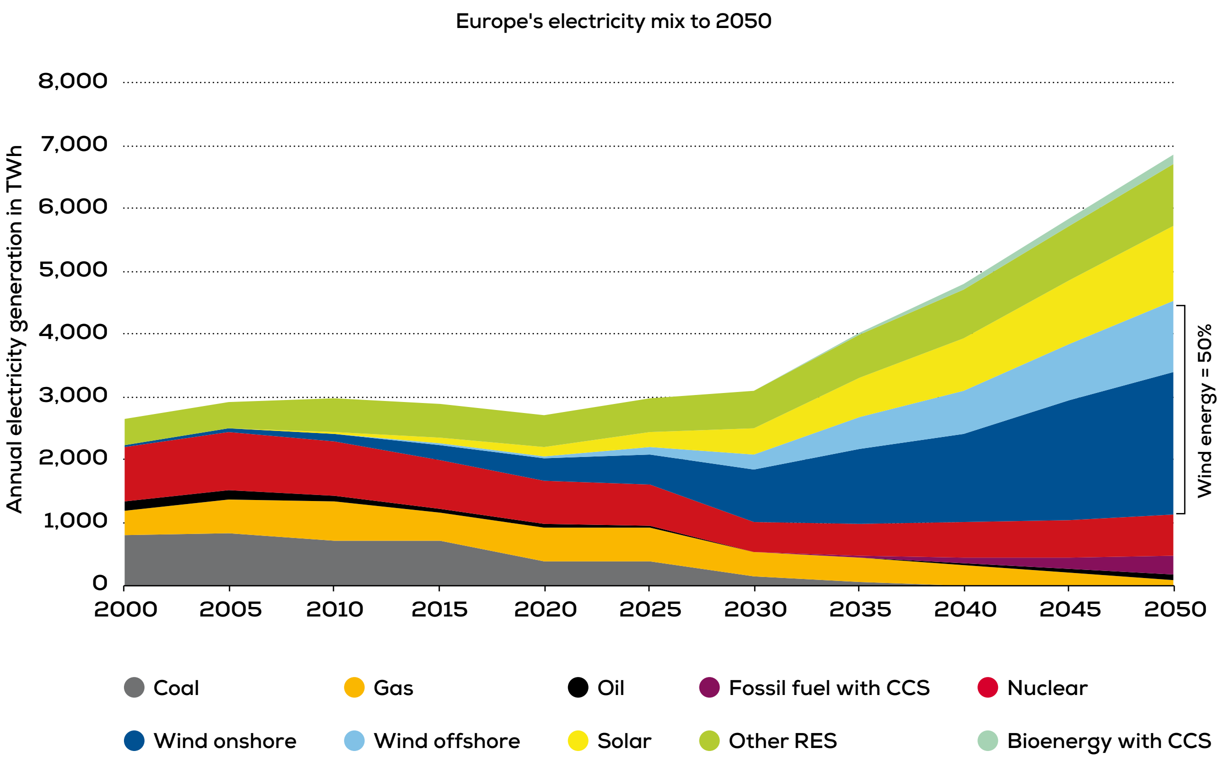


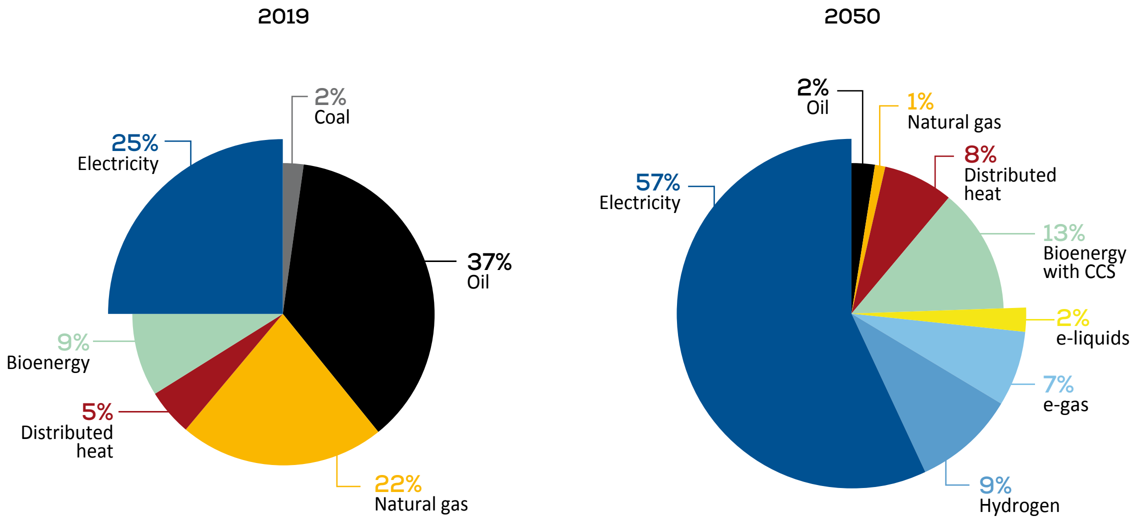

**Figure 2.** EU27 Electricity production mix to 2050. Source: WindEurope based on European Commission Impact Assessment, COVID MIX scenario, 2020.

Roughly two thirds of the electricity produced will be directly used by industry, buildings and transport, as this is the most efficient way to use the energy. And one third of the electricity will go towards producing renewable hydrogen and its derivatives, such as ammonia and e-kerosene. By 2050 these fuels would provide 18% of final energy demand[2], allowing hard-to-abate sectors to decarbonise.

Electricity will be responsible for meeting about 76% of the final energy demand, 57% directly and 18% indirectly using hydrogen and e-fuels[3].

Other scenarios[4] have shown that decarbonisation would be achieved with similar or higher direct electrification rates (around 60%). There is wide consensus that direct electrification will need to double in scale. The energy system, particularly the power grid, will need to rapidly expand and evolve to accommodate the production of these new fuels by coupling renewable power plants, electrolysers and related hydrogen infrastructure.

Final energy demand by energy carrier




**NOTE:** We assume that 100% of the "other RES" presented in the EC's scenario is ambient heat powered by heat pumps, which is allocated to direct electrification. It assumes 100% of hydrogen to be produced from electricity by 2050. E-fuels are also produced through electrolysed hydrogen, as specified in the EC impact assessment.

**Figure 3.** EU-27 final energy demand by energy carrier. Source: European Commission Impact Assessment, COVID MIX scenario, 2020.

Energy system costs in 2050 will be roughly the same as a share of GDP as in 2015. But the value of the energy system will be much higher than it is today as the externalities of fossil fuels such as the cost incurred by air pollution, water consumption and land use will be mitigated by the uptake of renewable energy technologies. The overall societal return on investment will be positive. In 2015, energy system costs represented 10.6% of the EU-27 GDP. In the period up to 2030 the average annual energy system costs would need to be worth about 11% of GDP to meet the new 55% GHG reduction target. But once earlier investments start to pay off the costs will begin to drop. By 2050 the annual cost should be worth 10.4%, or below 2015 levels.

A net-zero economy by 2050 can be achieved while yielding benefits in the form of renewable electrification – central to the energy system's transformation. But as will be shown in the following chapters, a number of crucial questions remain which policymakers and industry leaders will need to address going forward.

# 2

# The role of wind energy in the energy system transformation

## 2.1 The potential and ambitions for wind energy in Europe

Wind energy is a natural, clean, sustainable, and readily available energy source. And Europe has abundant wind energy resources. Public acceptance (not in my backyard syndrome) and technical constraints notwithstanding, wind resources in Europe have the potential to generate more than 33,000 TWh annually[5]. This would be enough to meet Europe's annual electricity demand ten times over. More than 8,000 TWh could be produced by onshore wind and more than 25,000 TWh from offshore wind. 60% of that would be accessible through floating solutions in waters deeper than 60m.

In 2020 wind energy produced 458 TWh in Europe (382 TWh in the EU27), making up 15% of the EU-27's electricity mix, and overtaking coal generation for the first time[6].

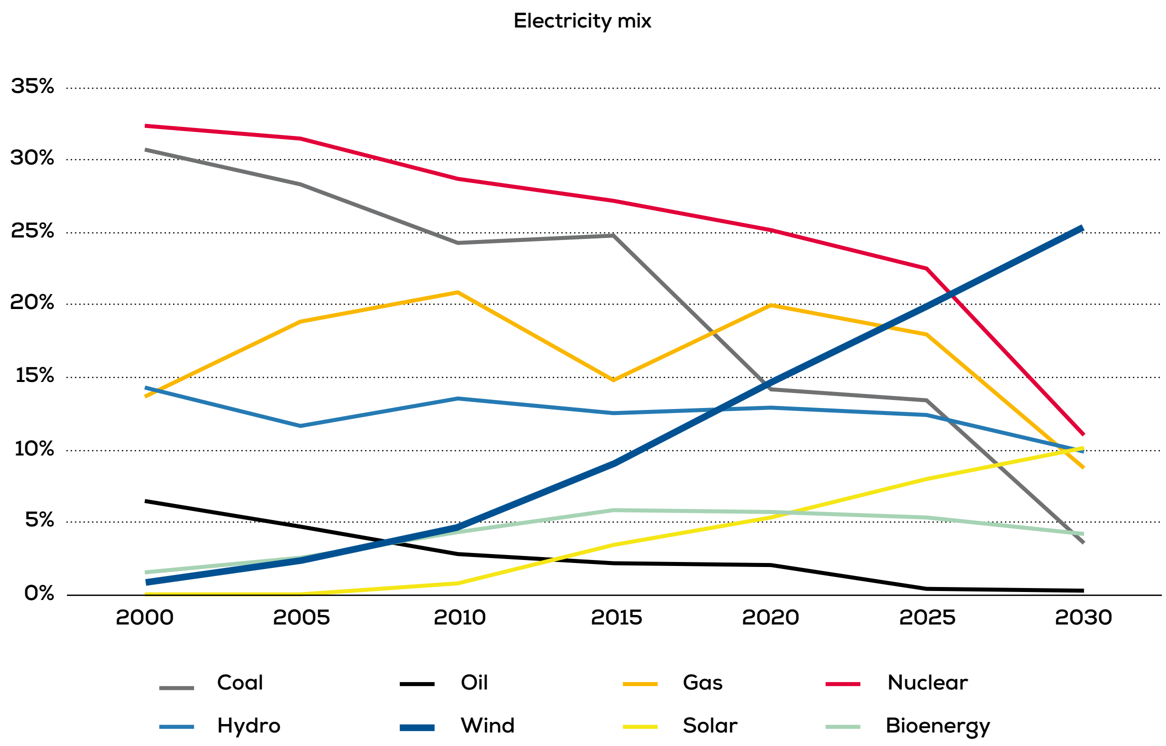



**Figure 4.** Electricity mix EU27. Source: Eurostat, Ember and WindEurope for historical data. Projections: European Commission Impact Assessment, COVID MIX scenario, 2020.

To deliver a climate neutral economy we will need to make greater use of today's' wind energy potential. The European Commission's scenarios see wind becoming the main electricity source for the European power system shortly after 2025 – by 2030 it will cover 25% of all electricity needs. Wind energy will also cover 50% of Europe's electricity production and one third of total final energy demand, as presented in chapter 1.

Onshore wind would be expected to generate about 2,300 TWh per year by 2050. For offshore, the figure would stand at 1,200 TWh. Together they would generate more electricity than that produced for the whole of Europe today. However, the split between onshore and offshore is indicative. The International Energy Agency for example expects offshore wind to become the largest source of electricity in Europe as soon as 2040[7]. The differences in these predictions stem from underlying assumptions about costs, capacity factors and lifetime, as discussed in section 2.2.

## 2.2 Technology improvements support cost reduction

The average size and power of wind turbines has grown significantly in the last 20 years.

In 2000 the average size of an onshore wind turbine was still below 1 MW. Today they are almost 3 MW on average. And we are beginning to see the first orders for onshore turbines with a capacity of 6 MW. This is mainly due to the new auction system and high market competition, which leads manufacturers to develop and bring newer more powerful models onto the market earlier, improving the economics of wind farm projects.

At the same time, the average size of onshore wind farms has doubled in the last four years, driven by the Nordic markets and Spain where there are fewer space constraints than in central and western Europe.

The growth in turbine sizes is even more pronounced in offshore wind. In the last 20 years the average turbine capacity of offshore wind turbines has increased fourfold. Offshore wind turbines installed in 2000 had an average capacity of 2 MW; in 2020 it was more than 8 MW, and growth is accelerating. It took the industry 15 years to go from 2 MW to 4 MW and just five years to go from 4 to 8 MW. In the next three to four years the industry expects to install 12 - 15 MW wind turbines in European waters.

Like onshore wind, the average size of offshore wind farms is also increasing. It has grown from around 400 MW in 2010 to almost 800 MW in 2020. This increase can be directly linked to increased turbine size, the experience in the sector and increasing confidence from investors and Governments.

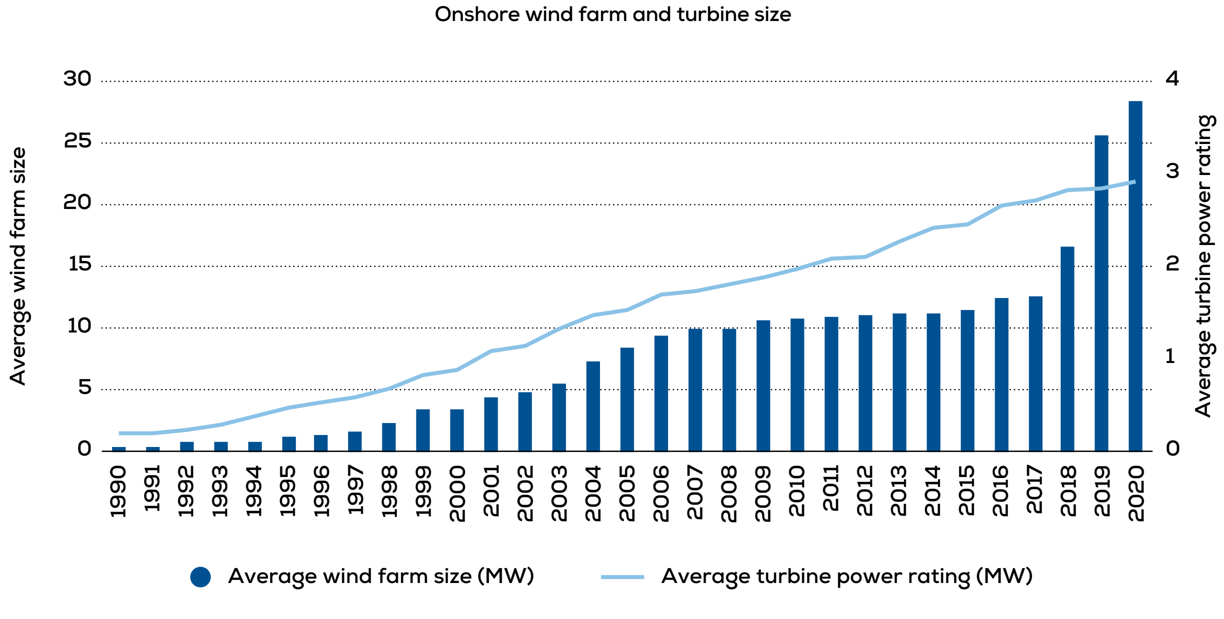



**Figure 5.** Average annual installed wind farm size and average turbine power rating for onshore wind in Europe.

Offshore wind farm and turbine size

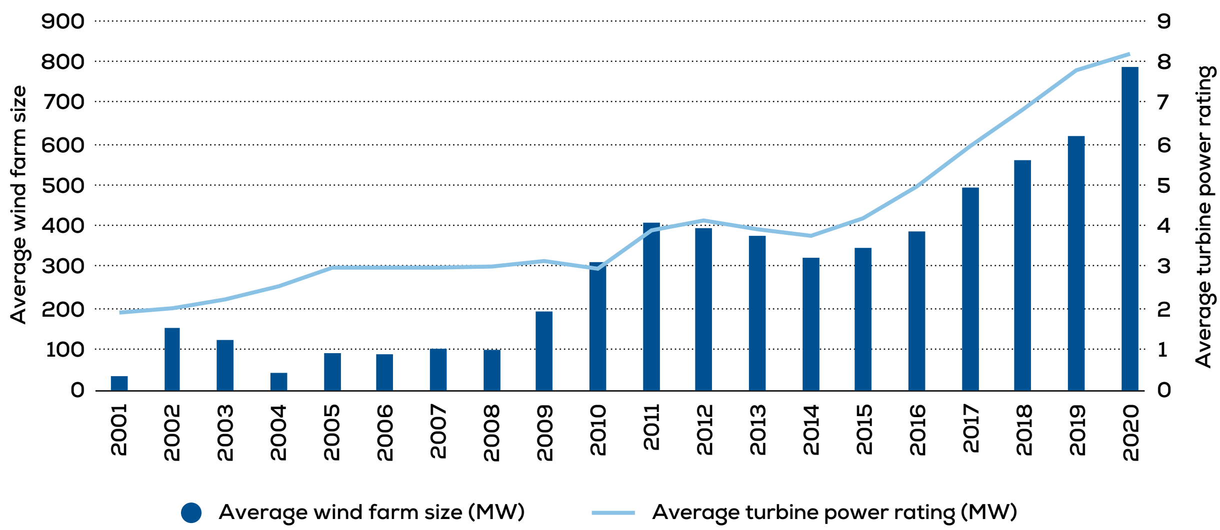



**Figure 6.** Average annual installed wind farm size and average turbine power rating for offshore wind in Europe.

But more powerful turbines need bigger components. Limiting the weight is essential to sustain the mass deployment and cost reduction potential of more powerful turbines. In bottom-fixed offshore wind leaner designs, innovative transition pieces and turbine uprating could reduce the relative weight of the monopile by more than 20% over the next five years[8]. Material research is another key area for innovation. Adding nanoparticles to composite materials used in rotor blades will for example allow the industry to build longer, lighter and more fatigue-resistant blades[9].

The growing demand for wind energy will lead to new manufacturing technologies. Components not only get bigger, but also more sought-after. Further modularisation and standardisation in designs will unlock the benefits of industrialisation. This is true for both the large components (blades, generator, gearbox) and smaller components such as slip rings and brushes. Many of these smaller components play a vital role in the operation of the turbine. Increasing their performance and reliability makes energy collection and delivery more efficient.

Wind farm CAPEX breakdown

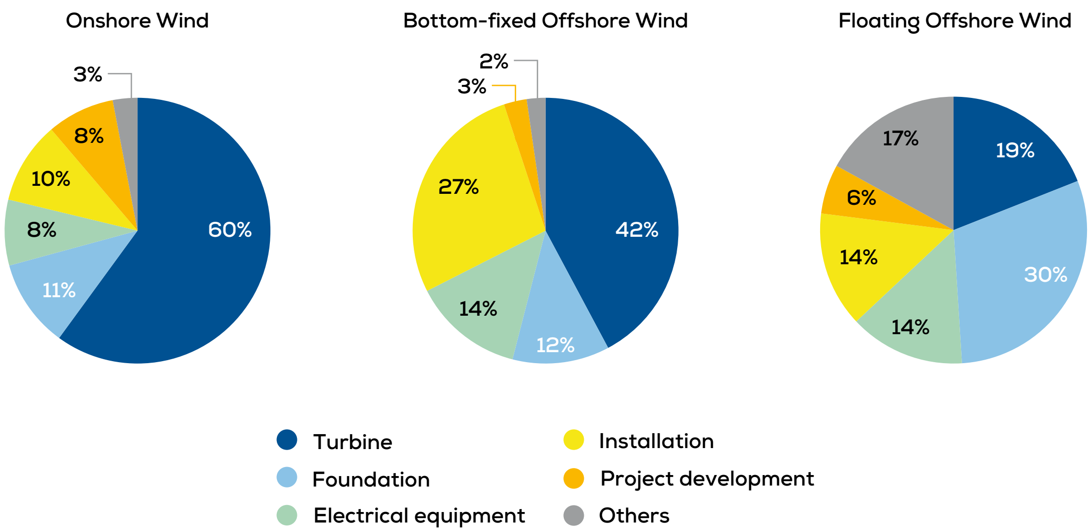



**Figure 7.** Relative weight of component in the wind farm CAPEX. Source: IRENA and BVG/InnoEnergy for onshore, BVGA for offshore (1 GW farm assumed with 10 MW turbines), ETIPWind for pre-commercial floating offshore wind (others include mooring and anchoring and port services).

# Mega trends in wind energy technology

When it comes to the future of wind energy technology, we can identify five mega trends. Each trend accentuates a specific value proposition of wind energy.

## 1. Scaling up offshore wind

Offshore wind technology will continue to scale- up. Europe’s very strong and stable offshore wind conditions are exceptional. To make the most of this energy potential, offshore turbines will become larger and more powerful. We will see multi-GW wind farms with +15 MW turbines. Offshore installations are challenging and costly, so installing a smaller number of more powerful turbines will reduce the costs of offshore wind. Developing offshore hybrid projects, connecting wind farms among themselves and to multiple countries will help get wind energy to the consumers that need it most (higher market price).

## 2. Industrialising floating offshore wind

Floating offshore wind can unlock 60% of Europe's offshore wind resources. It will also be central to decarbonising the energy system on Europe’s islands and in coastal regions with deep waters (in excess of 60 m). These include the Mediterranean, the Atlantic coast, and the coasts of Scotland and Norway. The first projects show average capacity factors of over 50%. Linked with offshore electrolysers they could become maritime fuelling stations that provide renewable ammonia. In 2024 the first ammonia-fuelled shipping vessel will be put to sea.

## 3. Happy co-existence with the onshore environment and society

Integrating wind turbines into the environment is a crucial step to enable large-scale deployment with full public support. New technologies that reduce noise propagation, visual impact and effects on wildlife will ensure onshore turbines maintain a low impact. There are simple solutions too. Ultrasound bird repellents or painting one turbine blade black will prevent birds from flying too close to a wind turbine.

## 4. Repowering onshore wind

Repowering old wind farms with fewer but leaner, more powerful turbines is key to capitalising on locations with the highest wind resources. Wind turbines are designed to last for 20-25 years on average. Even at this age many turbines still perform well and can get a lifetime extension. But sometimes it is better to replace the turbine altogether with a newer, better model. On average repowered projects have a capacity that is 1.84 times greater than the original project. And it does so with a third fewer turbines using the same land area.

## 5. Wind is going 100% circular

85% of a wind turbine is already recyclable. The wind industry is committed to 100% re-use or recycling of all wind turbine materials. This will further reduce the small environmental footprint of wind energy, decrease the sector’s dependence on critical raw materials and create new secondary material markets and economic opportunities. The top research priority is recycling and recovering the complex composite materials of the rotor blades. Recycling rare earth elements, such as for use in magnets, is also a priority.

## 2.3 Wind energy cost reduction

The costs of wind energy will continue to decline significantly in the next 30 years. The speed of that decrease depends on the delicate and mutually reinforcing interactions between market and technology. A strong and stable market will allow for investments in technology improvements. At the same time, new technologies can unlock new market opportunities.

The first 10 years will see the steepest cost reduction in all technologies. But incremental cost reductions will continue up to 2050. **By 2050 all wind energy forms are expected to have a levelised Cost of Electricity (LCoE) lower than €53/MWh. But many wind farms will produce electricity at much lower costs.**

**Onshore wind will remain the most cost-efficient source of wind energy. In 2030 the average expected LCoE for Europe will be €33/MWh for new installations.** This means a cost reduction of 28% compared to 2020. Most of that comes from turbine improvements resulting in lower CAPEX, higher capacity factors and longer lifetimes. Higher capacity factors are a result of both lower turbine-specific power (W/m$^2$) and access to higher wind resources (through taller turbines). In addition, we will see the benefits of repowering where new, better and more powerful turbines will gradually replace the first generation of wind turbines. By 2050 we expect an average LCoE of €25/MWh. Compared to 2020 levels this is a reduction of 45%.

The cost of offshore wind will follow a similar pattern. We expect an average LCoE of €48/MWh for bottom-fixed solutions in 2030, 44% less compared to 2020. This includes the grid connection to the nearest point onshore. Here the biggest reduction drivers are related to the CAPEX. This includes upscaling of turbine sizes, material efficiencies due to performance improvements and leaner designs, better installation techniques and processes and grid technology improvements. By 2050 we expect an average LCoE of €37/MWh.

For floating offshore wind the 2030 average LCoE is expected to be €64/MWh, including grid connection. This is a 65% cost reduction compared to 2020. The reduction is mostly driven by floating technology reaching maturity. This includes leaner floater and mooring designs, optimised manufacturing and assembly, and moving from "one-off" production series to serial production. Each project will help to optimise floating offshore wind technology and increase investor confidence. This will lead to bigger projects being commissioned bringing more value for money and, in turn, lowering the relative CAPEX for projects.

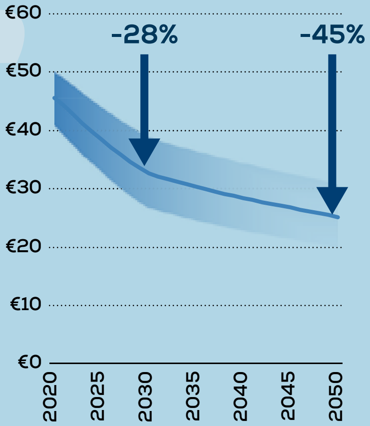
As of 2040 we see the costs of bottom-fixed and floating offshore wind technology converging. The costs will range between €30/MWh and €50/MWh for both technologies. This means that specific site conditions more than anything will determine the choice of technology for each individual offshore wind project.

Nevertheless, the cost of wind energy will always be different from project to project. The actual cost depends on a variety of factors including the wind resource, the environmental conditions, the technology used, the size of the wind farm and the evolution of raw material costs and trade restrictions. In addition, the regulatory framework and market conditions play a crucial role in delivering economies of scale and increasing investor confidence, thus reducing financing costs.

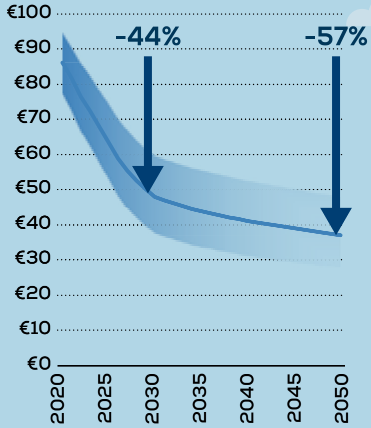
# Wind energy cost reduction

## LCOE %

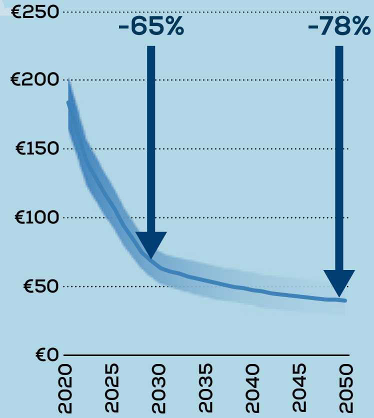
### Onshore Wind




### Bottom-fixed Offshore Wind




### Floating Offshore Wind




## LCOE €

**Onshore Wind**

**2020:** 41€/MWh-50€/MWh (€45)
**2030:** 27€/MWh-39€/MWh (€33)
**2050:** 20€/MWh-31€/MWh (€25)

**Bottom-fixed Offshore Wind**

**2020:** 77€/MWh-95€/MWh (€86)
**2030:** 38€/MWh-60€/MWh (€48)
**2050:** 28€/MWh-48€/MWh (€37)

**Floating Offshore Wind**

**2020:** 165€/MWh-202€/MWh (€184)
**2030:** 53€/MWh-76€/MWh (€64)
**2050:** 30€/MWh-53€/MWh (€40)

## Assumptions

**Onshore Wind**

**Capacity Factor:** 28-35%
**Lifetime:** 25-30 years
**WACC:** 3 – 3.5%

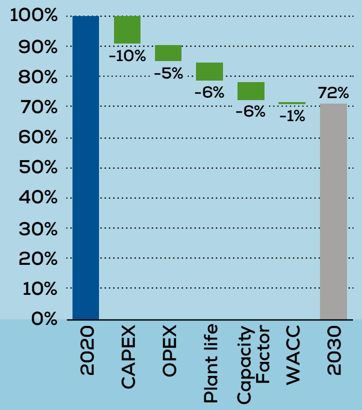
**Bottom-fixed Offshore Wind**

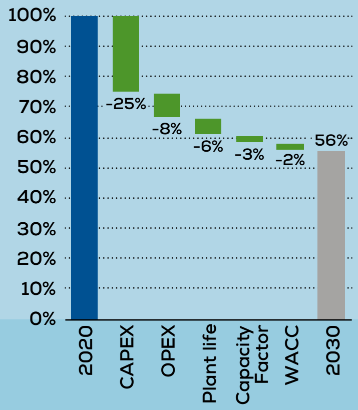
**Capacity Factor:** 45-50%
**Lifetime:** 25-30 years
**WACC:**4 – 5%

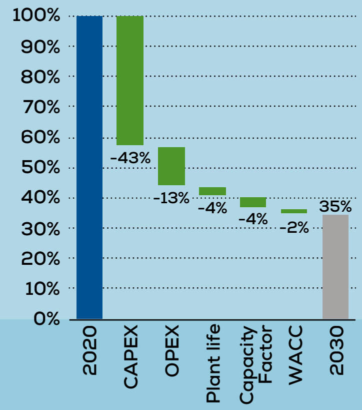
**Floating Offshore Wind**

**Capacity Factor:** 47-55%
**Lifetime:** 25-30 years
**WACC:** 7 – 8%

## Cost reduction contributions




## Short term cost reduction driver

**Onshore Wind**

- Faster permitting to deliver on installations and project certainty.
- Larger turbines at new and repowered sites delivering higher capacity factor and lower costs through a longer lifetime.
- Repowering of the best wind sites.

**Bottom-fixed Offshore Wind**

- Market volumes to achieve economies of scale.
- Bigger turbines with higher rated power capacity to generate bulk amounts of electricity.
- Industry continues to improve the operations and mainte-nance strategies.

**Floating Offshore Wind**

- Industrialisation of floating technology (floater, cables, mooring) to start large scale commercialisation.
- Building on the experience and knowledge transfer of both Europe's bottom-fixed and Oil & Gas sectors.
- Operating more and larger projects becomes cost efficient.

## 2.4 Total system value of renewables-based systems

The transition towards an energy system centred on renewables-based electrification, powered by wind and solar energy, requires significant investments. Energy system costs – investment and operational costs related to the use of energy – have been steadily increasing in recent years and are projected to grow, reflecting the effort needed to meet the current climate and energy targets for 2030. But in the long term, energy system costs related to investments in new technologies, infrastructure and system operation won't be any higher (relative to GDP) than today's figure.

On the energy supply-side we need investments in grid infrastructure, new power generation assets, the production of new types of fuels and sources of flexibility such as battery storage. On the demand side (57% of all investments) we need investments in building heating and cooling systems, transport, and electric solutions in industry.

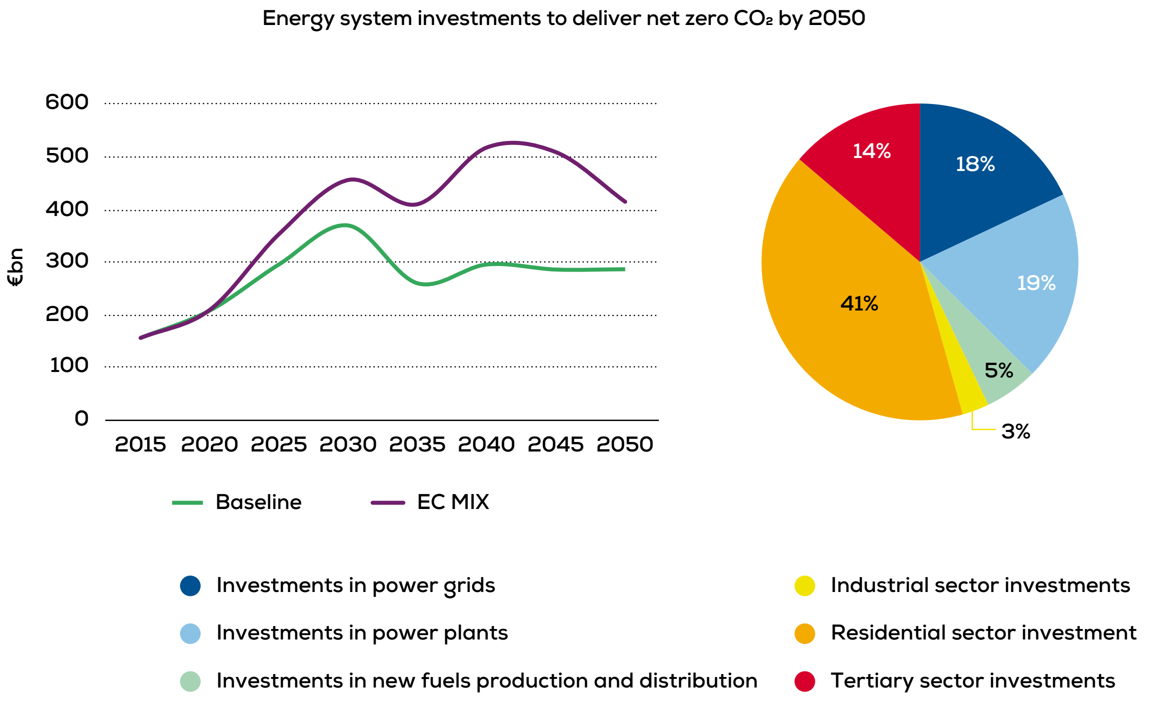



**Figure 8.** Energy system investment - Shares of investments for the energy system for the period 2021-2050 (excluding transport). Source: WindEurope based on the EC Impact Assessment COVID MIX.

But investment needs are just one side of the value of accelerating the clean energy transition. When accounting for lower GHG emissions, reduced air pollution – and thus reduced health costs - lower cooling water needs, and job creation, the benefits of renewable-based systems will exceed investments and deliver a higher societal return on investment than sticking to the status quo.

A recent joint initiative among the World Economic Forum, Accenture and 30 energy companies CEOs developed a framework to evaluate policy and investments that lead to the benefits mentioned above (see Figure 9).


**Figure 9.** System value components. Source: World Economic Forum[10].

But even when just the required investments are considered, overall energy system costs will not be expensive. In the long term it will even lead to a lower energy system cost. In 2015 the total energy system cost totalled 10.6% of EU GDP. Up to 2030 average annual energy system costs would be worth about 11% of GDP to meet the new 55% GHG reduction target. But as investments made in previous decades begin to pay off the cost will drop. By 2050 the annual cost is expected to be 10.4% or below 2015 levels[11 12].

The overall energy system cost is falling because low-marginal cost generation assets like wind and solar will keep system costs in check. Investments in infrastructure and flexibility are needed to cope with higher variability of generation and demand (see chapter 5). On the other hand, the fuel costs will decline significantly. Europe will need to import less fuel and be much more efficient with energy by applying electric solutions (e.g., EVs, electric heat pumps).

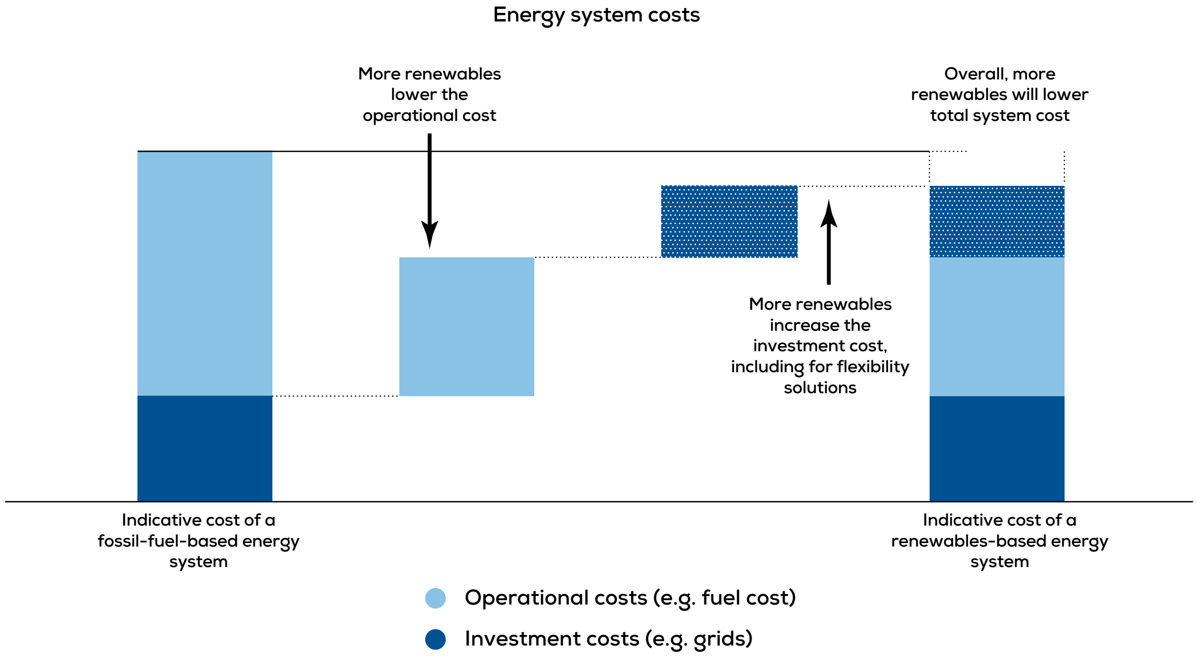



**Figure 10.** Indicative representation of how total system costs change.

## 2.5 Renewables will reduce the environmental impact of energy

Wind and solar energy unlike conventional power generation does not give off any emissions during operation. Switching to a system built on wind and solar will bring significant environmental benefits. Whilst the benefits are intuitively clear (no air pollution, no carbon emissions), we can also quantify these benefits using the system value approach which includes externalities.

Externalities include all positive or negative impacts associated with energy production and consumption. These costs or benefits do not directly appear on energy bills, but are borne indirectly by society as a whole[13]. They are related to areas such as to pollution, land use and climate change. They cover the entire lifecycle and include manufacturing, installation, and decommissioning. But they do not include the historic or legacy cost. They are also related to reduced health costs via lower air pollution, lower cooling water needs or job creation.

If we only take into account external costs of electricity production, in 2018 these amounted to €150.9bn in the EU-27 or close to 1.3% of EU GDP. But these costs were spread unevenly. Countries with lower GDP generally depend more on fossil fuels for their electricity production, so their citizens unknowingly paid a higher price as a consequence. In Poland, the external costs amounted to 5% of its GDP. In Bulgaria it was a staggering 10%[14].

Even if we assume constant pricing for externalities and no technological improvements, a wind-powered energy transition will significantly lower hidden costs even if the amount of electricity produced almost doubles. By 2050 in a climate neutral Europe, the external cost of MWh produced will be 60% lower than today. It will be 18€/MWh in 2050, down from 51€/MWh in 2020.

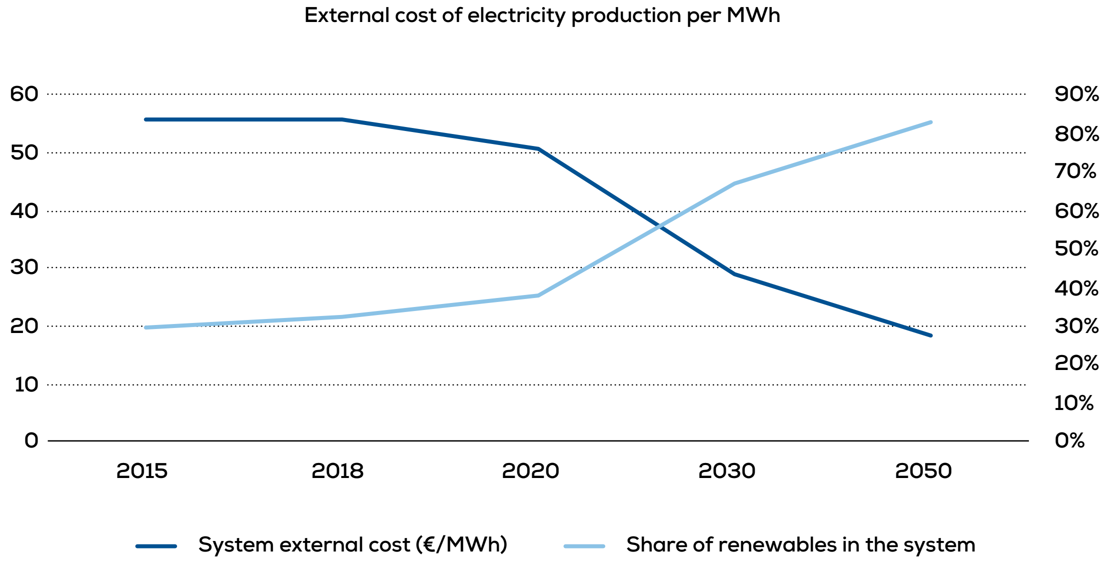



**Figure 11.** Historic and projected external cost of electricity production in EU-27+1 in €/MWh. Sources: ETIPWind based on Trinomics and Eurostat[15 16 17 18].

The fall in external costs is due to an increased share of renewables. By 2050 81% of electricity produced is expected to come from renewables, up from 38% in 2020. Electricity produced from fossil fuels costs society the most overall. Fossil fuels not only have the biggest impact on climate change due to $CO_2$ emissions, but are also the worst in terms of pollution, resource use and health impacts. In 2018 fossil-based electricity from lignite and coal cost European citizens between €127 and €147 on average respectively for each MWh produced[19].

Out of all technologies, wind energy has the lowest external cost. The average external cost of wind generated electricity in 2018 was below 3€/MWh. This is 50 to 60 times lower than solid fossil fuels and five times lower than Solar PV. Offshore wind had a slightly higher footprint than onshore wind. The difference can be explained by offshore wind's reliance on the maritime supply chain. As the maritime sector decarbonises the onshore-offshore disparity will diminish.

The wind energy sector has set itself the goal of lowering its environmental footprint. It is committed to keeping its carbon footprint low and minimising its environmental impact. Achieving this will require improvements in technology, material efficiency and sustainable supply chains across all steps of wind energy development.

## Wind Industry commitment to wind turbine circularity

One example is the sector's commitment to recycling. Around 85% of a wind turbine's total mass can be recycled. For most components there are established recycling practices. But wind turbine blades are more challenging to recycle. These blades are made up of complex composites materials that boost the performance of wind turbines. While various recycling technologies exist they are not yet widely available or cost-competitive.

The wind sector is working with other composites consumers and recycling companies to accelerate blade recycling. With more investments and European funding to diversify and scaleup composite recycling technologies, and to develop new, high performance materials with enhanced circularity, we can finally move towards a fully circular wind energy sector.

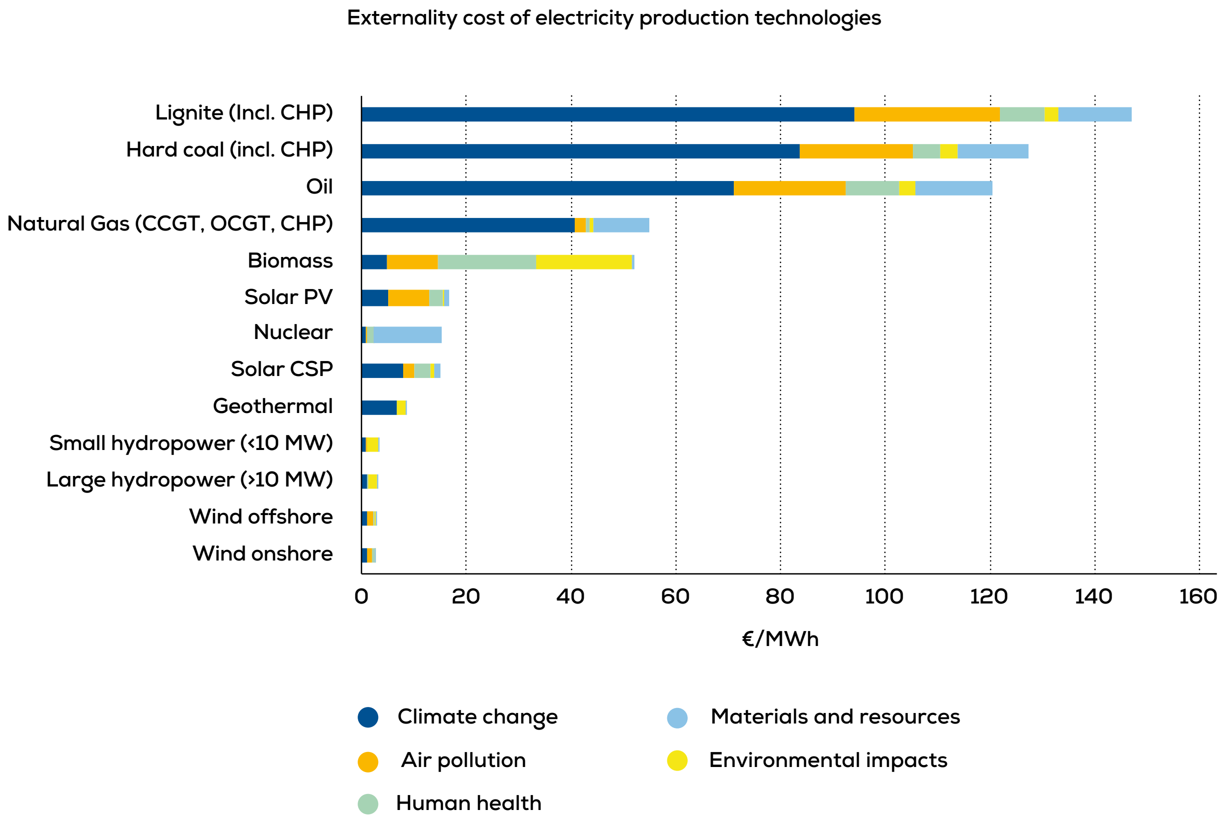



**Figure 12.** Weighted average external cost of electricity produced by each technology in EU-28 in 2018. External costs include internalisation of carbon pricing. Nuclear costs exclude the costs associated with waste treatment and risk. Source: Trinomics[20].

When considering other aspects of the system value approach, many of today's still-overlooked benefits are plain to see. A recent joint study between the World Economic Forum, Accenture and 30+ CEOs of global energy companies concluded that a renewable-based energy system will help Europe save around 205 billion litres of water by 2030 and €43bn in health costs due to lower air pollution. This is in addition to saving 117 million tonnes of $CO_2$ while creating over 1 million jobs[21].

# 3

# Electrification for net-zero $CO_2$ emissions

Total final energy demand is broadly divided into three sectors: industry, transport and buildings. Their relative share in 2019 is shown in Figure 13. This distribution is not expected to change much over time. In this chapter we look at which electrification technologies each sector needs to deploy to put them in line with a net-zero economy by 2050. And for those facing significant hurdles to decarbonise (the so-called harder-to-abate sectors) how the indirect use of renewable electricity to produce hydrogen and its derivatives could play a crucial role.

Wind energy is the perfect partner of many energy consumers, be it an industrial installation or a user of electric vehicles. Relying on the power grid, and through innovative commercial arrangement such as Power purchase agreements, the industry can supply renewable and clear power to a growing number of energy users.

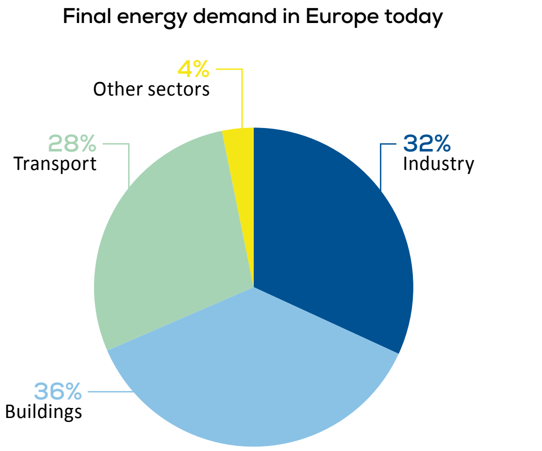



**Figure 13.** Final energy demand by sector in 2019. Source: Eurostat.

## 3.1 Industry

### ENERGY USE IN INDUSTRY

Industry emits 31% of GHG emissions[22] and uses significant amounts of fossil-based feedstock. Over one third of the final energy demand (including for feedstock) in industry is lost due to inefficiencies in conversion and other losses within various processes[23]. In 2019 transformation losses in industry amounted to around 1,300 TWh[24], or the equivalent of the annual electricity demand of Germany, France and Italy combined[25].

Another 30% of the industrial energy demand is for energy products which industry uses as feedstock. The effective energy consumed in industry for power and heat is around 38% of its total demand final energy demand[26]. Electrifying heating and substituting fossil-based feedstocks will be crucial to decarbonising industry.

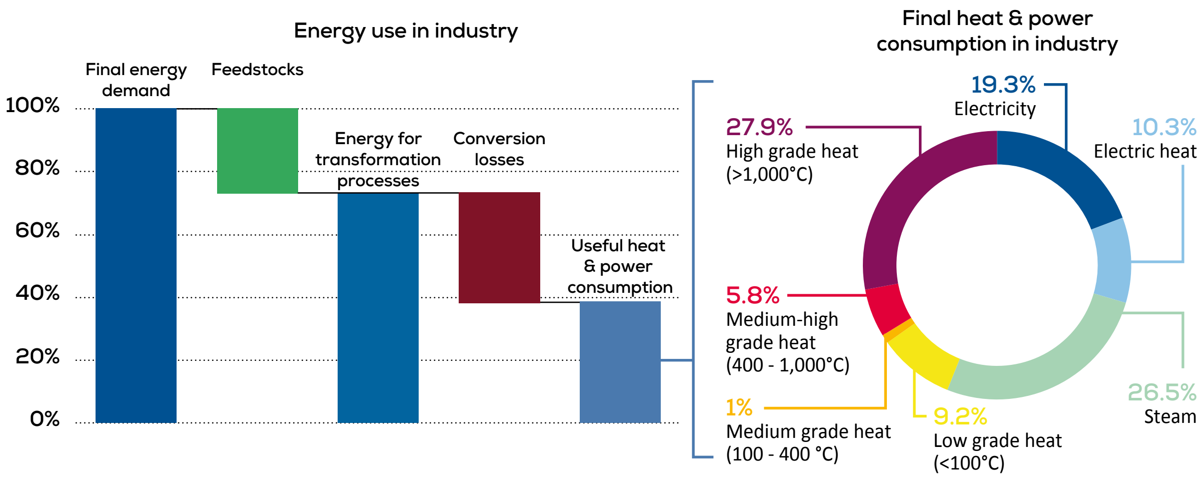



**Figure 14.** Final energy demand in industry in the EU (a) and breakdown of use for heat and power (b) based on 2019 data from Eurostat for EU-27.

## ELECTRIFYING HEAT AND POWER CONSUMPTION

About 30% of industry's final energy consumption is used as electricity (for both power and heating). The rest is for fossil-fired heating processes and production of steam. Out of this, 28% is high grade heat above 1,000°C. Most heating processes deliver temperatures below 1,000°C and thus could be electrified with existing and established technologies as shown in Table 2. However, this varies significantly by type of sector as shown in Table 1. In sectors such as iron & steel, cement and glass, production requires large amounts of very high-grade heat.

| | Break down of use for power and heat | | | | | | |
|---|---|---|---|---|---|---|---|
| | Electricity | Electric heat | Steam | Low grade heat (<100°C) | Medium grade heat (100 - 400 °C) | Medium-high grade heat (400 - 1,000°C) | High grade heat (>1,000°C) |
| **Total** | **19%** | **10%** | **27%** | **9%** | **1%** | **6%** | **28%** |
| Textiles | 34% | 10% | 29% | 27% | 0% | 0% | 0% |
| Wood | 29% | 3% | 55% | 13% | 0% | 0% | 0% |
| Non-Ferrous Metals | 23% | 40% | 14% | 2% | 0% | 6% | 15% |
| Transport Equipment | 40% | 18% | 10% | 18% | 7% | 0% | 8% |
| Cement | 9% | 0% | 4% | 0% | 0% | 23% | 64% |
| Machinery | 34% | 23% | 9% | 14% | 0% | 9% | 11% |
| Ceramic & Glass | 12% | 11% | 1% | 1% | 6% | 2% | 67% |
| Food | 23% | 17% | 44% | 13% | 3% | 0% | 0% |
| Paper | 24% | 1% | 46% | 26% | 0% | 3% | 0% |
| Chemicals | 13% | 9% | 62% | 4% | 0% | 13% | 0% |
| Iron & Steel | 12% | 7% | 2% | 1% | 0% | 3% | 75% |

**Table 1.** Final heat and power consumption in EU industries (excluding feedstocks). Source: Madeddu et al 2020.

| Technology | <100°C | 100–400°C | 400–1,000°C | >1,000°C | Technological Readiness | Applications |
|---|---|---|---|---|---|---|
| Compression heat pumps and chillers | ● | ● | | | Established | Space heating<br>Hot water<br>Low pressure steam drying<br>Cooling & refrigeration |
| Mechanical vapour recompression (MVR) | ● | ● | | | Established | Energy recovery (e.g. in distillation, evaporation) to provide steam and process heat |
| Electric boilers | ● | ● | ● | | Established | Space heating<br>Hot water<br>Thermal oil<br>Steam |
| Infrared heaters | ● | ● | ● | ● | Established | Drying<br>Paint curing<br>Plastics treatment<br>Food processing |
| Induction furnace | ● | ● | ● | ● | Established | Metals melting, re-heating, annealing, welding |
| Resistance furnace | ● | ● | ● | ● | Established | Metals melting, smelting<br>Heaters for the chemical industry<br>Ceramic firing<br>Glass melting<br>Calcination |
| Electric arc furnace | ● | ● | ● | ● | Established | Metals melting and partial refining |
| Microwave & radio frequency heaters | ● | ● | ● | ● | Not yet established (except in ceramics and cement) | Drying<br>Ceramics firing and sintering<br>Cement treatment<br>Food processing |
| Plasma technology | ● | ● | ● | ● | Not yet established | Waste treatment<br>Metals treatment (e.g. welding)<br>Sintering<br>Cement production |
| e-crackers | ● | ● | ● | ● | Not yet established | Chemical production<br>Oil refining |

**Table 2.** Electrically powered technologies for industry electrification (excluding the production of feedstocks). Source: Madeddu et al 2020.

According to a detailed review of 49 studies compiled in 2020 (see Annex 2), applying already established technologies (commercially available and applied in industry) as shown in Table 2 can directly electrify two thirds of fossil-fired steam and heating consumption in industry. These technologies however need to scale up so that the supply chain does not become a constrain on the huge ramp-up industrial needs.

This would bring electricity up to 76% of total final energy consumption, helping to reduce energy losses and $CO_2$ emissions.

With more investments in innovation and continued development of emerging electric technologies Europe could potentially directly electrify up to 99% of industrial processes[27]. This includes thermal plasma heating, electrolytic reduction of iron ore (electrowinning) and the energy required for the steam cracking and reforming. These technologies are however at an earlier stage of development and will require still significant R&I efforts.

Considering energy needs per sector and the availability of electrically-powered technologies for industry (all sectors included) it is clear that most sectors can electrify their power and heating needs with established technologies, as shown in Figure 15.

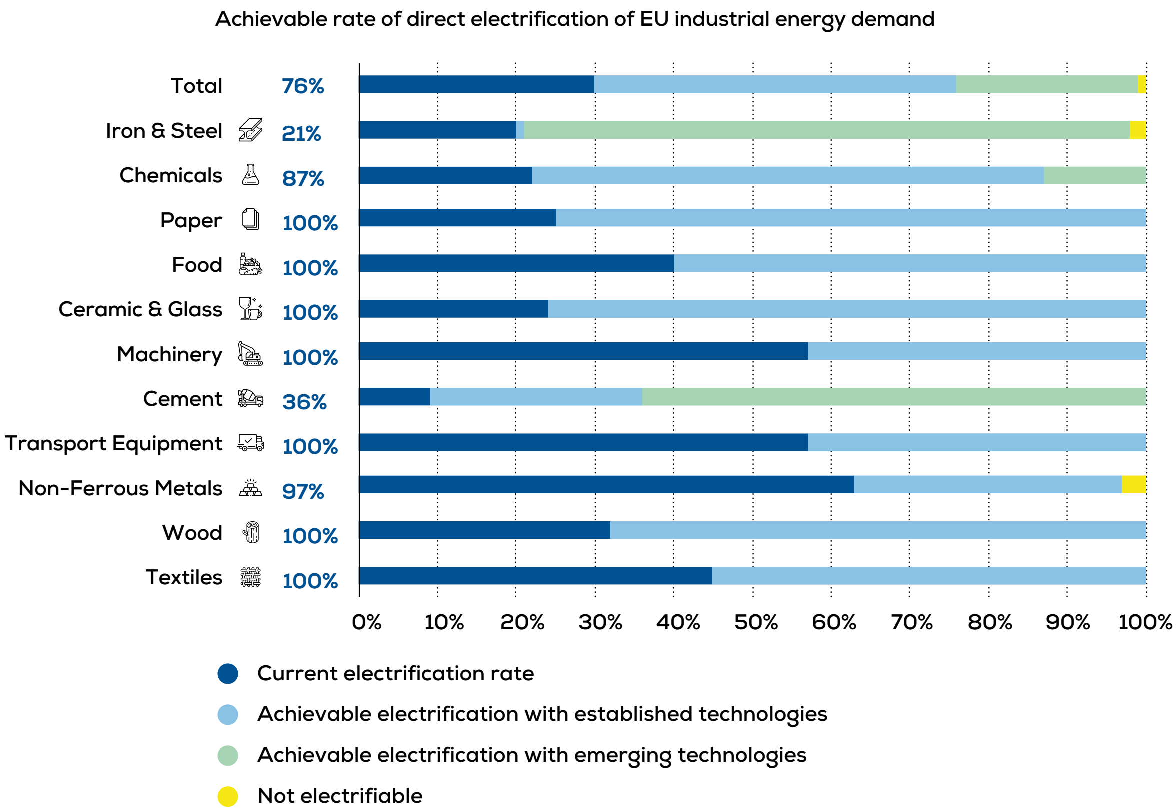



**Figure 15.** Achievable direct electrification rate of EU's industry's useful heat and power consumption (excluding feedstock production). Source: ETIPWind based on Madeddu et al 2020[28].

## BENEFITS AND CHALLENGES IN ELECTRIFYING INDUSTRY ENERGY DEMAND

Applying the achievable electrification rate (76%) with established technologies will reduce industry's final energy demand by 7% and its $CO_2$ emissions by 43%.

To meet net-zero industrial emissions Europe needs to further invest in emerging electrification technologies and in substituting fossil-based feedstock like coal and gas with renewable alternatives such as renewable hydrogen or ammonia.

Whether these direct and indirect electric technologies can be feasibly applied will largely depend on the electricity prices that consumers will be able to access. Other factors include the $CO_2$ price and other costs of alternative energy carriers (e.g. natural gas), and on the capacity utilisation of the electric equipment, space and other modifications needed to adapt adjacent processes.

Figure 16 shows the indicative electricity prices needed to make the switch to direct and indirect electrification in selected industries economically viable.

These break-even prices are higher than current electricity prices. Falling in renewable energy costs will help but it will not be enough to make the switch away from fossil fuels a feasible option. Stricter carbon pricing policies and other environmental measures (e.g. air pollution taxes, and tighter emission limits) will need to be put in place.

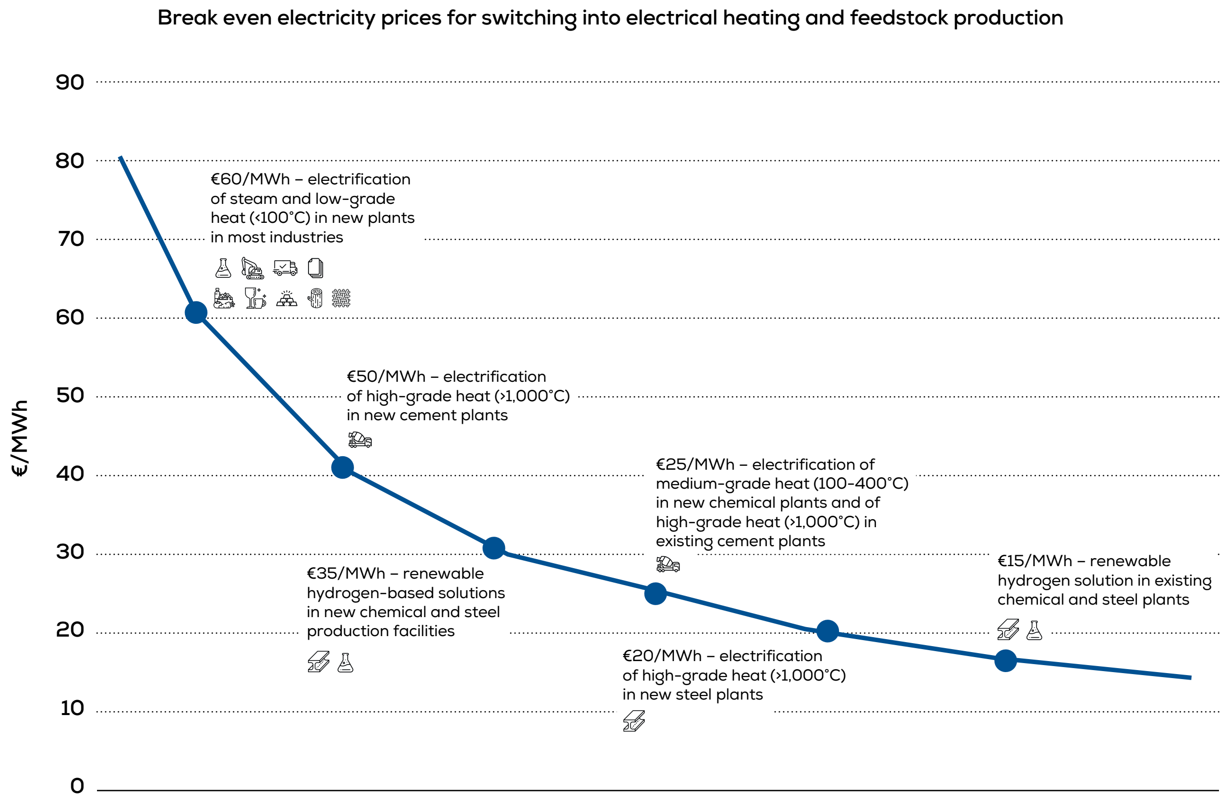



**Figure 16.** Electricity prices for electrification switch. Source: WindEurope based on McKinsey, Material Economics[29 30 31].

In the next few pages we will look at specific opportunities for electrification in the four most energy intensive industries in Europe. These include iron and steel, cement, chemicals, and refineries.

### 3.1.1 Iron and Steel

The iron and steel sector is the largest industrial $CO_2$ emitter in Europe and the second most energy-intensive industrial activity. For every tonne of steel that Europe produces, it emits one tonne of $CO_2$[32]. The iron and steel sector is hard to decarbonise because fossil fuels are an integral part of the production process. As it stands, blast furnaces and basic oxygen furnaces (BF-BOF) are the most widespread technology.

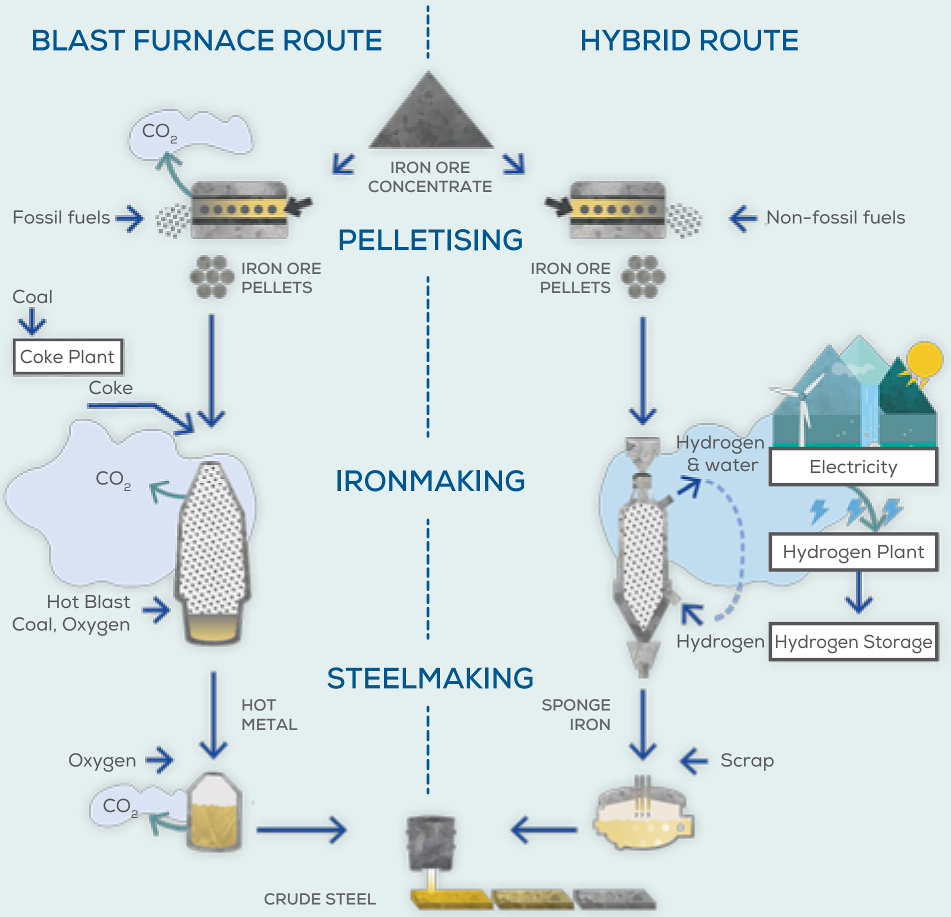
Blast furnaces are fired with coal or natural gas to "bake" coal at more than 1,000 °C. This produces coke, a hard, grey solid material used in the chemical reaction (called reduction) to extract (smelt) the base metal from iron ore. This virgin iron is then converted into steel by blowing oxygen into a basic oxygen furnace.

Close to 60% of the EU's steel comes from iron processes in BF-BOF. The other 40% comes from electric arc furnaces (EAF), which pass electricity through graphite electrodes to melt metal scrap. While electric arc furnaces are by far more energy efficient operationally (they use 1/8 of the energy needed to produce steel from raw iron-ore), scrap alone is not enough to cover the current and future demand of steel[33].

EAFs can also produce steel from solidified iron, or sponge iron, which are products from direct reduced iron (DRI). DRI is achieved using a mixture of gases, and notably includes hydrogen instead of coke. Europe is leading the way in developing this process, which has not yet been demonstrated at commercial level. If current projects are successful, this could revolutionise the sector.

## Fossil-free steel making

In 2016, SSAB, LKAB (Europe's largest iron ore producer) and Vattenfall (one of Europe's largest energy companies) joined forces to create HYBRIT - an initiative that will revolutionise steelmaking. HYBRIT aims to replace coking coal, traditionally needed for ore-based steelmaking, with fossil-free electricity and hydrogen. The result will be the world's first fossil-free steelmaking technology, with virtually no carbon footprint[34].



If the EU is to decarbonise its iron and steel production, it needs to take decisive action in the area of technological development and supporting frameworks. Europe has 59 plants using the traditional high-energy high-emissions process (BF-BOF)[35]. Some of these are nearly 25 years old and are due to be replaced over the next 15 years[36].

But it is not just about replacing BF-BOF technology. The entire manufacturing process should be adapted and the demand for clean steel needs to be addressed. This will require an integrated industrial approach. Arcelor-Mittal, Europe's largest steel maker, has estimated that making its facilities across the continent fossil-free would cost between €15-40bn[37].

Making all European steel close to net-zero would require some 400 TWh of renewable electricity, seven times the amount the sector purchases today, and close to the entire annual electricity demand of Germany. 62.5% would be used to produce 5.5 million tonnes of hydrogen[38].

### 3.1.2 Cement

Cement manufacturing accounts for ¼ of all industrial emissions in the EU. These emissions come from fossil fuel combustion generating heat (36%-38%) and from a chemical reaction called calcination (62%-64%) - involving raw materials, mostly clay and limestone. When limestone decomposes it releases $CO_2$[39]. The product of this calcination is called clinker, which is then grounded and mixed with other materials to produce cement. Cement mixed with water, sand, and gravel forms concrete, which is the main application of cement[40]. The clinker burning is where the calcination takes place. This is the heart of the manufacturing process, and is carried out inside kilns with temperatures in excess of 1,400 °C.

Reducing consumption of fossil fuels in the kiln is done by substituting them with a variety of waste streams (co-processing) and biomass. 46% of the combustion fuel used today is from co-processing, and it is technically feasible to increase this rate to as much as 90%[41]. But the availability of waste/biomass together with the need to control other combustion emissions such as fine particles, SOx and NOx are issues that still need to be addressed.

In addition, the energy efficiency of cement kilns can also be improved. Among other solutions, adding precalciner kilns and recovering process heat could generate up to 20% of the entire plant's electricity needs. And while electricity use makes up only a fraction of current emissions, moving to 100% renewable use would cut $CO_2$ emissions by 6%[42].

In the long term the use of electric heat for calcination is a possible option, as is the use of plasma or solar energy. If renewable electricity is used, it would cut down on fuel emissions by 55%. And if combined with renewable hydrogen and biomass, it could reduce $CO_2$ fuel emissions to almost zero.

Another option for reducing emissions in cement production is the use of carbon capture and storage (CCS) with centralised power generation. Operating at high-capacity factors would be needed to justify the high upfront costs and higher productions cost (up to 100%).

### 3.1.3 Chemicals

Manufacturing of chemical and petrochemicals consumes more than 20% of industry demand, the most out of all industrial sectors in Europe[43]. Half of the energy consumed goes to feedstocks[44]. Ammonia, methanol, and high-value chemicals (HVC) account for three quarters of the remaining energy consumed.

Renewable hydrogen may offer greatest potential for decarbonising the chemical industry. It can be used to manufacture ammonia, and if paired with captured $CO_2$ to manufacture methanol, olefins, benzene and other HVCs as well.

#### AMMONIA

Ammonia is needed to produce fertilisers. It is also used as a refrigerant gas, and for several products such as plastics, nylon and acrylics. Ammonia's basic component is hydrogen, and so its carbon footprint is determined by the carbon footprint of the hydrogen used. A large portion of hydrogen produced worldwide is used to create ammonia[45]. And it is dominated by natural gas-based hydrogen. There are a number of all-electric ammonia production plants around the world[46], but these are outcompeted by cheap natural gas prices.

All-electric ammonia plants only use air and water, which makes them particularly well-suited to locations with fresh water sources. However, ammonia plants can also use desalinated seawater if located near the coast. This is one reason why renewable ammonia is considered crucial to potentially decarbonising maritime shipping (see chapter 3.2.2).

Ammonia plants are designed to operate at full load for most of the year[47]. They need a stable grid connection, which can be readily supplied using renewables. This can be done directly onsite or through the use of corporate PPAs with renewable assets. For renewables-based ammonia and fertiliser plant projects currently in the pipeline, developers are exploring the most suitable business models and a range of government support possibilities (see box).

## Announcements for the production of renewable-based Ammonia projects

**Iberdrola and Fertiberia have partnered to build a 800 MW electrolysis plan to produce renewable hydrogen** that would be used in the Fertiberia ammonia plant in Puertollano, Spain[48]. Fertiberia will adapt its plant, which produces 200,000 tonnes per year, to the use of green hydrogen for manufacturing green fertilisers, reducing the need for natural gas in the plant by more than 10%. The partners aim to make the project operational by 2023.

**Fertiliser company Yara (the largest global producer) and Ørsted have joined forces**[49] in developing a breakthrough project aiming at replacing fossil hydrogen with renewable hydrogen in the production of ammonia, with the potential to abate more than 100,000 tonnes of $CO_2$ per year.

With a 100 MW electrolyser powered through Ørsted's offshore wind farms, the renewable hydrogen would generate around 75,000 tons of green ammonia per year - approx. 10% of the capacity of the ammonia plants in Sluiskil, the Netherlands. If the required public co-funding is secured and the right regulatory framework is in place, the project could be operational in 2024/2025.

**Yara has announced plans**[50] **to produce 500,000 tonnes of green ammonia per year at its plant in Porsgrunn, Norway**, aiming to fully electrify its ammonia plant and potentially cutting down on 800,000 tonnes/yr. They are currently looking for partners and possible governmental support.

#### METHANOL & HIGH VALUE CHEMICALS

Methanol, a chemical used in a variety of products[51], can also be produced via renewable hydrogen. Today it is created using natural gas steam methane reformation and coal gasification. Making carbon-free methanol would involve sourcing $CO_2$ from ambient air or replacing it with carbon monoxide, potentially from greening cement factories. The IEA estimates that to obtain 1 tonne of methanol, 875 kg of carbon monoxide and 125 kg of hydrogen would be needed[52].

High-value chemicals (HVCs) are typically created through steam-cracking petrochemical feedstocks like naphtha to produce ethylene, propylene and butadiene, among others. Organic materials can replace petrochemicals in the production of these HVCs. Ethylene and propylene can also be manufactured by recycling $CO_2$ via renewable hydrogen to provide methane through a process called a Sabatier reaction. The process is in the R&I phase and would require co-location of electrolysers with Sabatier reactors. According to some estimates, 1 tonne of ethylene requires 20 MWh of electricity and 3 tonnes of $CO_2$. Polypropylene would need a slightly higher rate of electricity, at 38 MWh/tonne. Based on this, Europe would need 800 TWh/year of electricity to produce ethylene and propylene at a consistent level[53]. And more importantly, the existing ethylene cracking capacity would need to be replaced with these new technologies, posing a significant challenges for the industry.

### 3.1.4 Refineries

Refineries process crude oil into various fuels and intermediate chemicals: fuels for transport (gasoline, kerosene, diesel, gasoil); combustion fuels for heat and power; raw materials for petrochemicals and other chemicals, lubricant oils, paraffin, and bitumen.

There are 89 operational refineries in Europe with a combined capacity of 12.6 million barrels a day[54]. Refineries emit around 130 $MtCO_2$/year via crude oil processing, or 7% of EU emissions[55]. This of course excludes emissions associated with burning the fuels themselves (e.g. in a vehicle or an oil powered plant).

The decarbonisation of refineries is one of the most challenging out of all energy-intensives, not only due to the size of their energy consumption, but also their intrinsic processes and emissions. The EU-based industry estimates it would need €650bn to decarbonise[56].

#### ELECTRIFYING HEATING

Refineries use electricity from the grid, but mostly from onsite combined heat and power (CHP) gas turbines as they need steam and process heat. $CO_2$ emissions from these CHPs account for 42% of total refinery emissions[57]. In order to decarbonise, refineries can still opt for onsite electric steam generation, which costs about as much as gas-fired boilers. But this may require electrical infrastructure modifications to the refinery itself[58]. Alternatively, refineries could upgrade low-grade heat using industrial heat pumps for generating medium pressure steam.

Electrifying process heat is slightly more challenging, but still feasible. Distillation needs medium to high temperatures of up to 400˚C, and pre-reforming needs around 500˚C. These temperatures can be supplied from stored heat in commercially available molten salts storage systems[59] which can be powered by renewables. Catalytic reforming and cracking both need higher temperatures, of around 900˚C. Both can be reached with renewables, but the size of the required heaters (100-200 MW) is a major challenge[60]. Other hurdles include their capacity utilisation, and space restrictions to generate renewable electricity.

## SUBSTITUTING FOSSIL-FUEL HYDROGEN AS FEEDSTOCK

Refineries use large quantities of hydrogen in the hydro-cracking of oil to clean (desulphurise) the fuel. The stricter the environmental regulations on sulfur content, the more hydrogen refineries will need. And while hydrogen is available as a by-product from their own refining process, they need more than they can produce themselves.

Today, most demand is met with hydrogen from the reforming of natural gas, which adds a significant burden to emissions. Natural gas-based hydrogen can be replaced with renewable-based hydrogen, improving the footprint of conventional oil and more importantly, the footprint of advanced biofuels.

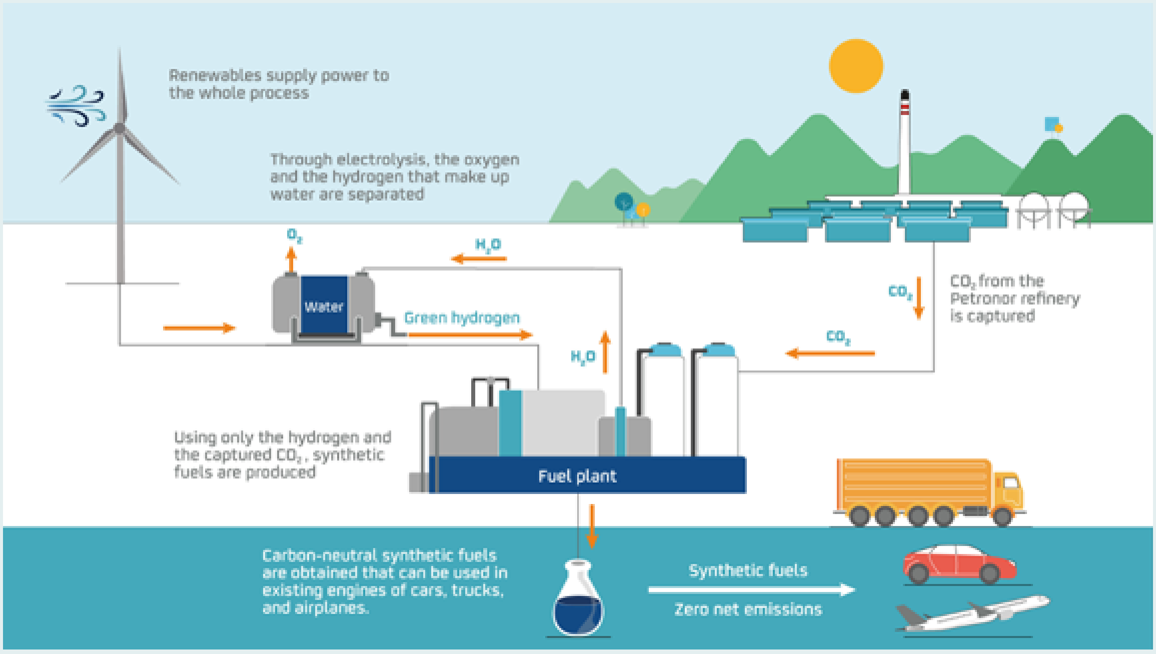
## NEW FUELS PRODUCTION

While road passenger transport will shift massively to EVs (as explained in section 2.2), maritime, air and heavy-duty road transport will drive the demand for cleaner fuels. This is the real transformation that refineries will have to go through: replacing oil-based fuels with electrolytic hydrogen-based ones (e-fuels). Some of these new fuels (e-fuels), such as hydrogen and ammonia can be directly produced via renewable power. Other fuels such as e-kerosene (synthetic kerosene) combine renewable hydrogen with $CO_2$ directly captured from the atmosphere or derived from another industrial process.

The European Commission expects that e-fuels will expand to cover 20-22% of all transport fuels by 2050, up from almost 0% in 2030[61].

## Repsol’s synthetic fuel plan plant in Bilbao

Repsol has announced it will build one of the world’s largest plants to manufacture net zero emissions fuels, using $CO_2$ and green hydrogen generated with renewable energy. Repsol’s partners include Petronor, one of Spain’s principal industrial centres; and the Energy Agency of the Basque Government (EVE), a public-sector leader in the energy transition. The facility, which will be fully operational within four years, will set a new benchmark in Europe thanks to its application of cutting-edge technology and the use of $CO_2$ captured in the nearby Petronor refinery.



## 3.2 Transport

The transport sector is responsible for almost a quarter of European GHG emissions and unlike other sectors, transport emissions have been rising over the last five years. Furthermore, European transport needs will grow significantly by 2050. Decarbonising transport will be a significant hurdle to achieving net-zero emissions by 2050.

### 3.2.1 Road Transport

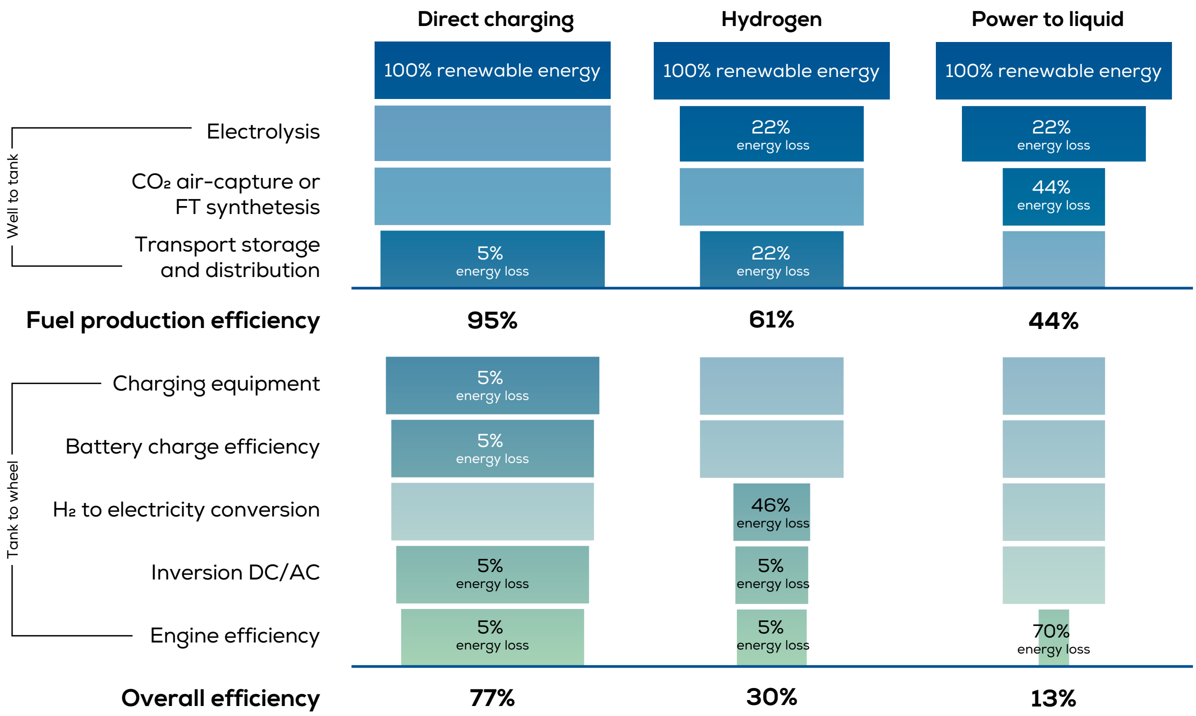
Road transport is responsible of three quarters of $CO_2$ emissions and three quarters of the transport sector's energy consumption[62]. Renewable-based electrification is the best way to reduce emissions. Electric road transport is far more efficient than fossil fuels, and helps to reduce $CO_2$ emissions, primary energy demand and EU reliance on fossil fuel imports.

#### BATTERY ELECTRIC VEHICLES ARE MORE EFFICIENT

From *tank to wheel*, battery electric vehicles (BEVs) lead to much higher efficiency than internal combustion engines (ICE). Electrical engines can deliver about 80% efficiency (tank to wheel), while ICE motors can only convert about 30% of the fuel energy into mechanical energy.

From a *well to wheel* point of view, considering energy losses across the whole value chain, BEVs are six times more efficient than conventional vehicles, with an efficiency of 77%. For ICE engines this drops to a mere 13%. BEVs are also a much better solution than Fuel Cell Vehicles CEV since they don't need to reconvert the fuel (e.g. hydrogen) into electricity.

Efficiency of direct and indirect electrification for road transport




**NOTE:** values displayed here are on the higher side (optimistic) of the ranges found in the bibliography.

**Figure 17.** Efficiency comparison of different technologies for road transport. Source: Transport and Environment.

#### BATTERY ELECTRIC VEHICLES HAVE A LOWER TOTAL COST OF OWNERSHIP

Battery costs continue to decrease and some analyses show that **the total cost of ownership (TCO) of EVs will meet that of ICE vehicles by the early 2020s**[63].

The battery size continues to increase and boosts the driving range of EVs. By 2027 this could exceed 600 km. This will make EVs even more competitive and increase consumer willingness to switch to EVs.

Electric vehicles cost decrease driven falling battery costs and raising drive range

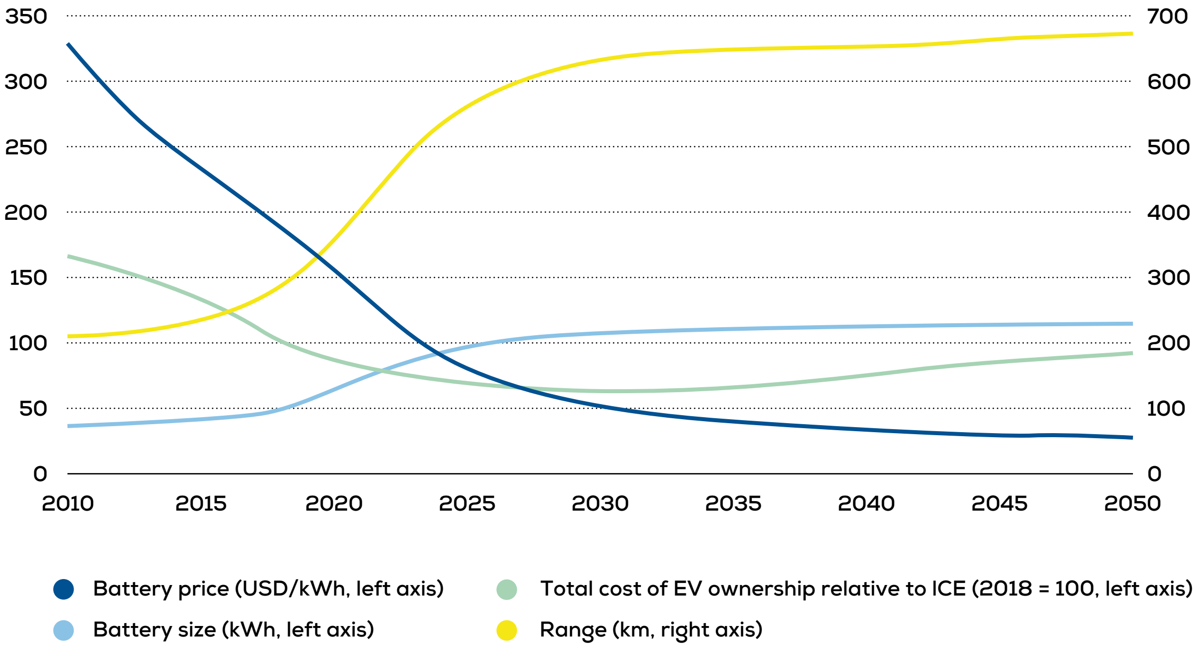



**Figure 18.** Development of passenger electric vehicle (EV) cost, battery size and range in Europe. Source DNV, 2020, Energy Transition Outlook 2020.

## ELECTRIFYING THE CURRENT PASSENGER VEHICLE FLEET

The number of passenger vehicles will decline by 40% between 2020 and 2050, owing to vehicle/ride sharing and automation. But these vehicles will be used more intensively, and so this will have only a minor effect on final energy use. Efficiency gains from electrifying these vehicles will be the main driver of falling energy demand in this sector.

Passenger road vehicle type to 2050

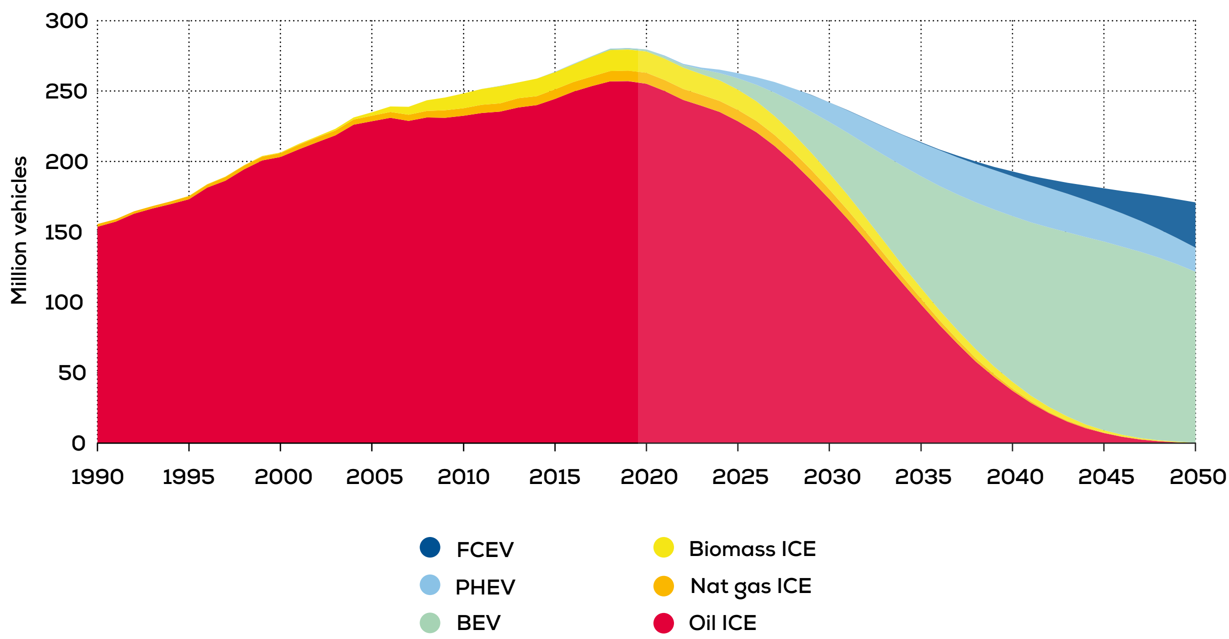



**Figure 19.** Passenger road vehicle types. Source: DNV for ETIPWind- based on the EU Impact Assessment COVID mix scenario.

**To achieve the decarbonisation of road transport, sales of new ICE passenger vehicles should be discontinued after 2040.** According to DNV, European EVs will reach 50% of the passenger market share in the late 2020s and 50% of the commercial market share by 2031. There is some uncertainty regarding the eventual vehicle type and fuel used by 2050. There is also concern about whether PHEV and FCEV vehicles will really take off after 2025 and 2035 respectively, as predicted in the EC's Impact Assessment (see Figure 19). By 2050, the entire passenger vehicle fleet will be powered by electricity, whether directly or indirectly (e-fuels).

## ELECTRIFYING THE COMMERCIAL VEHICLE FLEET

**Commercial and heavy road transport is harder to decarbonise through direct electrification** because the larger batteries needed to carry the load are more expensive, heavier and take up more space. As such, the potential competitiveness of these solutions is limited. Fuel cell and plug-in hybrids may have more to offer for busses, local small trucks, and even long-distance heavy-duty trucks depending on the specific case and on how technology costs evolve. Heavy-duty road transport is likely to see a more balanced deployment of both BEV and FCEV.

Several truck manufacturers have recently announced they will begin producing electric and fuel cell trucks (see box). Some manufacturers are hedging their bets on existing battery technologies while other are exploring fuel cells with hydrogen.

## Road transport- heavy electric vehicle

### Electric trucks announced by manufacturers

- **Volvo Trucks & Renault Trucks** have commenced production and sales in 2019 (up to 300 km range). Renault Trucks expects EVs to account for 10% of sales by 2029.
- **Daimler** has announced series production of electric trucks beginning in 2022.
- **DAF** offers the 9 tonne CF Tractor, with a 200 km range than can be fully charged in 75 minutes.
- **MAN** has announced small series production of eTCM in 2019 (with a 200 km range).
- **Scania** is planning a hybrid truck with pantograph charging and series production of its 20t electric truck in the first quarter of 2021 (with a 140 km range).
- **IVECO** is currently focused on the Daily Electric van (with a 200 km range) but has partnered with **Nikola** to deliver battery electric trucks with a range of about 500 km in 2021.
- **BYD** launched commercial EV trucks in 2020 including a 7.5t and 19t truck.

### Hydrogen fuel cells trucks announced by manufacturers

- **Nikola** has pledged to deliver two hydrogen-fueled heavy-duty trucks, the Nikola Two (up to a 900 mile range; <20 minutes refuel time; with production due to start in 2024) and the Tre FCEV (up to 500 mile range; <20 minutes refuel time; production due to start in 2023) within the next few years.
- Truck manufacturer **Navistar** will collaborate with **General Motors** to producing its International RH Series fuel-cell truck, powered by General Motors' fuel cells, in 2024. The target driving range is >500 miles with a refueling time of <15 minutes.
- **PACCAR** together with **Toyota** and Shell are testing their first hydrogen-powered trucks in the port of Los Angeles (with an estimated driving range of 450 km).
- **Hyundai Motor Company and $H_2$Energy**, are planning to bring 1,600 Xcient fuel cell trucks with a driving range of 400 km onto the Swiss market by 2025. Hyundai is planning to develop tractor units with a driving range of 1,000 km.

### BARRIERS FOR THE ELECTRIFICATION OF ROAD TRANSPORT

Regardless of what technology is chosen, the main barriers to electrifying road transport are the number and availability of charging and refueling stations. There won't be any electric fleet uptake if there aren't enough charging stations. Without fast uptake, any cost reduction potential cannot quickly materialise. Clearly, there is a massive need for readily available EV distribution infrastructure. While the number of charging points is increasing across the EU, it is not growing fast enough, and isn't well distributed. In 2020, there were about 250,000 public electric charging points, out of which only 25,000 were high-power public recharging points. Meanwhile there was a total of around 125 hydrogen filling stations across the EU[64]. These numbers are a long way off the EC's previous goal of one million public recharging and refuelling stations by the year 2020.

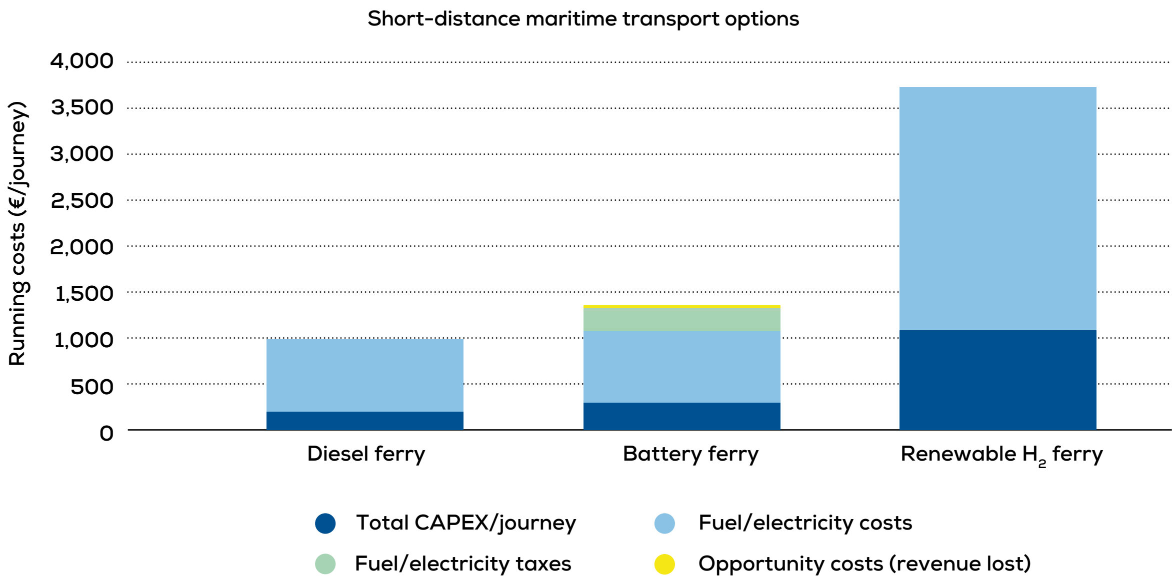
## Connecting wind energy and electric vehicles infrastructure

The development EV charging infrastructure along with wind farms is become increasingly interesting, as it reduces the amount of power flows between the transmission and distribution grids, potentially leading to significant savings on grid investment and congestion management. It also allows to supply power to areas where the distribution grid might be too weak to facilitate fast charging points.

Kallista Energy, in partnership with Enercon, is developing in a network of 80 ultra-fast charging stations with up to 40 charging points each powered directly from nearby wind farms, along and around France's motorways[65]. The network's first charging stations will come into operation in 2024 to accompany the rise of electric vehicles. Each charging station will be connected to two wind turbines, that can produce the equivalent of the energy required to drive 10 million kilometres a year. And the electricity not used for charging will be injected into the national grid and help increase the share of renewable energy in France's energy mix.

## 3.2.2 Waterborne transport

**Battery-electric propulsion offers a high efficiency rate and is the most attractive solution to decarbonise inland waterways and short-sea shipping** (see Figure 20). This technology is viable because of the relatively shorter range needed, the nature of the traffic (e.g. regular port calls) and the availability of strong grid infrastructure (e.g. e-charging of vessels at harbours).




**T&E analysis:** modelled on per journey operational costs of the Pride of Burgundy (~1,500 pax and ~530 cars); based on 25 year ship lifetime, historical operations of 209 days per year and 6 journeys per day with an average speed of 18 knots. CAPEX includes only propulsion related costs. Battery prices assumed €230/kWh; MGO price 430/tonne, fuel-cell price €3,000/kW, H2 fuel price €0.14/kWh; Efficiency: ICE (42%), electricity motor/battery storage/AC-DC-AC inverter (81%), H2 fuel-cell/electric motor/DC-AC inverter (45%).

**Figure 20.** Battery electric and $H_2$ fuel-cell ships in real operational conditions for short-sea shipping. Source: Transport & Environment, Roadmap to decarbonising European Shipping, 2018.

**Renewable hydrogen and its derivatives such as ammonia are ideal for decarbonising deep-sea shipping** as they easily meets the requirements. Deep-sea shipping (or large distance cargo journeys) requires much higher energy densities. The distances covered are larger and the cargo is much heavier. The batteries needed to power long distance cargo ships would take up so much space that less cargo could be shipped and the trips would become less economic.

Ammonia has some advantages over hydrogen. It has a higher energy density, reducing the need for storage space. And it can be easily liquified under pressure at ambient air temperatures or at -33°C at atmospheric pressure. Liquified hydrogen on the other hand requires high energy for compression and cryogenic conditions of -253°C for storage.

It is possible to almost fully decarbonise maritime shipping by 2035 using currently known technologies. In order to do so hydrogen and ammonia would need to provide around 70% of the fuel mix of maritime ships[66]. But the reality is less promising. The rate for substituting fuels is nowhere near as high as this. DNV predicts that by 2050, only between 25% and 50% of fuel consumption could be replaced by ammonia[67].

We also need to shift towards international emissions policies. The International Maritime Organisation (IMO) aims at a 50% reduction in global $CO_2$ emissions from 2008 to 2050. But this is far from what's needed to support net-zero emissions by 2050. The EU should review its emissions policy as it currently only covers GHG emission reduction policies for domestic maritime transport. For the intra-EU maritime sector, emissions should be covered within the ETS.

From a technological and infrastructure point of view, it is key to assess supply and infrastructure needs and identify routes and ports that could support demand – through the development of ammonia and hydrogen refueling infrastructure. The shipping industry will also need to make speedy efforts to adopt the technology onboard ships[68].

### 3.2.3 Aviation

EU domestic aviation is responsible for 15% of transport emissions. Aviation relies on energy dense fuels as it needs to move heavy loads over long distances, making it difficult for battery-based solutions, which are heavy and have lower energy densities than other fuels.

Only short-haul flights may be fully electrified, but new electric airplane designs will take time to be fully developed.

This is why we need to look into alternatives such as e-kerosene, an e-fuel based on renewable hydrogen and $CO_2$ (which can be sourced from carbon capture systems) that has considerable higher volumetric energy density than pure hydrogen. If the carbon used comes from non-fossil sources, e.g. air capture or carbon capture, then these fuels are practically zero-emission and carbon circular. The use of e-fuels has important advantages. Synthetic hydrocarbons such as e-kerosene can be combusted in a conventional jet turbine. It would be based on engines and fuel infrastructure similar to what is used today requiring only minimal or no modifications[69], and therefore minimising the investments needed.

The downside however is that these fuels are very expensive – around €3,000/tonne[70] i.e. six times more than fossil kerosene. E-fuels will not be the silver bullet to decarbonising aviation. In addition, exclusive use of e-fuels to meet aviation's growing fuel demand by 2050 would require 95% of Europe's current renewable electricity generation[71]. Other technologies such as advanced biofuels will also play a key role in the decarbonisation of the aviation sector. We can expect $CO_2$ emissions from the European aviation sector to decrease rapidly as of 2030 when efficiency measures, advanced biofuels and e-fuels take off.

#### Renewable hydrogen for hard to decarbonise transport modes

Ørsted has teamed up with Copenhagen Airports, SAS airline, DSV Panalpina, DFDS and shipping giant Maersk to develop a renewable hydrogen facility delivering clean fuels to buses, trucks, ships and planes. The Danish facility is expected to be fully operational by 2030, while the first stages of the project could be completed as early as 2023[72].

### 3.2.4 Rail transport

Rail transport is worth only 2% of total EU energy consumption in the transport sector, but it still important to make efforts to decarbonise its energy supply. Today, four out of five trains are already running on electricity, and although this electricity in most cases comes from the grid mix, a few Renewable PPAs have been signed between train operators and renewable power producers. For instance, German train operator Deutsche Bahn has signed seven PPAs worth 358 MW of renewable power in the last two years alone. Dutch Railway and French operator SNCF have signed eight and two renewable PPAs for capacities worth 449 MW and 163 MW respectively.

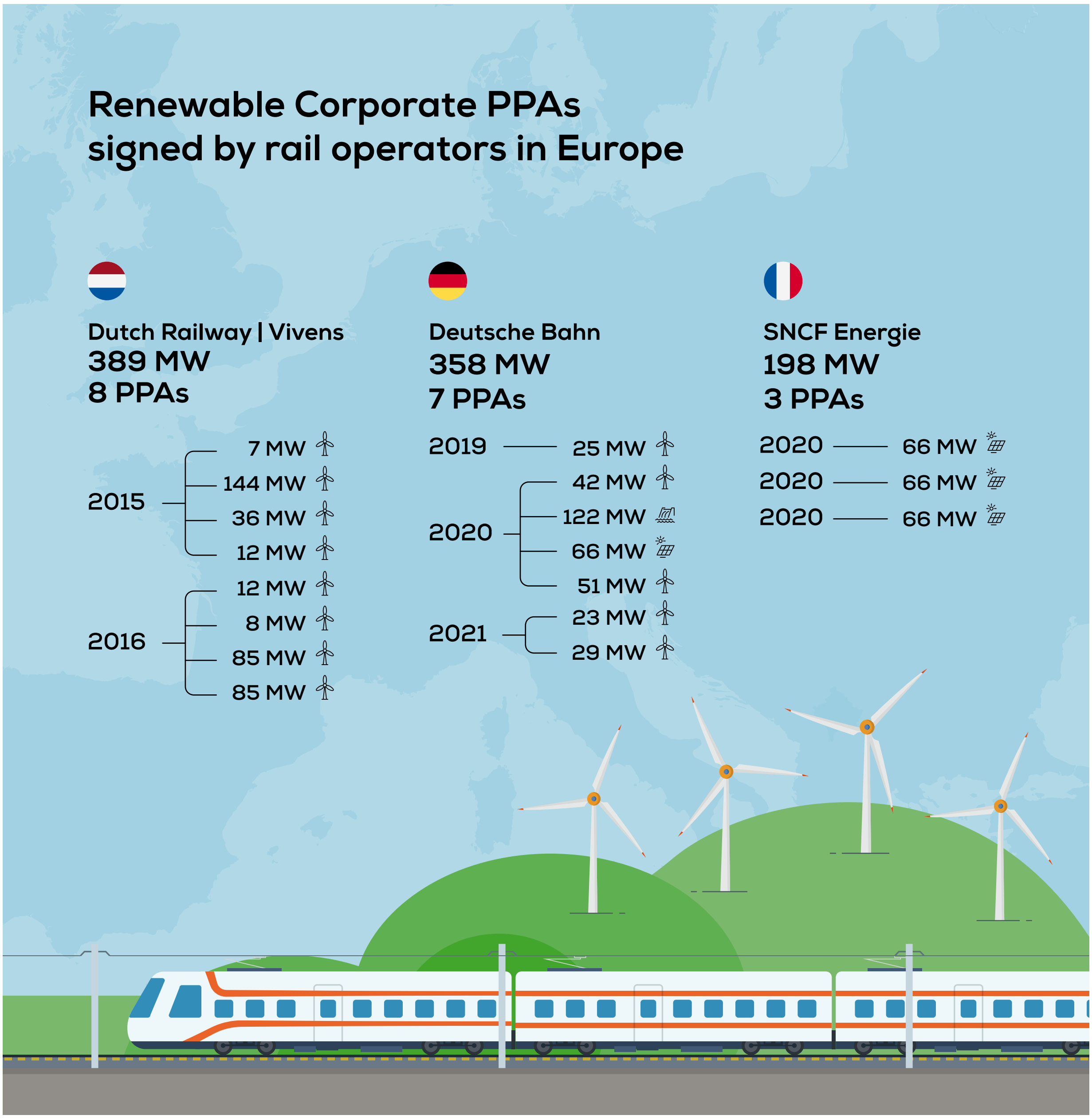



**Figure 21.** Renewable Corporate PPAs signed by rail operators in Europe. Source: WindEurope.

By 2050, rail transport could be almost fully electrified. The main barrier to electrifying remaining rail transport is its reliance on a secondary network that can be difficult to connect to the grid. In these cases fuel-cell powered trains are also being developed and offer an excellent complementary solution. By the end of 2020, Alstom's Coradia iLint, the world's first hydrogen fuel cell train, completed three months of successful test operations in Austria.

## 3.3 Buildings

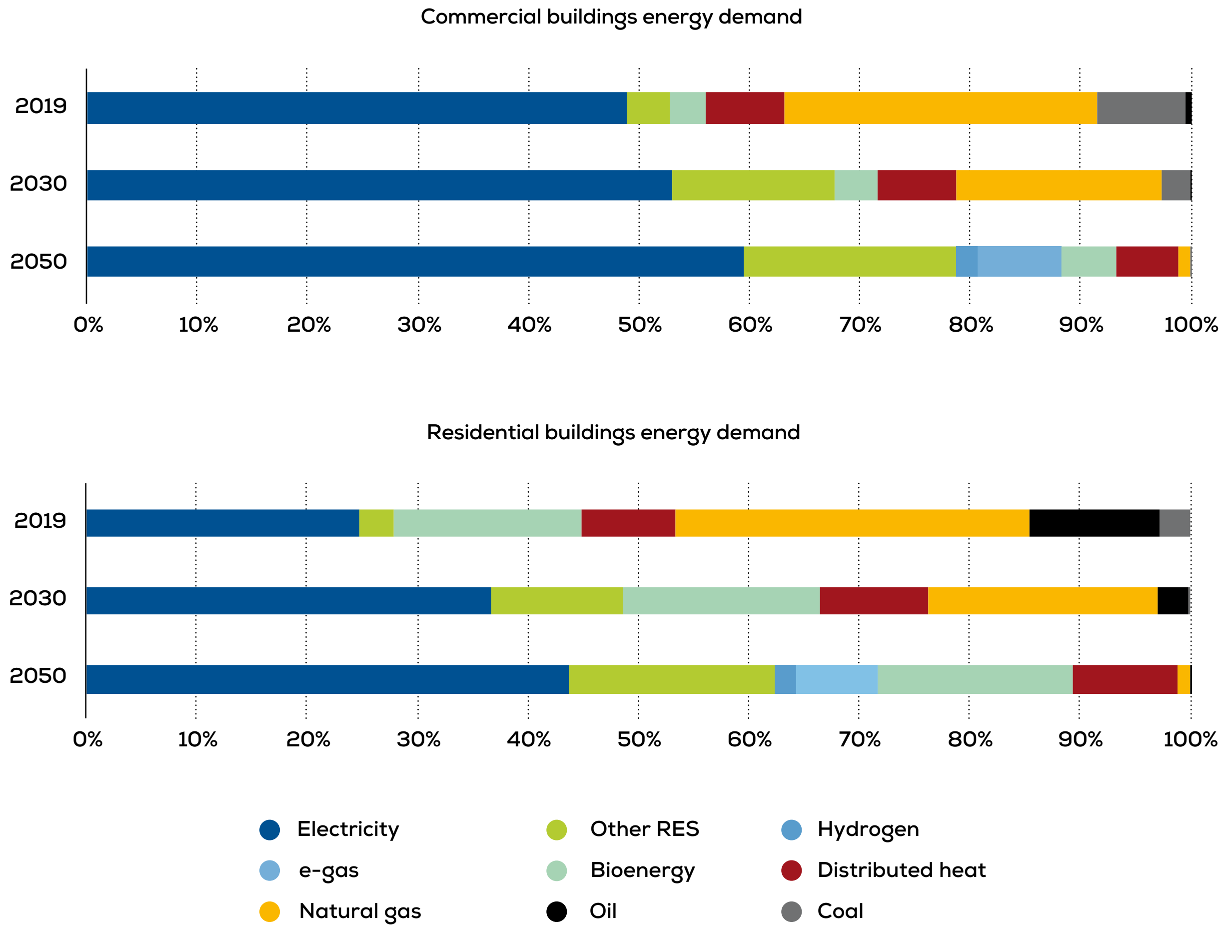
The building sector is actually the largest energy consumer in Europe today, representing about 30% of energy demand. The role of electricity in buildings is rapidly increasing at the expense of a smaller reliance on oil and natural gas.

### ELECTRIFYING BUILDINGS' ENERGY DEMAND

Today electricity is the main energy source in commercial buildings and its role in residential buildings is rapidly increasing as well. The increased uptake of modern electric heating (notably heat pumps) is the main alternative to natural gas in both residential buildings and the services sector. **Due to the high efficiency of heat pumps compared to fossil fuels, the total energy demand for heating and cooling could fall by 39% and 19% for residential and commercial buildings respectively by 2050**, as highlighted by the European Commission's latest analysis.

In the residential sector, the share of electricity in energy demand will grow from approximately 25% today to 40% by 2030 and 50-70% by 2050 according to the European Commission's expectations. The share of electricity in the services sector is expected to grow from 50% today to around 65% by 2030 and 80% by 2050.

By 2050 it is possible that renewable electricity will also contribute indirectly via reconversion to other synthetic gases. Hydrogen is likely to play a role, albeit marginal, in very specific locations where hydrogen infrastructure will be available (e.g. buildings within industrial areas).




**NOTE:** other RES include ambient heat extracted from heat pumps.

**Figure 22.** Commercial and residential buildings energy mix. Source: European Commission Impact Assessment COVID MIX scenario, 2020[73].

## HEAT PUMPS ARE THE BEST SOLUTION FOR SPACE HEATING AND COOLING

Among the five typical uses of energy in buildings (appliances and lighting, cooking, space cooling, space heating and water heating), space heating and cooling are the largest source of demand. **Thanks to electric heat pumps, the energy use for space heating is expected to decrease significantly and important emission reductions will be achieved.**

Electric heat pumps are two to three times more efficient than fossil fuel space heating. Switching to electric heat pumps today will already reduce emissions. Electric heat pumps generate a quarter of the carbon emissions of a gas natural boiler in 2020 (Figure 23). Furthermore, their carbon emissions will continue to drop as the share of renewables in the power mix continues to grow. Heat pumps are also a mature off-the-shelf technology. They can also be operated in a very flexible manner, providing valuable flexibility for the power sector, as discussed in chapter 5.2.7.

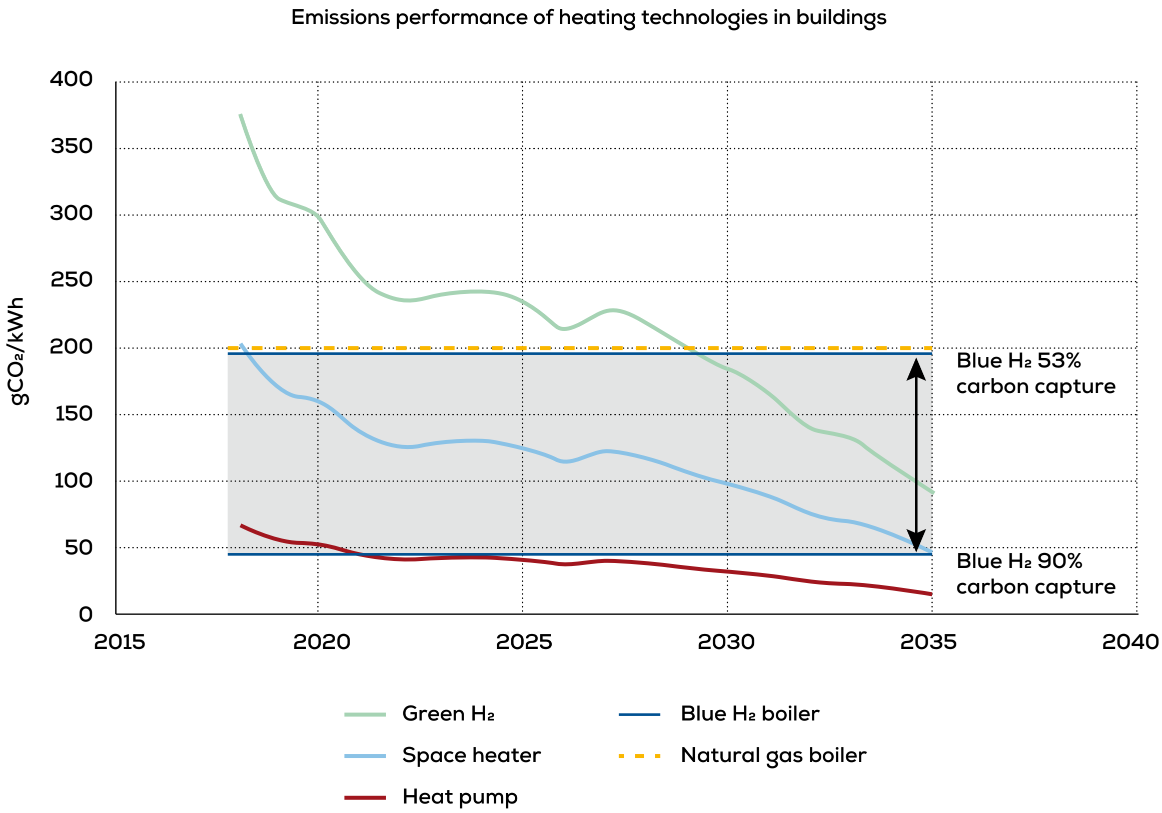



**Figure 23.** $CO_2$ emissions from various heating technologies for buildings. Source: University of Cambridge[74].

Heat pumps and electric boilers will not just be installed in the building itself. They will also deploy within existing district heating networks, which today get most their heat from combined heat and power plants, mostly fired with fossil fuels. This approach allows to develop larger heat pumps, tapping into economies of scale and providing a larger source of flexibility for the integration of renewable electricity sources.

In addition, the use of space cooling is set to increase, especially in southern Europe. Today it is almost fully supplied via electricity and it will become an important source of demand flexibility at times given the large shares of solar PV in the system.

## BARRIERS FOR THE DEPLOYMENT OF HEAT PUMPS

Today there are 14.8 million heat pump units installed in the EU 27[75]. And although their overall cost is falling sharply, their high upfront costs can still present a barrier to private use. However the **most important barriers at the moment are the relatively high rates of taxes and levies applied to electricity, and the lower levels of taxation for fossil fuels (oil, gas and coal) used in the heating sector.** (See Figure 24). $CO_2$ prices are also not internalised for heating fuels. All these factors translate into low replacement rates and low development and modernisation of district heating/cooling networks and buildings.

**Local regulations, policies and energy efficiency incentive schemes and obligations determine the growth rate of heat pump installations.** For instance, future home standards in the UK require low-carbon heating for all newly constructed buildings from 2025 onwards. In Germany and the Netherlands subsidy schemes for implementing heat pumps have been introduced. The Netherlands is providing a 20% investment subsidy to heat pumps and other technologies (a subsidy of €164m is available for 2021). In Germany heat pumps are supported with an investment grant of up to 35%; this rises to 45% when replacing old oil heating systems.

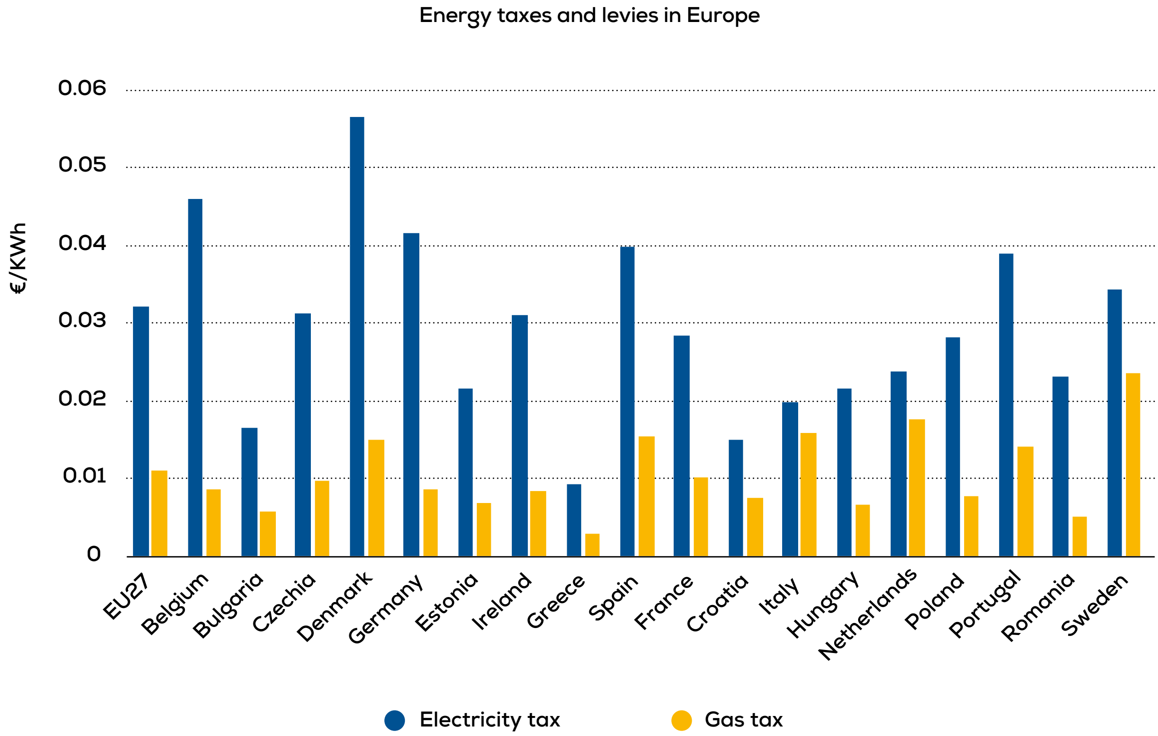



**Figure 24.** Taxes and levies for electricity and gas across the EU in 2020. Source: Eurostat.

# 4

# The power grid - the backbone of the energy system

Until now, the decarbonisation of the EU energy mix has been possible largely through the efficient operation of the power grid. **The power grid is and will remain the backbone of the energy system and the best platform to build upon for accelerating Europe's decarbonisation targets.**

Within the next three decades the energy system will undergo a radical transformation and the power grid will need to evolve fundamentally to allow for ambitious electrification of industry, building and transport demand. The extended infrastructure will accommodate direct demand from new users (e.g. electric road transport) as well as the production of e-fuels and e-gas through the conversion of renewable electricity into hydrogen. The latter will be vital for industries such as steel and chemicals and would also help decarbonise the maritime and aviation sectors. As renewables become the main energy source, the grid will need to ensure the energy can be carried over long distances (from offshore wind farms to demand centres) as well as bidirectionally between the distribution and transmission grid. This will require stepping up investments to extend the grid (as explained in section 4.1), better planning and stronger cooperation particularly for offshore (section 4.2), and closer collaboration between distribution and transmission operators. For the final point, better communication and grid optimisation technologies could facilitate this, as explained in section 4.3.

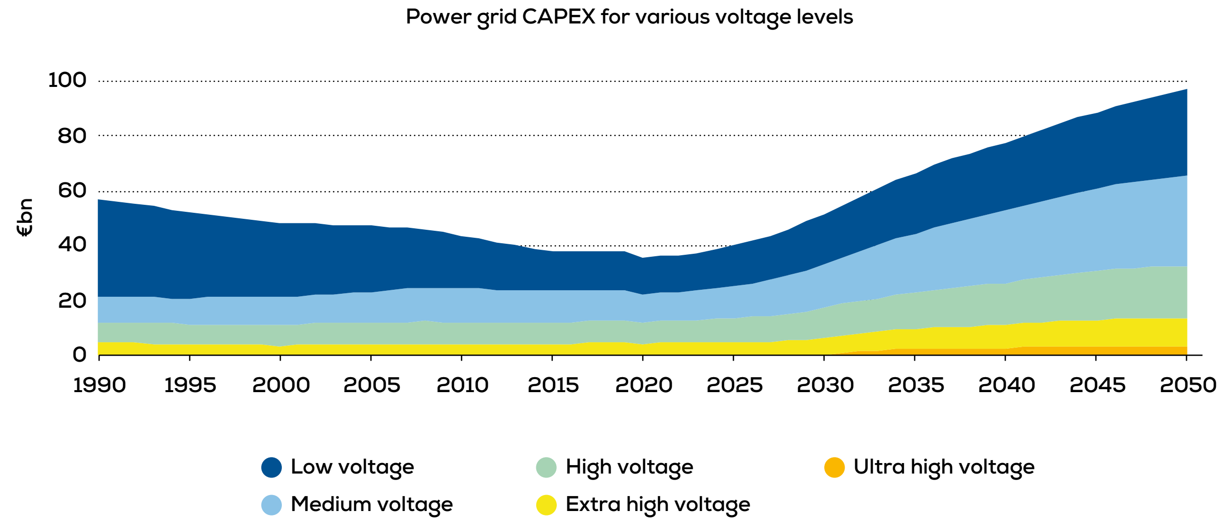
**Even with 70% of the total share of wind and solar the grid can remain reliable and resilient.** For this to happen decisions will have to be taken to enable grid expansion and reinforcement – onshore and offshore – as well as optimisation. The respective investments also need to be in place to enable these decisions.

The regulation governing system operators planning decisions must also evolve to reward even more the optimisation of existing assets and operational savings brought by the use of grid optimisation technologies; moving from a CAPEX based to a TOTEX based investment framework.

## 4.1 Grid expansion

### INCREASING INVESTMENT ON GRIDS

Europe currently invests around €40bn a year on grids. Investments need to increase rapidly, to double today's figure by 2025, to expand and optimise our grid infrastructure. **Annual investments on grid infrastructure need to double over the next thirty years** (€66-80bn investments annually on average between 2021 and 2050). Efforts will be needed at all voltage levels driven especially by the exponential growth of distributed assets at low and medium voltage, such as electric charging stations, solar PV systems, small wind farms and electric loads in buildings. The European Commission expects that investments in the power grid will make up 18% of all necessary investments in the energy system, as illustrated in Figure 8 in chapter 2.4.




**NOTE:** All power lines values are reflected as average. Low Voltage 0.4 kV. Medium Voltage 20 kV. High voltage 130 kV. Extra High Voltage 350 kV. Ultra High Voltage 800 kV

**Figure 25.** Power grid CAPEX for various voltage levels. Source: DNV for ETIP Wind (EU COVID-MIX scenario)[76].

**Plans for grid replacement and restructuring existing infrastructure need to get underway** Existing eHV grids will likely still be functional in 2050 but large parts of current regional grid – transmission and distribution – will reach the end of their service life by 2050. Half of all low-voltage lines could be over 40 years old by 2030[77]. Grid replacement and restructuring will also be an opportunity to modernise distribution grids and repurpose them to deliver energy from locally produced renewable generation to new variable loads.

## COORDINATION IS KEY TO ACHIEVE THE GRID BUILD-OUT TARGETS

Decarbonisation won't just require a new wave of power grid investments. **It also requires an EU-coordinated and strategic approach to ensure social acceptance of new grid infrastructure.** Today social acceptability is the biggest constraint to managing the grid transformation.

With current lead times for permitting and development, **plans for grid expansion projects need to be finalised at least 10 years before their expected commissioning date.** Today there is a significant cumulative delay in transmission infrastructure development (Figure 25). More than a third (11.5 GW) of all capacity increase reflected in the TYNDP pipeline has been in development for the past ten years, mostly cross-border transmission lines. Only a few projects currently under construction were thoroughly planned out since 2010 and were able to stick closely to their original timeline.

Based on WindEurope's thorough analysis of the TYNDP, we can conclude that one in every three investments has been delayed or rescheduled in every TYNDP process. This is bad news for the energy transition. We will need a more streamlined process for the permitting and approval of transmission infrastructure projects to avoid a continued postponement. On the other hand, transmission grid developers need to systematically apply all forms of social engagement to reduce potential delays. The work done under the Renewable Grid initiative is an example to follow. The LIFE Elia-RTE projects[78] led by two NGOs, Solon ASBL and CARAH, is creating green corridors under overhead lines in wooded areas in Belgium and France enhancing biodiversity and raising public acceptance.

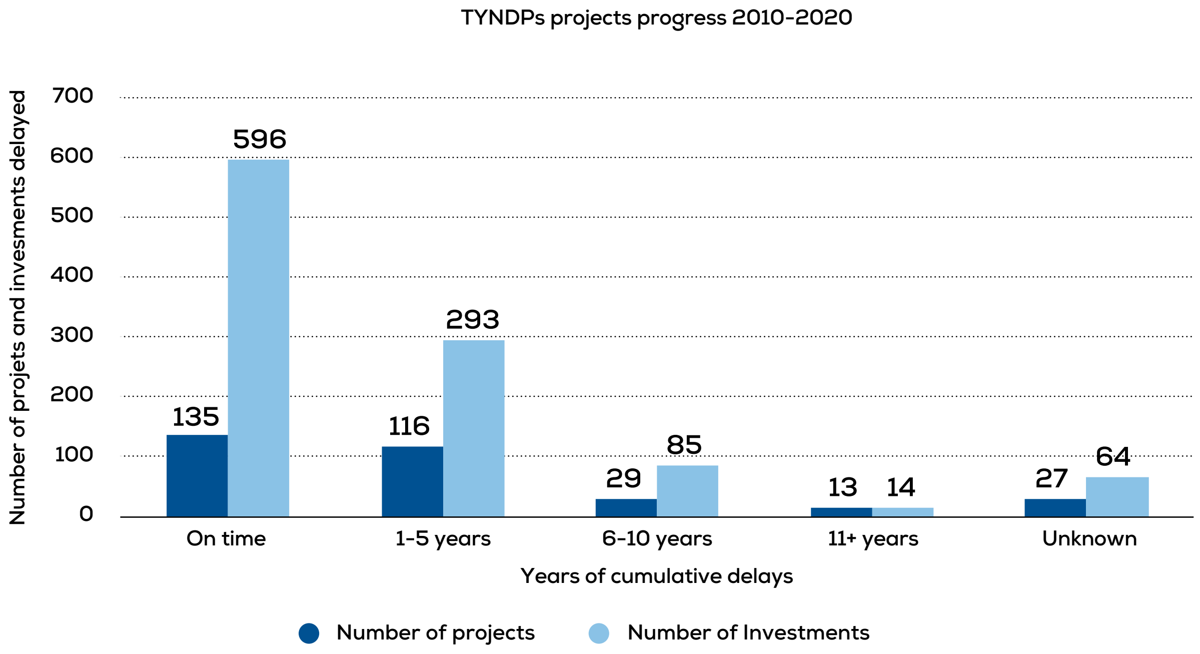



**Figure 26.** Cumulative delay in transmission grid projects. Source: WindEurope based on TYNDPs.

A clear example where more forward-looking planning is still needed is in the offshore grid. Member States (as well as the UK) have pledged to develop approximately 111 GW of offshore by 2030 under the National Energy and Climate Plans. Today's offshore grid expansion plans won't be able to deliver this capacity on time or even in an efficient way. The TYNDP 2022 process is an opportunity to address this, as is the ongoing revision of the TEN-E regulation**. Member States should support the EC's proposals in the TEN-E for developing integrated offshore network development plans for each sea basin, starting as soon as possible.**

### LACK OF AMBITION IN THE CURRENT INVESTMENT PLANS

**Europe's cross-border capacity needs to triple in the next ten years.** Today Europe's cross border capacity is approximately 50 GW[79]. ENTSO-E has called for 85 GW of additional cross-border capacity to be deployed between 2021 and 2030. Most of this capacity is in the planning stage or under permitting but we cannot afford for it to be delayed. The latest TYNDP, based on 2030 National Energy and Climate Plans for a 40% $CO_2$ reduction has a pipeline of projects totalling 70 GW and worth €50bn (or €5bn per year) that should be commissioned by 2030. To reach 55% we will clearly need to re-assess and fine tune the plans to account for a greater electric load and much larger shares of renewable energy capacity.

**To achieve the desired grid by 2030, final decisions on the necessary projects need to be taken before 2022.** Thus, the industry needs to make a monumental effort to plan for the system that Europe needs. The TYNDP 2022 and PCI list in 2023 should reflect all of these investments. Inadequate planning will inevitably lead to repeated delays as projects will face an early lack involvement from affected parties and local groups. These delays will also slow the substitution of conventional power generation with renewable power plants.

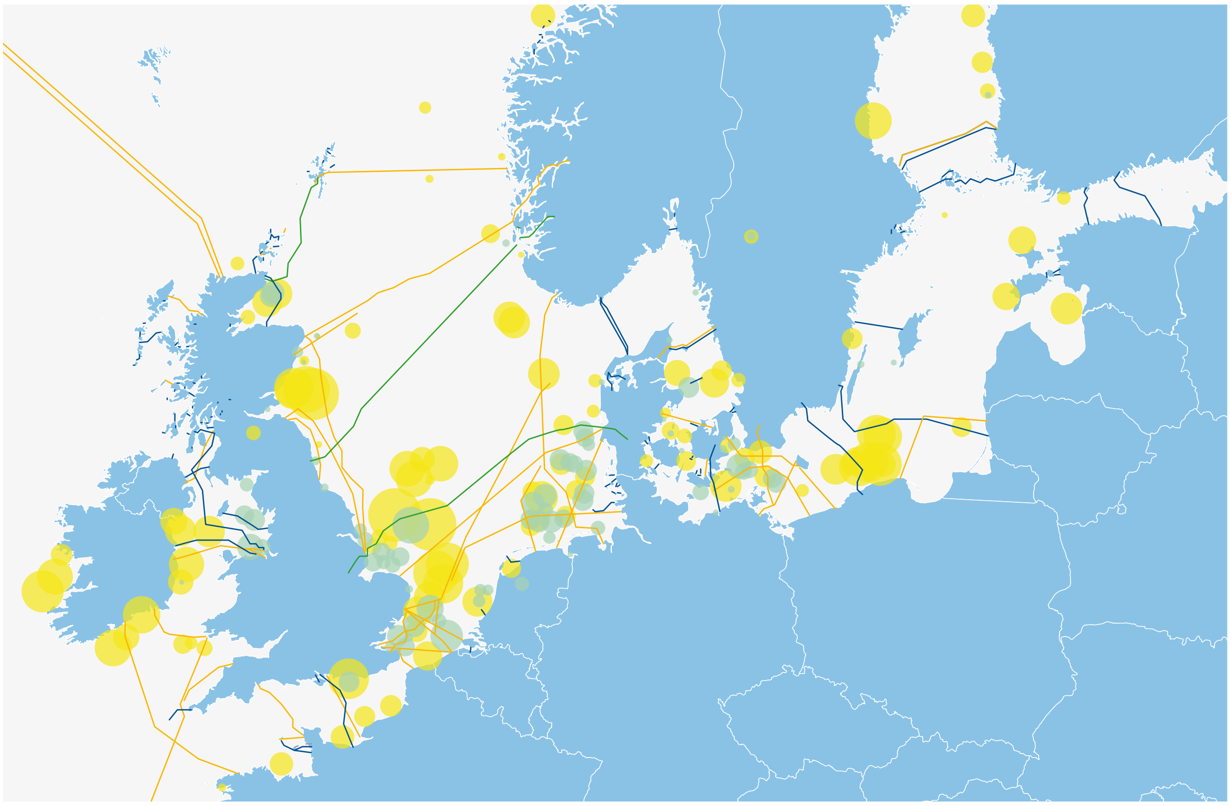
## 4.2 Offshore grid development

### ROLLING OUT THE NECESSARY GRID TECHNOLOGIES

Stepping up offshore generation will require significant investments in new extra-High Voltage assets connected to the shore and to further interconnect countries. Operation-wise, big offshore wind volumes combined with onshore distributed generation and demand facilities will completely change power flows across Europe. Investments will be needed to reinforce close-to-shore transmission grids. But the ability to control power flows will also become more important. HVDC and other grid optimisation technologies (e.g. FACTS) together with digital capabilities will play a key role here, as will be discussed in section 4.3.

Offshore wind cannot grow sustainably without the parallel development of an interconnected offshore grid. The latter will optimise the volume of new necessary infrastructure and cut down on the number of onshore landing points, improving social acceptability and co-existence with the marine environment. Furthermore, it will reduce investment costs and allow social welfare to be maximised as the power will be delivered to end-users that need it the most at any given hour (the market with the highest price). This offshore grid will largely be based on multi-terminal HVDC systems connecting generation and loads. Europe is currently home to world-class electrical technology providers that design HVDC systems as point-to-point and multi-terminal transmission systems. Today these systems need to evolve and become interoperable, allowing multiple technologies and suppliers to co-exist and adapt to future-proof designs. WindEurope and its members are working closely with TSOs and HVDC suppliers to make this happen.

The offshore environment also presents opportunities for innovative grid topologies. Denmark has committed to building the first energy islands in the North and Baltic Seas, allowing to connect up to 10 GW of offshore wind capacity. The VindØ consortium will develop the island in the North sea, connecting at least 3 GW by 2030. The island will include an HVDC platform, a power-to-X facility and harbour to provide O&M services to offshore wind farms[80].



**INTERCONNECTORS**

- In operation
- Under construction
- In development / planning

**WIND FARMS**

- In operation
- In development / planning

**NOTE:** the map represents the status as of April 2021. The size of the wind farms is relative to capacity. Access the latest Offshore Wind Farms database at WindEurope's Intelligence Platform: windeurope.org/wip

**Figure 27.** Map of existing, planned and prospective offshore transmission lines in the North and Baltic Seas. Source: WindEurope based on 4C Offshore data on interconnectors.

### SETTING THE RIGHT REGULATORY FRAMEWORK

**Technology is not the main barrier to offshore grid development however. There are no market arrangements for offshore hybrid projects[81] to be bankable**. Countries have different investment schemes and market operation rules which prevent investments on offshore hybrid projects from being released. The lack of certainty on future market design (and revenue streams) for offshore hybrid wind farms hampers the process of building an integrated offshore grid. **The European Commission needs to offer clarity (e.g. through regulatory changes to the Electricity Regulation) on how hybrid offshore projects will be treated when it comes to congestion income distribution and cross-border capacity allocation. And the TEN-E revision should better address coordination between transmission grid plans and the location of new generation assets.**

Without a clear framework, it is difficult to commission a pipeline of projects. And without a pipeline of projects, it is difficult to plan and build the necessary infrastructure.

Through a coordinated approach among all relevant stakeholders, Member States, and dedicated EU policy and funding frameworks, Europe will be able to deliver cost-effective and future-proof offshore DC grids before 2030.

## 4.3 Optimising the grid

### PLANNING AND OPERATING MORE EFFICIENTLY

An EU-wide perspective and coordinated approach will be needed to ensure maximum efficiency and optimal use of resources and grid infrastructure both onshore and offshore. Grid planning and investment frameworks need to evolve to account for the benefits of grid optimisation in improving efficiency and cutting down on total cost expenditure (TOTEX: capital and operational expenditure together).

**Grid efficiency is important for reducing operating costs. The operating cost of a highly electrified and renewable energy system will be higher using an identical approach to system planning and operation.** The ongoing integration of new types of loads such as Electric Vehicle (EV) charging and renewables will drive up operating costs. Without dedicated policy to improve grid efficiency using a cost-driven approach, operational expenses (OPEX) will double for transmission and triple for distribution by 2050[82].

Strong efforts should be made to optimise operational practices with a system-wide approach and to improve interoperability of assets.

Interoperability and connectivity between all connected devices and grid users – both at transmission and distribution level – will be key to stemming this flow. Above all they are vital for matching supply and demand efficiently. Investments to upgrade the energy system's communication infrastructure and to strengthen technological development, testing, prototyping and demonstration will be necessary. Policy makers should also ensure that the right policies are in place to enable maximum interoperability and connectivity of assets[83].

**Adopting a concrete EU-wide smart grid approach can reduce costs over the lifetime of grid infrastructure.** Smart grid performance should be assessed at all stages and processes. This includes grid planning and development, system and market operation, asset management (e.g. ageing assets, assets under restructuring), and innovation. We need to develop benchmarks, applicable metrics and highlight replicable practices[84].

### MAKING USE OF AVAILABLE AND STATE-OF-THE-ART TECHNOLOGIES

Grid optimisation includes the wide deployment of innovative grid technologies but also ensures maximum flexibility of available resources with a cost-driven approach. WindEurope has created a library of commercially available technologies under the headline of grid optimisation technologies[85] that can be classified in five broad categories (Figure 28). These technologies are key to maximising the performance of new and old assets and to better exploit installed renewable capacity until we achieve urgent build-out of new grid capacity. They can offer the following benefits:

- Increasing the line transfer capacity of transmission and distribution assets;
- Improving controllability of power flows and system parameters, potentially reducing power losses;
- Reducing asset failures and extending their life span;
- Increasing safety margins; and
- Improving system resilience and risk mitigation.

| GRID OPTIMISATION TECHNOLOGIES | | |
|---|---|---|
| Advanced monitoring | | • Dynamic Line Rating<br>• Substation Fleet Digitalisation<br>• Asset Performance Management |
| Advanced system operation control devices | | • Phase-Shifting Transformer<br>• Solid-State Transformer<br>• Static Synchronous Series Compensator<br>• Modular Power Flow Control Technology<br>• Thyristor-controlled Series Compensator<br>• Static Synchronous Compensator<br>• Static VAR Compensator<br>• Adaptive Protection Scheme<br>• Synchronous Condensers |
| Advanced converter technologies | | • Grid-forming capabilities<br>• Black-start |
| Line and voltage upgrades | | • High Temperature Low Sag conductors<br>• Voltage uprate |
| DC transmission | | • HVDC technology<br>• AC TO DC line upgrade<br>• Superconductor |

**Figure 28.** Categories and examples of grid optimisation technologies[86]. Source: WindEurope.

## 4.4 Grid resilience

We need to plan for and invest in resilient grid infrastructure. Grid assets need to become weatherised. Generation and demand assets complemented by advanced technologies (e.g., grid-forming converters and smart storage technologies) will be able to actively contribute to grid resilience against lengthy power shortages, cyber-attacks and other unpredictable threats.

### 4.4.1 Resilience against extreme weather events

Extreme weather events such as rising global temperatures, wildfires, extreme precipitation, flooding, storms and other events are expected to become more common. These events can lead to sudden simultaneous unavailability or underperformance of multiple grid assets, affecting generation and grid transfer capacity. In certain cases, extreme weather events can even lead to widespread physical damage of assets with short- and long-term implications for the power supply.

A recent example is the cold wave that hit Texas in February 2021 and left millions of users without electricity and gas for several days due to frozen pipelines, wind turbines and other equipment. Neither natural gas infrastructure nor the power grids (including wind turbines) have been properly winterised, contrary to common practices in northern US states, Canada or across northern Europe. In Finland and northern Sweden, for instance, wind turbines have used ice-detection and de-icing equipment for many years, enabling high performance even in the harshest conditions. This practice is also common in central Europe across the mountainous regions of the Alps, where IEA Ice class 3[87] and above are widely used. The good news is that this equipment can be easily added to existing machines.

**Figure 29.** Frozen gas valve and a high-pressure pipe (© Nenets - Shutterstock) - top, and wind turbines operating in cold weather (© Feher Istvan - Shutterstock) - bottom.

Other extreme weather events can lead to blackouts across the grid. A well-known example was the black out in South Australia in 2016. This was the result of lightning strikes across a poorly interconnected power grid with operational practices and technologies not fully designed to cope with this. The wildfires in California over the summer of 2020, along with poor system planning, resulted in several blackouts. Whatever the cause of the blackout, the system needs to be resilient and able to return to stable power levels within hours, avoiding costly impacts. Today, some conventional thermal power plants and hydroelectric power plants are equipped with auxiliary systems (e.g. stored fuel and engines) to deliver these services (black start capabilities).

As we shift away from obsolete fossil-based thermal power towards renewables, an emphasis needs to be put on ensuring these capabilities can be maintained. Offshore wind farms, due to their large size are likely to play a crucial role in future restoration strategies at the transmission level. Following a blackout, a self-start unit within the wind power system would be energised, causing the rest of the wind farm to restart their turbines. This is known as islanding operations, which would then be used to actually restore the power system. The wind farm would then energise a part of the grid, leading to further energisation of the whole system.

Black Start capabilities could be provided by offshore wind farms with the use of grid-forming converters and batteries. And they would provide more value than conventional power plants since their restoration time is much shorter, potentially avoiding further blackouts. But they are not yet commercially deployed as the market has not evolved to reward this sort of technological development and integration at this stage. Transmission system operators and the industry are working together developing EU grid code and defining market products, which could potentially send the right investment signals to attract industry research efforts.

### 4.4.2 Resilience against cyber risks

Digitalising and connecting energy sectors and assets have undeniable benefits and are a major stepping-stone towards decarbonisation. But it also multiplies the risk of cyber-attacks that can impact several interconnected assets simultaneously. Cyber-attacks can cause physical equipment damage (with potential cascading failures in other interconnected assets), and widespread electricity supply disruption with devastating impacts on critical services, households, and businesses. Total costs for the asset owner in mitigating these impacts, revenue losses and dealing with the cyberattack (e.g., investigation, containment) can run into millions or even billions of euros[88].

In December 2015, a massive cyber-attack took place leaving 250,000 Ukrainians without electricity for hours during winter. The power outage was the result of a Trojan which was found on several electricity substations, believed to be associated with a BlackEnergy Malware campaign utilising remote cyber intrusion[89]. This was the first known instance where a cyberattack caused an electricity blackout. Although the security was restored within hours it highlighted the vulnerability of assets and the need for prescriptive measures. Extreme technical events like these are expected to grow not only in scale but also in cost. The grid has proven its resilience during the pandemic, but the energy system needs to be able to withstand a growing number of unforeseen events.

Regardless of any mandatory or prescriptive measures, full protection against cyber-attacks in the electricity sector is impossible. Policy makers should design strategies to build-up cyber resilience and should consider a wide range of approaches from prescriptive to performance-based ones. These approaches should be able to address specific aspects of different systems and assets, and any potential risks and impacts. In the case of grid and generation assets, specific attention should be given to potential risks for OT equipment as well as IT infrastructure which might be the main concern in many other sectors.

Over-prescriptive policies for cyber resilience might allow for more efficient monitoring of compliance, but these will not be able to cover all potential risks. The process of improving cyber resilience should be continuous. Setting metrics and targets and giving asset owners room to implement the measures they need to meet these targets can help build resilience and adapt to evolving needs.

## 4.5 Infrastructure for renewable hydrogen

As we continue expanding and modernising the power grid, we also need to streamline investments in hydrogen infrastructure helping to couple renewable energy production and hydrogen demand from hard-to-abate sector - primarily industry over the next few years.

An increasing demand for hydrogen is expected in Europe with the European Commission aiming to produce 10m tonnes of hydrogen by 2030. And there is specific ambition to develop 40 GW of electrolyser capacity by the same year. Several Member States have committed to these targets by developing national hydrogen strategies and by supporting large infrastructure projects, also known as IPCEIS (Important project of Common European Interest). Currently announced projects amount to at least €10.6bn[90] worth of investments in electrolyser technology.

Some of these projects will aim to combine production and consumption of renewable hydrogen in the same location. However, as demand from specific users grows steadily (e.g. a steel smelter or a refinery), combining production and demand will not always be feasible or desirable.

Indeed given that electrolyser projects currently under development are of a small-scale - in the range of 20 MW to 50 MW, the power grid should provide the necessary infrastructure to optimise electrolysers and enable them to provide services to the system. For much larger projects, in the range of hundreds of MWs, dedicated hydrogen infrastructure could prove to be viable, as it can also act as a source of storage. But specific hydrogen storage facilities will need to be developed. Salt caverns, abundant in central and western Europe, could be a good option for dedicated underground hydrogen storage. Converting all existing facilities currently used for natural gas storage would unlock about 50 TWh of storage capacity in the long-term[91].

## THE EMERGENCE OF HYDROGEN VALLEYS

Some countries are beginning to plan and develop regional hydrogen infrastructure around the first emerging hydrogen supply and demand hubs – also known as "hydrogen valleys" (e.g. industrial clusters, ports, cities). Examples include the Netherlands and Germany (North-West) where there are plans to convert a low calorific natural gas grid no longer in use. There is also potential for developing dedicated hydrogen infrastructure to export large amounts of energy produced from future offshore wind power islands[92], especially in the North Sea.

Emerging hydrogen infrastructure (by 2040)

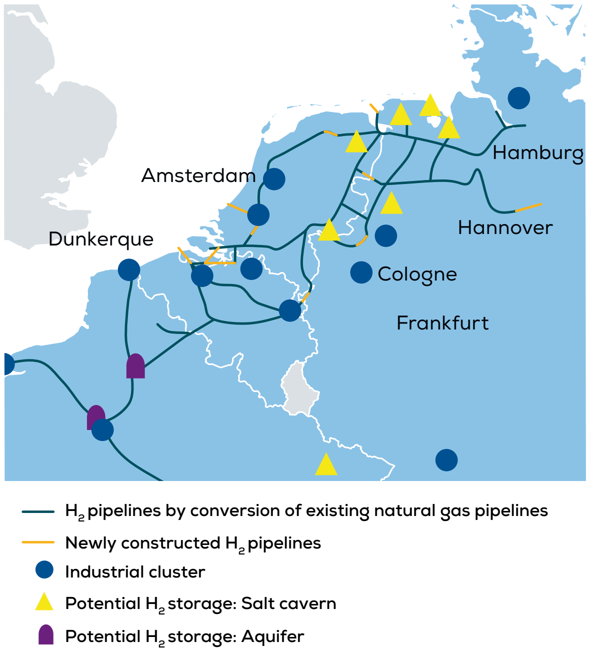



**Figure 30.** Emerging Hydrogen infrastructure in North-West Europe. Source: Gas for Climate.

As renewable hydrogen allows production and demand for renewables to be decoupled, it will also act as a flexibility source (discussed further in Chapter 5). Clearly, it is vital that regulation governing renewable hydrogen production is well-designed to support the integration of renewables, while not putting any further stress onto the energy system.

**It is important to strengthen investments in infrastructure,** maximising system efficiency and minimising infrastructure CAPEX, including for electricity, gas and hydrogen. A coordinated EU-wide approach will need to address the governance of new hydrogen infrastructure, its planning and development. This joint planning should consider both the energy supply and system flexibility needs. A joint approach will allow the efficiency of the system to be maximised. But it is also a complex exercise that should involve all stakeholders from the demand side, renewable production, hydrogen production & suppliers, and grid developers.

# 5

# Flexibility needs and enabling technologies

## 5.1 Variability and flexibility needs

With the ongoing electrification of industry, transport and buildings', along with heightened demand and increasing shares of renewables, **the residual load (total electric demand minus wind and solar generation) will become much more variable across all time horizons**.

### SOURCES OF DAILY VARIABILITY

**Daily variability will increase with the introduction of new variable loads for EV charging, heat pumps and higher shares of solar PV generation**. The daily pattern of solar PV generation will be reliably predicted thanks to advanced forecasting techniques but as it stands, the development of EV charging demand patterns is today a big unknown. Figure 31 gives a good round-up of the expected hourly dynamics of demand during winter (left) and summer (right) weeks 2050. The main contributors to daily variability of electricity demand are heating, cooling, appliances and lighting, and road vehicles (both in winter and summer). These same sources of demand variability (heating and cooling, transport) will also be big contributors to demand-side flexibility as presented in chapter 5.2. Electricity demand for converting power to hydrogen is stable during winter at around 250 GWh, when the supply of wind is plentiful, but drops to almost zero for three days, providing flexibility to the system. During the summer power to hydrogen demand is coupled with daily cycles, accounting for the large changes in solar PV.

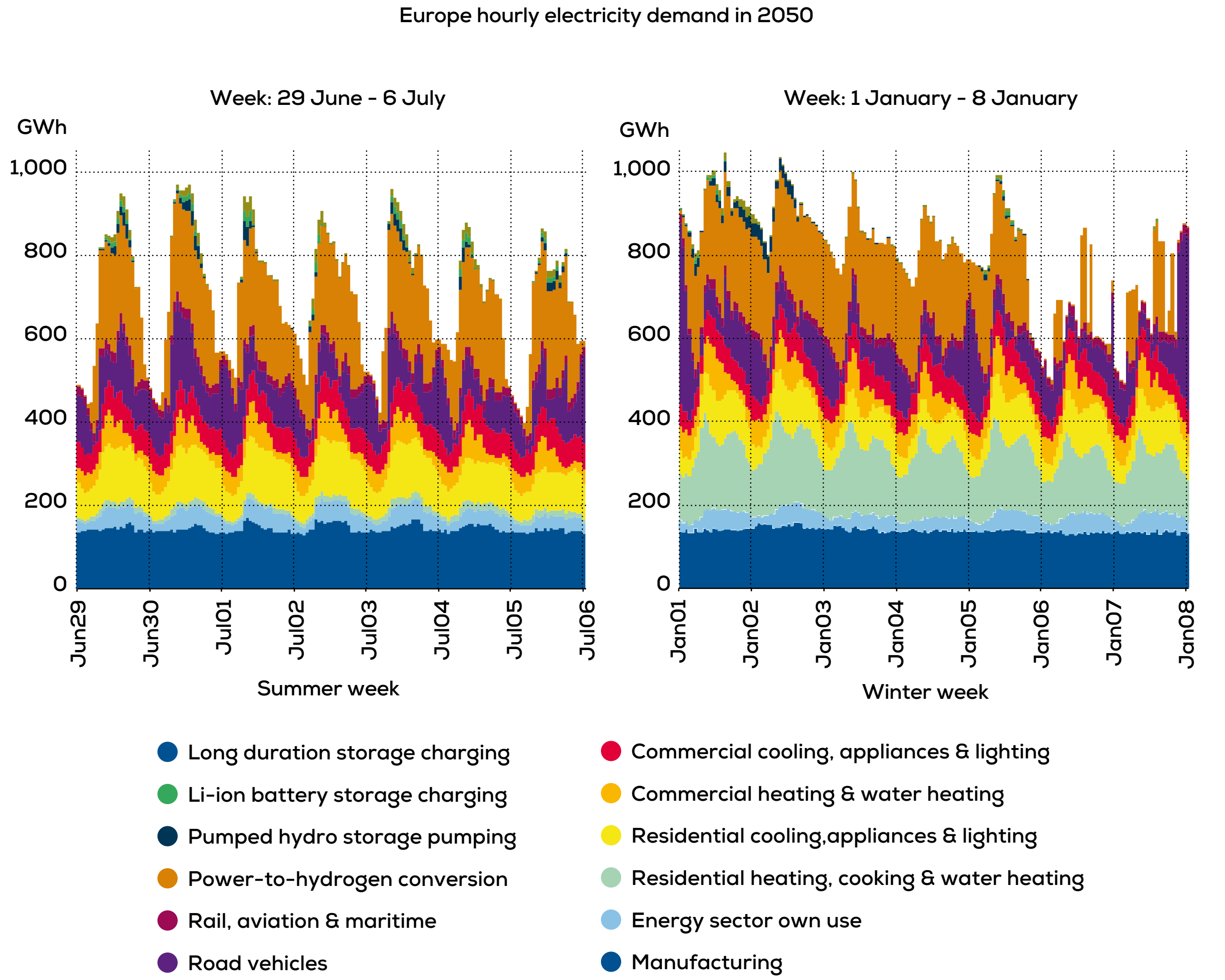



**Figure 31.** European electricity Hourly demand in July (left) and January (right) in 2050. Source: DNV for ETIPWind[93].

## SOURCES OF SEASONAL VARIABILITY

**Seasonal variability in the residual load will increase with the large roll-out of electric space heating and cooling appliances in buildings and larger amounts of solar PV.** To a lesser extent, wind energy will also add more variability to the residual load. Weekly and seasonal variability of electrified demand in buildings e.g. electric heating and cooling, will follow a predictable pattern but the order of magnitude for the different peaks will not be easy to project. The potential contribution of electric heating to flexibility is further discussed in chapter 5.2.

Extreme weather events have an important impact on wind and solar output. For instance, the North Atlantic Oscillation a seasonal weather phenomenon over North Atlantic and Europe caused by differences in air pressure, can lead to a variation in wind and solar generation as high as ten times[94]. But improved long-term weather forecasting will help us to anticipate future weather events and climate change[95].

## AN INCREASING CHALLENGE

The variability of the residual load varies across markets (colder geographies will rely more heavily on heating during winter months) and will also depend on the existing renewables mix. A simulation done by DNV for Germany and Spain shows how the residual load variability will increase as the load becomes further electrified and the share of wind and solar increases (Figure 32). While the results of the simulation are highly dependent on a number of assumptions (see Annex 3), particularly installed solar PV capacity, EV charging behaviour and climate models, there is an obvious conclusion to be drawn: **the largest stress on the system will be faced within the daily timeframe.** For instance, in 2050 Germany would be faced with residual load changes as high as 40 GW given the large decrease in PV capacity during the evening alongside the peak demand around the same time. This ramp is four times larger than the situation today. The system would also need to cope with load changes of about 6 GW within one hour, double than what it is today.

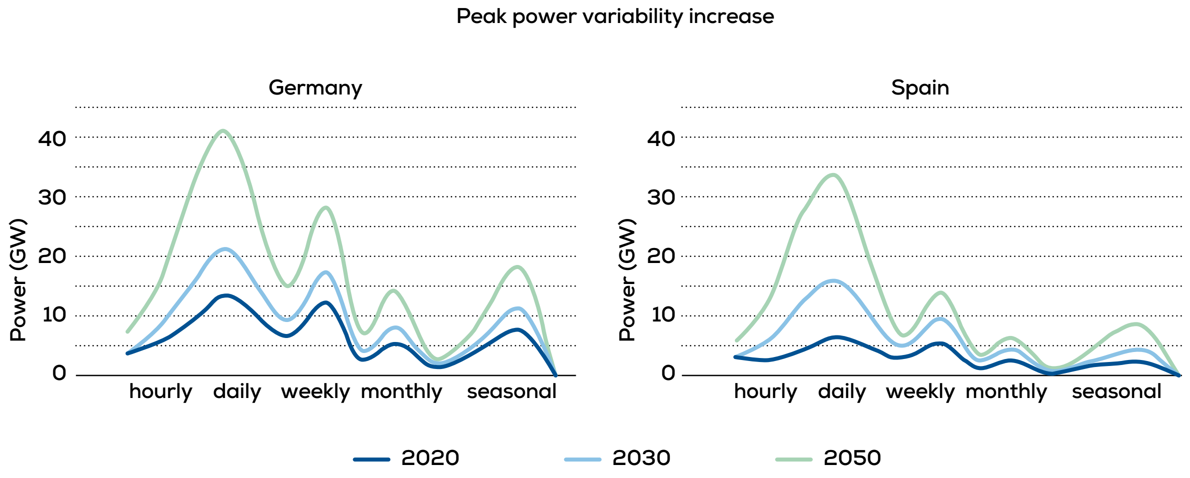



**Figure 32.** Peak power variability in Germany and Spain based on the residual power load in 2020, 2030 and 2050. Source: DNV for ETIPWind.

Managing the balance between supply and demand will become a much more demanding task. And **while the increasing share of renewables and ongoing sector coupling will multiply the number of variability sources, these same sources could become flexibility resources, if the right pricing signals are in place**.

## 5.2 Enabling technologies

**Dealing with the challenging task of balancing supply and demand over different time cycles will require a diverse portfolio of flexibility resources:** generation units with different flexibility capabilities, small- and large-scale storage, demand-response, grid interconnections and coupling with other energy carriers (Figure 33).

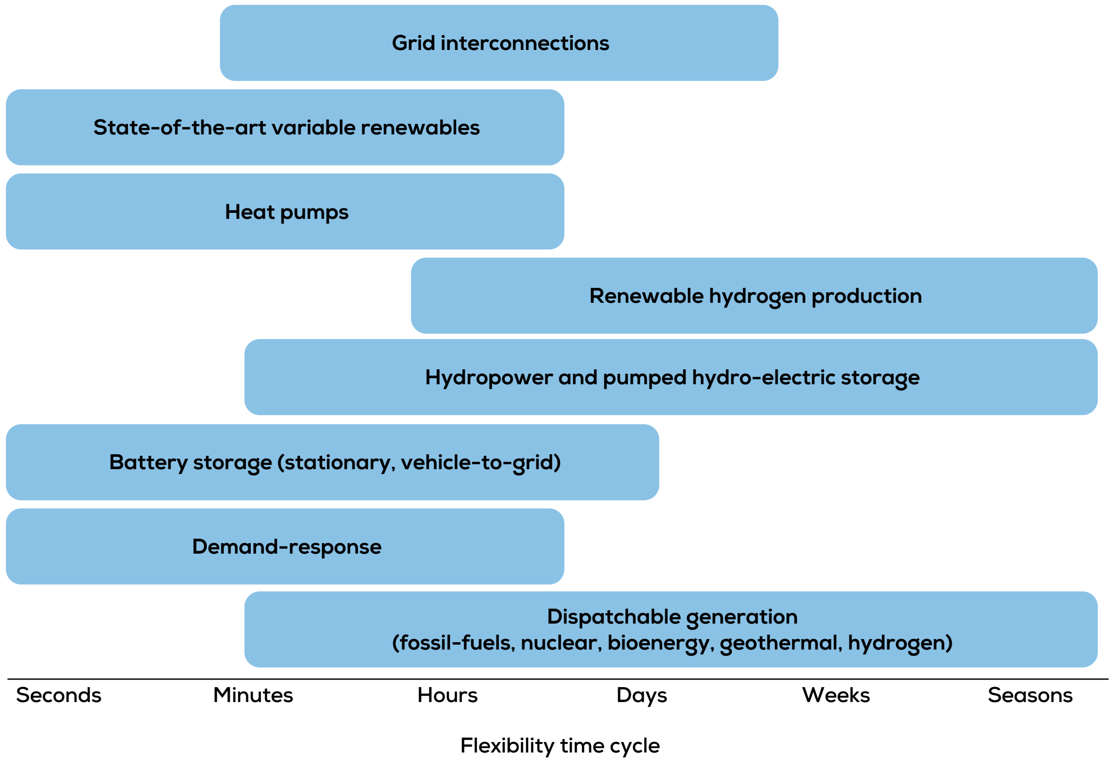



**Figure 33.** Flexibility resources for different flexibility time cycles. Source: WindEurope based on IEA[96].

Grid interconnections play a crucial role in valorising flexibility from neighbouring countries to alleviate technical constraints, such as congestion and peak load.

Daily flexibility needs can be provided by state-of-the-art variable renewables, demand response from industry and heat pumps in buildings, and battery storage – including stationary and vehicle-to-grid.

Seasonal flexibility needs can be met through hydropower, pumped hydro-electric storage (PHS), and power-to-hydrogen, along with a limited use of dispatchable power plants based on bioenergy, fossil fuels and possibly hydrogen.

Conventional power plants and power plants fuelled by bioenergy and clean fuels such as hydrogen and ammonia can also help mitigate variability over different time cycles. However, given their carbon footprint (when based on fossil fuels), and their lower round-trip efficiency (when based on alternative fuels), their contribution will be limited. The European Commission in their impact assessment estimates that about 4% of electricity needs by 2050 would be covered by fossil fuels with CCS. Less than 3% would be covered by oil and gas peaking units with very low utilisation rates (14%). Bioenergy plants would also provide around 5-7% of the electricity needs, similar to today's levels.

However, maintaining conventional plants in operation or stand-by operation only to cover extreme flexibility needs will require maintenance, retrofit and ramping costs which are not inconsiderable and should be counted when comparing costs and environmental impact of different flexibility resources during the transition to a decarbonised energy system.

As discussed in the following sections, variable renewables, smart charging and vehicle-to-grid, demand response and battery storage can all offer serious potential for short-term flexibility services if existing market design and pricing are adapted to reward them. Pumped-hydro storage and renewable power to hydrogen can offer great potential for weekly and seasonal flexibility provision, but in this case a new market needs to be created with clear pricing signals.

### 5.2.1 Renewables: from "variable" to "dispatchable"

#### THE POTENTIAL FOR FLEXIBILITY FROM VARIABLE RENEWABLES

Today wind and solar are mostly thought of as major sources of variability but they have the technical capacity become dispatchable resources for power reserve and flexibility. This would apply as a self-healing system mechanism against variability and could become a major part of a wider toolbox of flexibility. Flexibility from variable renewables can be offered in two main ways:

- **By changing operational practices.** This does not require any capital investment, but improved data collection and communication. It can also have important impacts on the operational costs and energy yields. From a technical point of view, variable renewables can generate at full output capacity and dispatch downward when necessary. This is common practice today in some European countries like Spain, Denmark, and Ireland as well as overseas (e.g., Texas) through the participation of wind in ancillary service markets. Variable renewables can also generate at reduced capacity and use the available capacity margin (based on their forecasting schedule) to dispatch upward or downward when necessary. This is how battery storage currently operates to provide power reserve and flexibility. The technical capabilities of variable renewables for to provide fast active power in frequency response markets are well known and have been proven by Transmission System Operators in various markets. Figure 34 illustrates such an application deployed in at the Tule wind farm in the United States[97]. It shows the regulation accuracy of different technologies responding to the same signal. Not only does the wind farm can provide this capability, but it is much more controllable manageable than conventional synchronous generators. When operated in such a way modern wind and solar technologies can directly participate in wholesale and reserve markets and support the operational balance between supply and demand[98 99].

However, providing this sort of flexibility from wind and solar only becomes economically viable if the value of flexibility is higher than the value of clean and carbon-free electricity is otherwise not generated. Today, with relatively low shares of variable renewables and a large fleet of thermal generators and hydropower plants, this flexibility is not often needed. But when it is (during summer weekends with low demand, high shares of wind and solar and unavailable thermal plants), wind power plants become the main source of flexibility in the system. System operators need to urgently bring renewable power plants into their flexibility systems and markets. This requires state-of-art communication and control systems, such those of Red Eléctrica de España's control room[100], and adapting flexibility products to account for the characteristic of variable renewable energy sources. These products should offer sufficient rewards to variable renewables not just for the kWh of flexibility provided but also for their commitment potential, and availability to be flexible and react bi-directionally (dispatched down or operated at reduced output) when necessary.

Regulation accuracy of various technologies

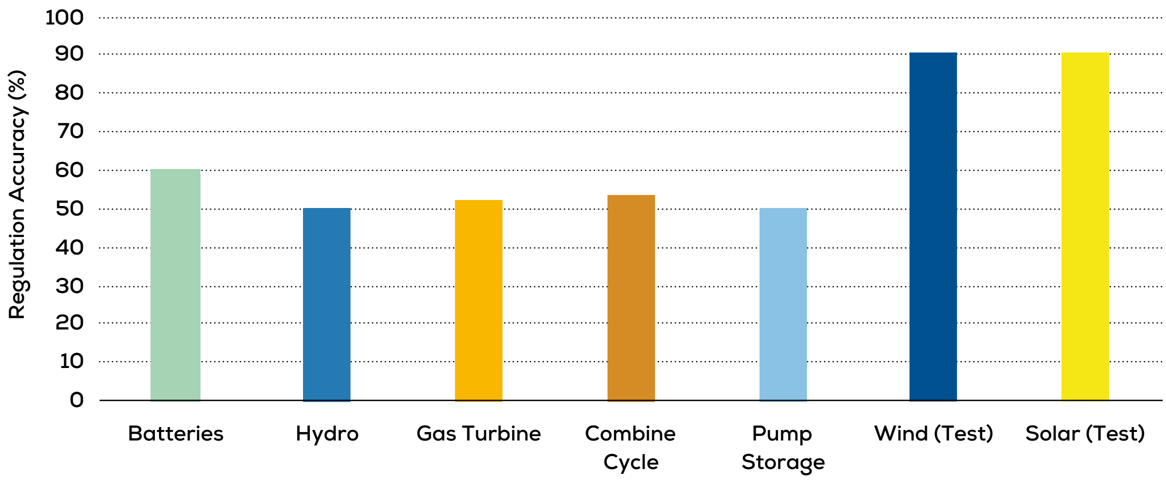



**Figure 34.** Comparison of typical regulation accuracy of CAISO conventional generation[101].

- **By technology integration**. When integrating battery storage into a wind farm or a power plant combining both wind and solar generation, the power plant becomes dispatchable and a significant source of flexibility. Integrating hydrogen production onsite could also greatly support system balancing and congestion management. **These solutions can be applied in new power plants and by retrofitting existing plants as well.** From an investment point of view, this is similar to retrofits of conventional power plants to change their operational profile and ramp capability[102]. Wind and solar have low marginal costs and cost less to maintain than conventional power plants. At the same time, storage has become a viable way to unlock flexibility.

### DRIVERS AND BARRIERS TO ENABLE FLEXIBILITY FROM RENEWABLES

The solutions mentioned above should be thoroughly assessed for short-term flexibility provision. In many cases it comes at a lower cost to society than maintaining multiple conventional power plants in stand-by operation, as back-up resources, only to cover extremely rare flexibility needs. Medium- and long-term flexibility needs (e.g., during long extended periods with light winds) cannot be addressed using these options, so other solutions need to be considered (as discussed in the following paragraphs).

To motivate system-oriented behaviour by weather-based renewables, the electricity market should be changed to reflect not just economic conditions but also meteorological and technical (electricity flow-related) principles which usually depend on the location in question. In most cases these principles might not be reflected in current electricity and flexibility market prices for variable renewables. But they still affect system operation costs by, for example, preserving long-term capacity reserve contracts with fossil-based plants depending on the location.

## 5.2.2 Demand response

### THE POTENTIAL FOR DEMAND RESPONSE

Demand response can be a very efficient strategy to mitigate load peaks and balance supply and demand. Today it has large untapped potential at all end-use levels, from the residential to the most electricity-intensive industries. The International Energy Agency estimates that only 40 GW of flexible load was used in 2018. 33 GW of this being provided in the United States[103].

From a technical point of view, residential end-users could provide flexibility largely through managing the demand pattern of their electric space heating and cooling, water heating and individual EV charging. The same type of flexibility could be provided in much greater volumes by large residential buildings or office blocks. Releasing this flexibility could be feasible at bulk volumes only if the comfort of respective end-users is not compromised. To better enable this, battery storage, water tanks for heat storage or community shared smart EV charging stations could be used.

The flexibility provision of energy-intensive users such as industry, operators of big transport fleets and tertiary buildings (e.g., multiple commercial centres owned by a single entity, airports, data centres and others) can be significant. The number of electricity-intensive end-users providing flexibility services or investigating different business cases for this has grown in recent years. Such services are provided not only for system balancing needs, but also for congestion alleviation and for power reserve. A big shift in mindset still needs to happen, and the role of market incentives and policy frameworks will be vital.

### DRIVERS AND BARRIERS TO ENABLE DEMAND RESPONSE

Today there are two main drivers enabling flexibility services:

(1) **Dynamic price signals** which include both energy and capacity components. This allows for the aggregated flexibility of hundreds/thousands of end-users (e.g. residential, office blocks), increasing flexibility volumes and encouraging competition.

(2) **Direct contracts with Transmission and Distribution System Operators**. This option might still be needed in specific cases where only a few end-users are available to provide services.

Dynamic prices for large categories of end-users (e.g., residential, office block owners) are still rare in Europe given the slow roll-out of smart meters and the very slow-moving reform of electricity markets. Only a few market parties (aggregators and industrial players) have direct access to the wholesale and balancing markets, can do arbitrage or can react to price signals due to current requirements for minimum size capacity bids. Parties operating smaller capacity portfolios only have indirect access through separate contracts with aggregators, which are often seen as a market entry barrier due to the high costs of the aggregation service.

## 5.2.3 Battery storage

### THE POTENTIAL OF BATTERY STORAGE

Technological developments and falling costs over the last decade have put battery storage centre-stage in the electrification of the transport sector and the large-scale integration of wind and solar.

One of the major advantages of battery storage is that it can undertake multiple tasks at the same time, such as providing energy and power reserve, providing fast-responding ancillary services to the power system, mitigating grid congestion, or merely time-shifting a few hours energy consumption of end-users. Figure 35 shows the total amount of power and energy capacity that was available for different applications per System Operator (PJM, ERCOT, CAISO, ...) in the United States in 2018.

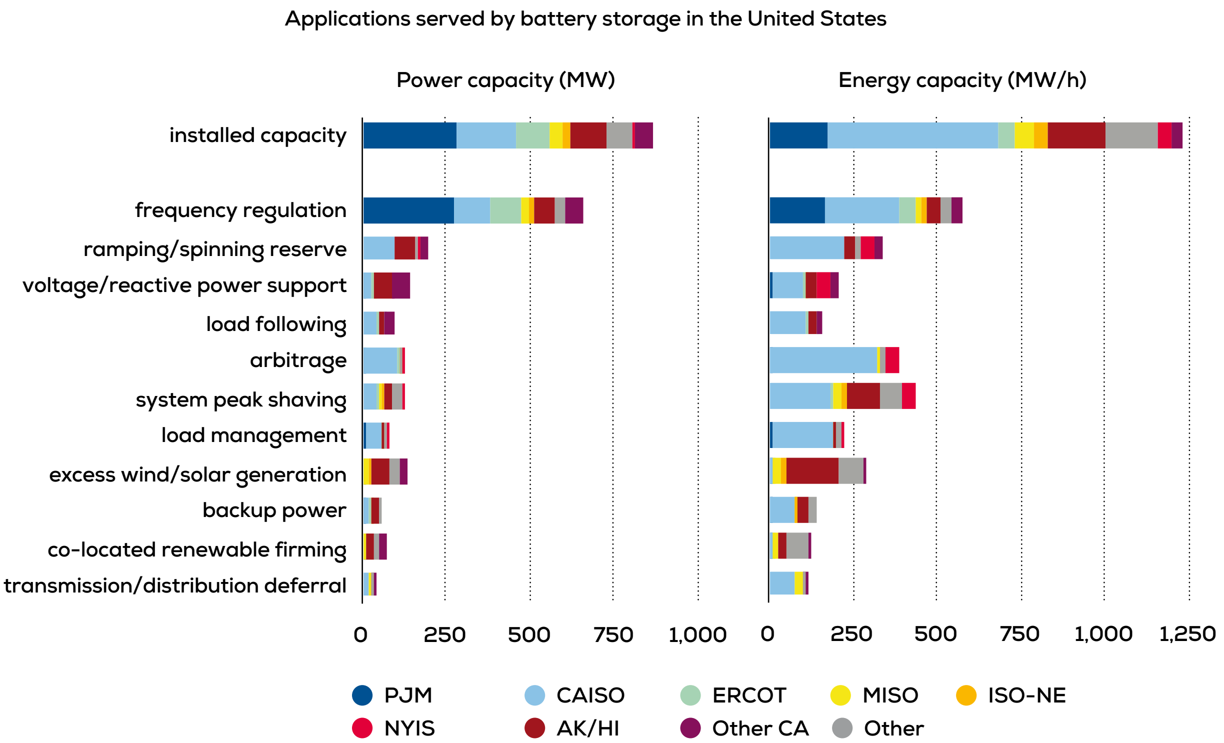



**Figure 35.** Applications served by large-scale battery storage in the United States (2018)[104].

Li-on batteries are the most widely used battery storage technology today. They provide services across a second to hours - long time cycle and offer a large range of storage capacities (from a few kW to hundreds of MW per asset). The primary application of batteries in the power sector today is frequency regulation. But with further improvements in cost[105], energy density, weight and volume other applications may also become more attractive, including energy arbitrage or capacity provision. Consequently, the average charge/discharge period of battery storage is expected to shift from less than an hour today to a couple of hours or more. A trend towards longer-lasting batteries would also mean a greater need for alternative chemistries and technologies: e.g., vanadium redox flow batteries, zinc-based chemistries, or compressed air. If these longer-duration applications are to become widespread however, new battery chemistries will need to compete with Li-ion's existing energy density, manufacturing infrastructure and cost.

### DRIVERS AND BARRIER FOR THE DEVELOPMENT OF BATTERY STORAGE

Battery storage is not yet recognised under national regulatory frameworks in most European countries and its integration into demand or generation assets, or its stand-alone development have not been addressed in current grid connection and operation rules. Even in cases where it has been recognised, market frameworks by and large do not allow battery storage to provide different services simultaneously e.g. through overlapping contracts linked to different capacity blocks of the same asset, making the monetisation of the assets almost impossible. In some countries, batteries are still obliged to pay grid charges twice, when consuming and injecting energy, thus limiting their business case.

Another common market barrier for other flexibility resources is that asset owners cannot sign separate contracts (with different aggregators for instance, or both the TSO and DSO) providing different flexibility services with different components or capacity blocks of their assets. An industrial asset with an EV charging station can offer demand response by shifting its industrial production load and frequency regulation using a vehicle-to-grid application, activating completely independent assets and capacities for the two services. Under current market frameworks, the aggregator running the vehicle-to-grid operation must sign a separate agreement with the industrial site’s balancing responsible party (BRP). Market design should enable the asset owner to act independently of its BRP and sign different flexibility provision contracts maximising the revenue from his assets. Of course, this requires operational data to be effectively communicated between all relevant stakeholders, including the system operators. But this should clearly be a case of streamlined monitoring requirements by the system operator rather than a commercial agreement between the different service providers and the BRP.

In most countries it is still not possible to monetise the value of flexibility coming from residential storage assets. Tariff schemes rarely incentivise residential storage owners to manage their consumption or renewable generation peaks, whereas elsewhere the provision of certain ancillary services from DSO network level is simply not allowed. Finally, emerging capacity remuneration mechanisms (CRMs) don't consider storage assets at their true value. For example, in some countries capacity remuneration for storage is highly derated due to concerns about limited energy content, rewarding fossil-fuel units instead.

Policy makers should carefully consider these aspects in future market design. Giving variable renewables the chance to act as flexibility resources in energy and capacity markets, at least on the same footing as the ones currently available for conventional power plants, will be a major driver in combining wind and solar with battery storage.

## 5.2.4 EV charging infrastructure

### THE POTENTIAL OF SMART CHARGING AND VEHICLE TO GRID SERVICES

Electrifying transport could offer significant flexibility based on the principles of demand response and battery storage (as explained above). This could be done in two ways:

- **Demand response based on smart charging**: Individual users or operators of shared EV charging hubs in private or public spaces can time-shift the charging demand in function of local grid conditions while managing the necessary State-of-Charge (SoC) of the vehicles at any given time.
- **Providing energy and grid services to the grid operator based on a bidirectional smart charging (V2G) strategy**: This deployment, also known a vehicle-to-grid (V2G), will need more advanced coordination and optimisation of the EV charging process. Thus it is more likely to be deployed by operators aggregating individual users and shared EV charging hubs (e.g., bus depots, large delivery fleets used for postal services or even charging points for battery-powered rail vehicles).

What distinguishes EV charging from demand response and battery storage is that enabling its full potential for flexibility will often be required to mitigate the impact on the grid or minimise grid reinforcements to integrate the charging infrastructure.

The big challenge in projecting flexibility provision from smart charging infrastructure is the current uncertainty around the planning, design & development, operation, and ownership of EV charging infrastructure.

## DRIVERS AND BARRIERS TO DEPLOYING FLEXIBILITY FROM EV CHARGING INFRASTRUCTURE

In a recent paper[106] ENTSO-E identifies four categories of EV charging use cases in function of their impact on the grid. Figure 36 outlines these use cases, their flexibility potential and possible grid reinforcement measures needed to mitigate respective grid impacts.

Flexibility potential of different EV charging technologies and strategies

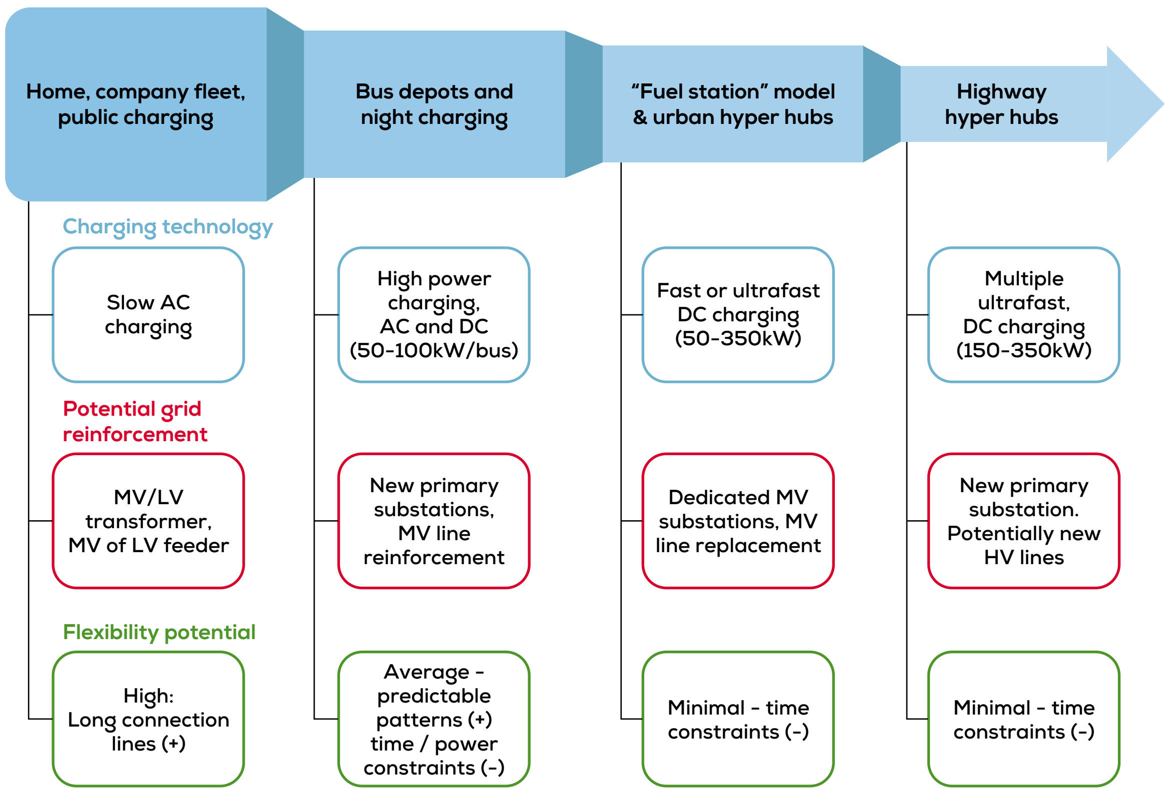



**Figure 36.** EV charging use cases, potential need for grid reinforcement and flexibility potential. Source: WindEurope based on ENTSOE[107].

- Case 1 **(home, company fleet or public charging points using slow AC charging)** has strong flexibility potential thanks to the EVs' long connection times. Company fleets are the most promising thanks to their more predictable use patterns compared with public or home charging. In terms of grid reinforcements, these use cases might need MV/LV transformer or feeder replacements.
- Case 2 **(electric bus depots)** has good night-time flexibility potential due to easy control of bus consumption when parked and their predictable usage. Necessary grid reinforcement measures might include new primary substations or reinforcement of MV lines.
- Cases 3 and 4 **(urban and highway hubs)** using fast or ultrafast DC charging have low flexibility potential due to time constraints, although this may be remedied if additional storage for flexibility or power reserve provision is integrated. New primary substations, MV line replacement or new HV lines might be necessary to mitigate grid impact.

### 5.2.5 Renewable power to hydrogen

The production of renewable hydrogen for industry and transport will require substantial amounts of electricity. This electricity will be used as hydrogen and/or further converted into other e-fuel and e-liquids, such as ammonia. Bearing in mind that hydrogen, e-fuels, and e-gas could make up around 18% of final energy demand[108], and will largely be produced via renewable electricity, this could account for up to ¼ of all electricity needs by 2050. This would be a great opportunity as hydrogen production could be coupled with the availability of wind and sun resources. Power-to-gas could become the largest source of demand response and load shifting. This would help minimise wind and solar electricity curtailment.

In principle, hydrogen could also be reconverted to electricity to cover the monthly and seasonal variability of demand, and of wind and solar resources (as explain in section 5.1). However, given the low round-trip efficiency, and the value of renewable hydrogen for many energy users (in the hard-to-abate sectors), we feel that hydrogen's role in electricity production will be relatively minor. But this will ultimately depend on the competitiveness of thermal power plants (with CCS) which can remain idle and be activated only for long-term flexibility needs.

In any case, the cost-effectiveness of this flexibility provision will depend on existing national infrastructure. Countries with a widespread hydrogen (and natural gas) network will be better suited for this type of flexibility provision.

### 5.2.6 Pumped hydro-electric storage (PHS)

#### THE POTENTIAL OF PUMP HYDRO-ELECTRIC STORAGE

Pumped hydro-electric storage (PHS) is a major resource that can provide flexibility at different time cycles, from short-term (second to hours) to long-term (over days and months). Today PHS already participates in capacity markets and balancing markets. In the UK, it also provides inertia though a power system stability contract[109]. The role of PHS in ancillary service markets is expected to grow significantly in the next few years, especially with revenues shifting from the spot market (with price arbitrage) to ancillary services (e.g. reserve and response market including frequency restoration reserves - FRRs). Currently, about half of PHS revenues in Germany are derived from the reserve market. In some countries, however, the market remuneration for PHS system service provision is not enough to make investments in these capabilities viable.

There are 51 GW of PHS plants installed across Europe today[110], offering the largest source of energy storage in the power grid. While its potential is large, its spatial dependency poses a limitation and makes it unsuitable for certain locations. Public opposition due to environmental concerns or/and nature conservation projects also limits its expansion. Existing sites can often be converted into PHS by connecting existing reservoirs, which limits total intervention, and is thus less controversial. Converting conventional hydropower plants to PHS can dramatically alter the impact of this technology[111]. The European Commission expects about 75 GW of capacity to be available in the EU-27 by 2050 (up from 45 GW in 2015).

From a technical point of view, most existing PHS plants can only pump water up (charging mode) at a fixed speed representing one fixed power level. These fixed-speed PHS plants are only able to regulate their power output or power generation (discharging mode) behaviour between its minimum stable level and its maximum installed generation capacity. As a result, most existing PHS plants offer more flexible balancing power in discharging mode than in charging mode. Converting fixed-speed PHS plants into variable-speed (VS) PHS plants able to regulate in the pumping phase (charging mode) is technically feasible. It is also economically attractive by show by projects in place. The additional revenues from the increased balancing capacity (downward and upward) while pumping at low spot market prices, can overshoot the additional CAPEX required for the upgrade[112].

### 5.2.7 Heat pumps

#### THE POTENTIAL OF HEAT PUMPS

Heat pumps are a mature off-the-shelf technology. They are the best solution for decarbonising heating and cooling in buildings. They are two to three times more efficient than fossil fuel space heating and generate ¼ of the carbon emissions from a natural gas boiler (as presented in Chapter 3.3). They can also be used to electrify low and medium temperature industrial processes while advanced heat pump concepts for higher temperatures are being developed.

Heat pumps are great source of flexibility, especially for the short-term (seconds to hours). This potential will be even higher in the case of new buildings integrating hybrid heat pumps with hot water loops – providing negative thermal sensitivity and flexibility even when their operation isn't related to cold periods[113]. As the PowerMatching City project showed, depending on the thermal mass, the heat storage capability and the duration of the shift could be in the order of 1–6 hours (Figure 37). Finally, a wide deployment of district heating through heat pumps also offers major flexibility potential through these technologies.

The potential of heat pump flexibility can only be tapped into if users are exposed to electricity prices changes. Thus it is crucial to include smart meters and to offer the possibility of accessing dynamic prices. Many electricity users in Europe today do not have access to smart meters and have fixed electricity prices.

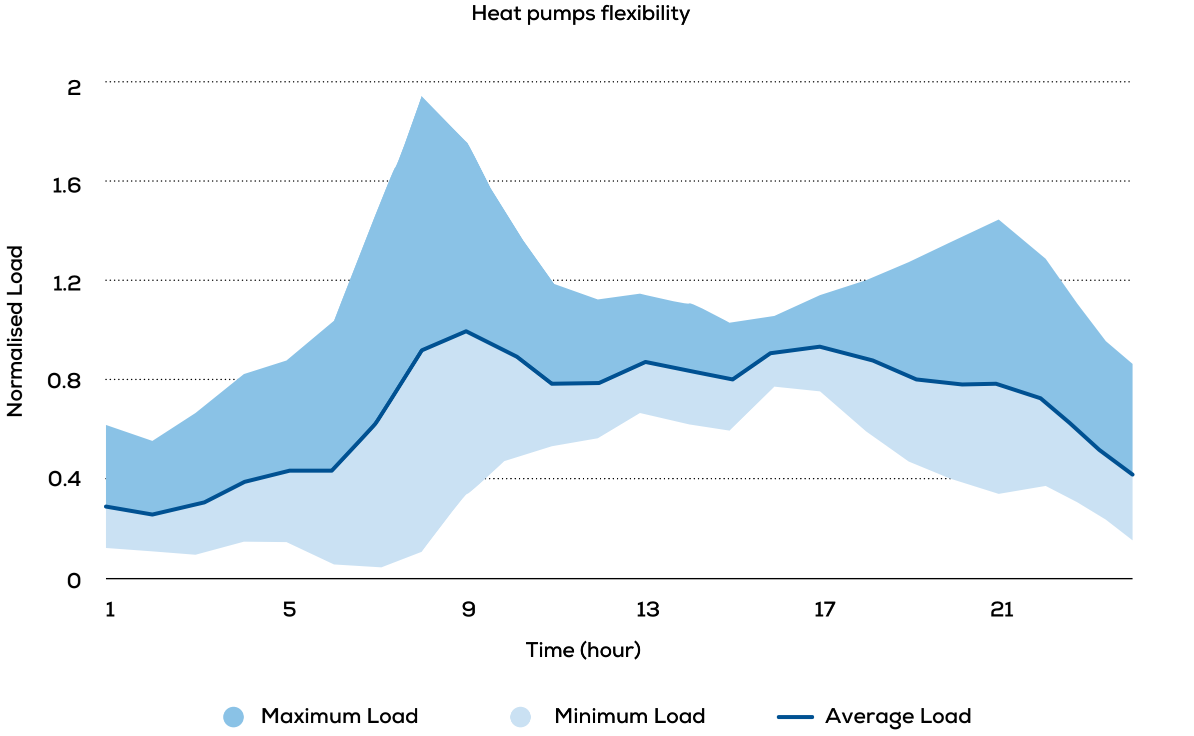



**Figure 37.** Normalised load flexibility from heat pumps. Source: Eindhoven Technical University [114].

# 6

# Policy recommendations

## What can the EU do to unlock massive supplies of competitive renewable electricity?

- Support National Governments in simplifying the permitting of wind projects, and ensure that authorities have the necessary resources to provide enough wind sites. The EU must give Members States guidance on the correct permitting procedures.
- Ensure EU State aid rules to 2030 help unlock wind investments through Contracts for Difference and technology-specific auctions. State aid guidelines should ensure auction designs allow government-backed revenue stabilisation to be combined with corporate renewable PPAs. This will help accelerate the shift to a demand-driven energy transition.
- Ensure that spatial planning mainstreams climate targets and accelerates wind deployment.
- Provide long-term visibility and stability by setting a renewable energy target in line with the 55% climate target. Adapt the existing national energy and climate plans accordingly.

## What can the EU do to support further cost reductions and technology improvements?

- Invest more in wind energy innovation. Focus on the recommendations of the ETIPWind roadmap and strategic research and innovation agenda:
  a. **Grids and system integration.** Support further research to optimise the use of existing grid infrastructure, develop High Voltage Direct Current (HVDC) technology, demonstrate combined wind, PV and battery projects and virtual power plants, and develop tools to enhance digital communication and cybersecurity.
  b. **Operations and Maintenance.** Innovate smart tools to monitor conditions and control turbines and their components, apply remote sensing and robotic inspection and repair methods.
  c. **Next generation technologies.** Prioritise R&I funding to diversify and scale-up recycling technologies, study new substitute materials to improve circularity by design and reduce the EU's dependence on material imports, develop new technologies to reduce noise and visual impacts.
  d. **Offshore balance of plant.** Make cables less likely to fail as a result of twisting, overloading, and erosion of the seabed cover, develop smart and lead-free cables, demonstrate new dynamic cable concepts for floating offshore wind.
  e. **Floating offshore wind.** Develop and mature concepts suited to scale-up and industrialisation, demonstrate ease of manufacturing, transportation, installation, and operation of floating designs.
- Support fundamental research sustaining Europe's academic and scientific community.
- Foster educational programs in schools and universities that focus on decarbonisation and the electrification of the economy.

## What can the EU do to help drive demand for renewables?

- Accelerate the uptake of corporate renewable PPAs by allowing all renewable electricity to be underpinned by Guarantees of Origin.
- Close the cost gap between fossil fuel and renewable hydrogen while accelerating the scaling up of electrolysers.
- Set targets for renewable energy consumption in hard-to-abate sectors and minimum target for renewable hydrogen as a share of overall hydrogen consumption by 2030.
- Strengthen the $CO_2$ emission performance standards for cars and vans by setting a reduction target of at least 50% and moving it forward to 2027.
- Support the market uptake of renewable electricity, renewable hydrogen, and its derivatives through fuel supplier obligations.
- Increase requirements for renewable and efficient heating in buildings through targets for new and refurbish buildings.

## What can the EU do to send the right carbon price signal and accelerate decarbonisation?

- Align the ETS with the EU's new climate target and set up adjacent carbon pricing mechanisms for mobility and buildings.
- Reflect carbon intensity through energy taxes and levies as part of the Energy Taxation Directive.
- Incentivise the switch to more sustainable transport. This includes subsidising the purchase of new electric and fuel cell vehicles and lowering registration and vehicle taxes for EVs. These incentives should be provided to both passenger and fleets/ heavy duty transport.
- Incentivise the use of rail transport to make it competitive with short-distance flights (e.g., reduce/ eliminate domestic airlines connections on routes where there is a direct rail alternative available in under two-three hours).

## How can the EU help to develop infrastructure forming the backbone of a net-zero energy system?

- Double the rate of investments in electricity grids, especially anticipatory investments to address growing industry demand for electricity.
- Coordinate the buildout of electricity grids with renewable hydrogen infrastructure.
- Urgently address regulatory barriers to investments in an optimised offshore grid, especially in hybrid offshore power plants.
- Avoiding public spending on infrastructure that works against a renewable electricity-based energy system.
- Set National binding targets for e-charging and $H_2$ refuelling infrastructure (revision of the Alternative Fuel Infrastructure Directive).
- Adapt an investment framework for grids to account for TOTEX as well as CAPEX savings, helping to valorise grid optimisation technologies in addition to new power lines.

## How can the EU enable the deployment of flexibility resources?

- Ensure all markets reward upward and downward flexibility and power reserve from wind and solar, including upgrading them with advanced capabilities (black-start, storage...).
- Ensure countries recognise battery storage and power-to-hydrogen in their national frameworks and network codes, avoiding double charges for the provision of storage. They will then need to update their market frameworks to enable battery storage assets to provide different flexibility and power reserve services simultaneously Finally, pricing for such services by battery assets should reflect both CAPEX and OPEX including aggregation costs.
- Create a new market framework with clear pricing signals for weekly and seasonal flexibility provision that strengthen the business case for pumped hydro storage and renewable power to hydrogen.
- Remove barriers and strengthen price signals to incentivise demand response by industries and by heat pumps at residential and industry level. Accelerate the roll-out of smart meters and dynamic prices.

# Annexes

## Annex 1 – Supporting wind energy technology leadership

Technology leadership is the cornerstone of the European wind industry's competitiveness. Each year the industry invests the equivalent of 5% of its contribution to EU GDP in Research & Innovation. In 2019 this was worth €1.9bn.

At the same time, we have seen a fall in public support for wind energy R&I across Europe. Both Japan and Norway provided more R&I support on their own than all EU Member States combined[115]. In 2019 EU Member States only provided €130m in funding for wind research and innovation. The EU-28's share in global wind R&I funding has dropped from 36% in 2010 to 23% in 2019.

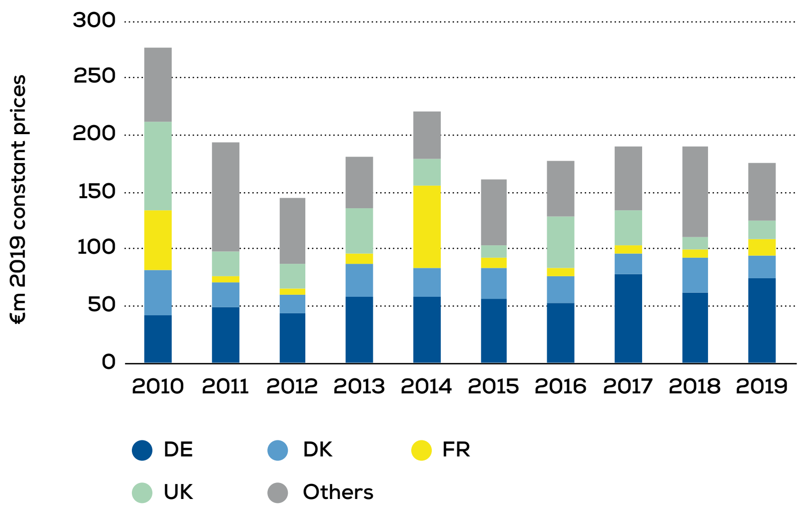



Figure 38. Public funding for wind energy research & innovation in the EU-28[116].

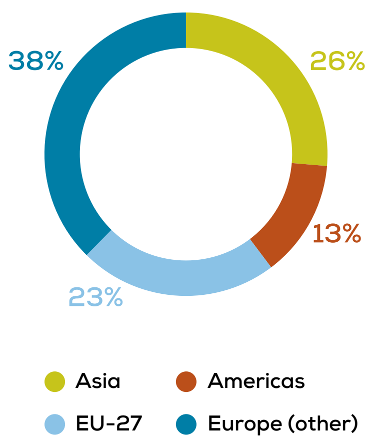



Figure 39. Global funding for wind energy research & innovation in 2019[117].

Governments should support strategic sectors such as wind energy with strong industrial policies. Public funding for R&I through grants and loans is a key instrument to easing the pressure on European manufacturers. The benefits of public funding in wind R&I are twofold. Firstly, it will enable the sector to provide the low-cost electricity Europeans need and want. Secondly it ensures that the economic benefits and manufacturing jobs remain Europe. Profit margins for European manufacturers have been in steady decline since 2017. In the last decade 97 manufacturing facilities have closed in Europe and in some countries a significant number of jobs were lost.

The drop in funding particularly hurts the scientific community. Europe is home to some of the best wind energy research centres and test facilities in the world. There are around 100 research institutes and universities that perform fundamental science and applied research in wind energy. They ensure that the latest scientific breakthroughs find their way into the industry. And they train and educate the much-needed talent European companies are looking for.

More than 60% of their resources come directly from public funding. Less funding for fundamental science will not only reduce the rate of advancements in wind, but also limit the ability of European universities to educate the next generation of wind energy workers.

## THE WIND SECTOR'S RESEARCH & INNOVATION PRIORITIES.

Governments should focus their funding on the five pillars of wind research & innovation (see figure 40) and the specific research actions spelt out in the ETIP-Wind Roadmap for 2019[118]. These recommendations will enable the European wind industry to meet the expectations of European policymakers and citizens, sustaining the cost reduction trends and ensuring Europe remains the global leader in wind energy technology.

**Grids and system integration.** To enable a renewables-based energy system more research into optimising the use of existing grid infrastructure and developing High Voltage Direct Current (HVDC) technology is essential. In addition, hybrid projects combining wind, PV and batteries, and virtual power plants need support to demonstrate benefits at larger scale and across Europe. Tools that enhance digital communication, data management and cybersecurity are also a research priority.

**Operations and Maintenance.** Wind turbines are exposed to a variety of weather conditions ranging from frost to extended heat waves. Innovation in smart tools to monitor these conditions and control the operation of turbines and their components will allow the sector to get the most value out of each wind turbine. Research into applying remote sensing, robotic inspection and repair methods will increase the availability of wind turbines and reduce the need for risky, manned interventions.

**Next generation technologies.** A turbine today is 85% to 90% recyclable. The EU must prioritise R&I funding to diversify and scale-up recycling technologies so we can recycle 100% of the material. But we also need further research into new substitute materials to become more circular by design and reduce the EU's reliance on material imports. Developing new technologies to reduce noise and visual impacts is still a priority as turbines become increasingly powerful.

**Offshore balance of plant.** Offshore wind can provide bulk amounts of renewable electricity. But it will need reliable cables to transport that electricity to consumers. Offshore cables are susceptible to failures linked to twisting, overloading, and erosion of the seabed cover. More research and innovation into smart and lead-free cables will make offshore wind the reliable backbone of the future energy system. For floating wind new dynamic cable concepts will require further research and demonstration.

**Floating offshore wind.** To make floating offshore wind cost-competitive with other energy sources, large volumes of floaters need to be produced and installed. Concepts need to demonstrate they are suited to scale-up and to meet growing demand. R&I and demonstration projects should highlight the ease of manufacturing, transportation, installation, and operation of floating designs. For more details see also the ETIPWind report - Floating offshore wind: delivering climate-neutrality[119].

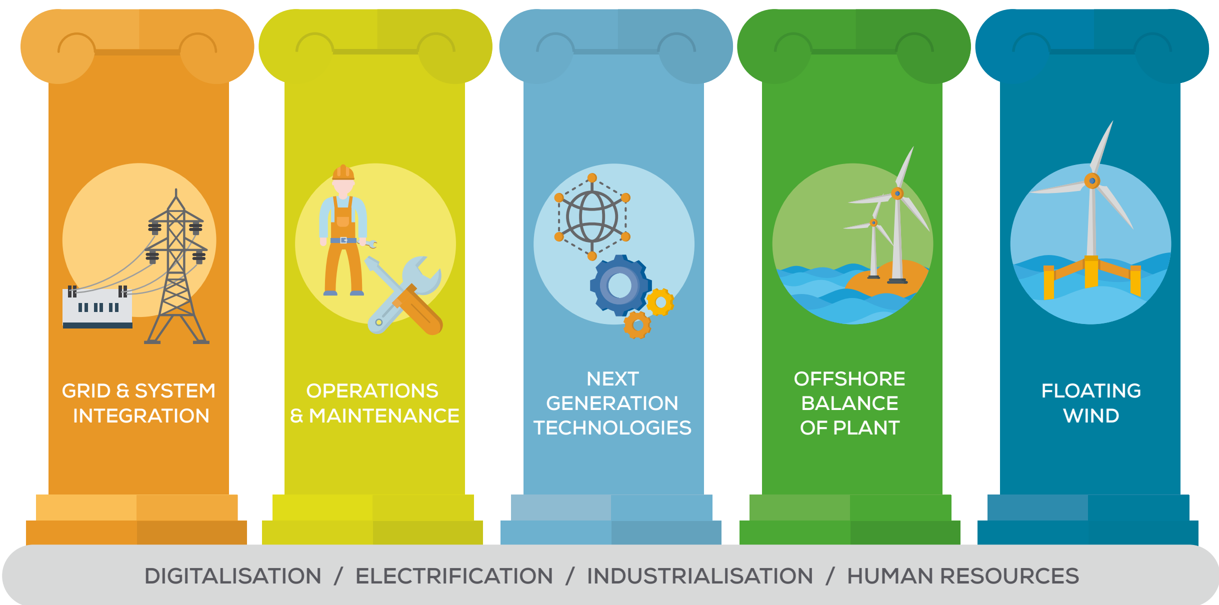



**Figure 40.** The five pillars of wind energy research & innovation. Source: ETIPWind, 2018, Strategic Research & Innovation Agenda.

# Annex 2 – References for Table 2 Electrically powered technologies for industry electrification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# Annex 3 – Assumptions for the simulation of peak power variability

| | Germany | | Spain | |
|---|---|---|---|---|
| | Today | 2050 | Today | 2050 |
| Annual load (TWh) | 512 | 697 | 253 | 371 |
| Total installed wind power capacity (GW) | 63 | 172.5 | 27.2 | 70 |
| Total installed solar PV power capacity (GW) | 54.6 | 177.1 | 11.5 | 79.3 |

**Figure 41.** Assumptions for the simulation of peak power variability. Source: DNV for ETIPWind.

# Annex 4 – End notes

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3 We assume that 100% of the ''other RES'' is ambient heat powered by heat pumps, which is allocated to direct electrification. It assumes 100% of hydrogen to be produced from electricity. E-fuels are also produced through electrolysed hydrogen, as specified in the EC impact assessment

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13 External cost will include the internalisation of carbon pricing through the European Union's Emissions Trading Scheme and national policies. In 2018 the average carbon price was €24.72 $tCO_2eq$. The total internalised external cost of electricity was €28.1bn. Source: Trinomics, Enerdata, Cambridge Econometrics, 2020, Energy costs, taxes and the impact of government interventions on investments

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