Breaking new ground

Wind Energy and the Electrification of Europe's Energy System

WindEurope

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EXECUTIVE SUMMARY

Europe has long spearheaded the global fight against climate change. Now Europe is examining its 2050 decarbonisation strategy. This includes pathways to net zero Greenhouse Gas Emissions (GHG) in 2050.

Such a transition represents a formidable challenge, but it is also a remarkable opportunity for the European economy. Renewables-based electrification is key to the decarbonisation of Europe's energy system. If EU policymakers make a clear choice for renewables-based electrification, Europe will hold the key to a successful decarbonisation strategy while ensuring it retains its competitive edge in key climate mitigation technologies. In the process, Europe will make its energy system more resilient, drastically cutting dependence on imported fossil fuels, improving Europeans' living standards by limiting air pollution and cutting the energy bills of citizens and businesses.

This report sets out two scenarios to decarbonise the EU economy:

- an *accelerated electrification scenario,* which speeds up the effects of current policies by envisaging their impeccable implementation; and

- a *Paris-compatible scenario*, which would ensure global temperature rises are well below 2 degrees, and thus requires more ambitious policies.

The report also analyses the policy levers that will drive electrification and addresses the challenges related to the electrification of three sectors: industrial processes, transport and buildings. Crucially, the report also spells out the implications of shifting to a renewables-based energy system for both infrastructure and system integration.

With the right policies it is technically and economically possible to increase the share of electricity in energy from 24% today to 62% in 2050, 78% of which would be coming from renewables. And thanks to its cost-competitiveness and scalability, wind energy is uniquely placed to make a central contribution to this transition.

KEY FINDINGS

Europe's energy future is electric

- With ambitious Paris-compatible policies, Europe's electricity share in energy use could reach 62% in 2050.
- By contrast, even an impeccable implementation of current policies up to 2030 would yield only 51% of electricity share in energy use by 2050.
- Pursuing a Paris-compatible trajectory would reduce Europe's energy-related emissions by 90% by 2050.
- By contrast, an impeccable implementation of current policies up to 2030 would reduce Europe's energy-related emissions by only 74% by 2050.
- Integrating transport and heating into a renewables-based power system is the next frontier that will shape the future of Europe's energy system.

Renewables-based electrification benefits Europe

- It would both decarbonise and boost the European economy.
- It would reduce dangerous air pollutants from cars, industry and homes.
- It would strengthen energy security by decreasing the amount of fuel imports from foreign countries.
- It would improve energy efficiency and reduce final energy demand.
- It would accelerate digitalisation, allowing customers to take control of their energy bill.

An ambitious electrification is affordable

- Energy expenditure in the Paris-compatible scenario would be 2.7% of Europe's annual GDP to 2050, only 0.5 percentage points more than the accelerated electrification scenario.
- The Paris-compatible scenario would reduce the costs of climate change mitigation. These costs would amount to 0.86% of Europe's annual GDP. By contrast, not implementing this scenario would carry costs amounting to 1.2% of Europe's annual GDP.

Renewables-based electrification drives down energy consumption

- The Paris-compatible scenario means 33% in overall energy savings to 2050. Energy demand in industrial processes would fall 36%, 18% in buildings and 46% in transport.
- By contrast, the accelerated electrification scenario means only 30% in overall energy savings to 2050. Energy demand in industrial process would fall 36%, only 7% in buildings and 51% in transport.

Industrial processes are key to meeting the Paris Agreement

- The Paris-compatible scenario means reaching an 86% share of electricity in industrial processes by 2050.
- But the accelerated electrification scenario only delivers a 62% share of electricity in industrial processes by 2050.
- The Paris-compatible scenario would reduce 88% energy-related emissions from industrial processes by 2050. But the accelerated electrification scenario would only reduce emissions by 70%.

Heat pumps in buildings to drive breakthrough

- The use of electric heat pumps will drive energy savings and emissions reductions. Although they represent only 2% of today's final energy demand for heating and cooling, they are quickly spreading.
- In the Paris-compatible scenario, electrification in commercial buildings would be 78% by 2050. By contrast, under the accelerated electrification scenario, this would be only 62%.
- In the Paris-compatible scenario, electrification in household buildings would be 59% by 2050. By contrast, under the accelerated electrification scenario, this would be only 39%.
- The Paris-compatible scenario would reduce 70% energy-related emissions from buildings by 2050. But the accelerated electrification scenario would only reduce emissions by 50%.

The mass uptake of electric transport will take place under all foreseeable scenarios, but needs policies to sustain it

- Sales of passenger vehicles with internal combustion engines will peak in 2025 under current policies.
- According to both the Paris-compatible and the accelerated electrification scenarios, electric cars should account for 95% of new sales by 2035.
- According to both the Paris-compatible and the accelerated electrification scenarios, rail transport should be 90% electric by 2030.
- According to the Paris-compatible scenario, hydrogen demand could be up to 426 TWh/year - equivalent to 4.8% of energy demand in 2050 - mainly to heat buildings and as a fuel for road transport.
- The uptake of hydrogen cars, however, requires further policy ambition.

Wind energy at the heart of electrification in Paris compatibility

- Wind energy could install more than 20 GW/year from 2030-2050.
- At this rate, wind energy would generate 2,223 TWh of electricity by 2050, equivalent of 36% of Europe's power generation.
- Renewables would then account for 66% of Europe's final energy demand, significantly contributing to a 90% reduction of CO_2 emissions.
- Investment costs for onshore wind would average €1.1m/MW by 2050, a decrease of 30% from today. Offshore costs would be €2.2m/MW, a 23% decrease.

Electrification is essential for the optimal integration of variable renewables

- The massive uptake of electric batteries for passenger vehicles would provide enough short-term storage capacity for managing high shares of wind and solar PV, even assuming that only 10% of EV battery capacity is made available to the grid.
- For longer timeframes, power-to-X development would provide the required seasonal storage capacity and will become an important source of flexibility.
- Managing the future energy system requires a paradigm change in the use of digital technologies.

Power grids deployment is a no regret option

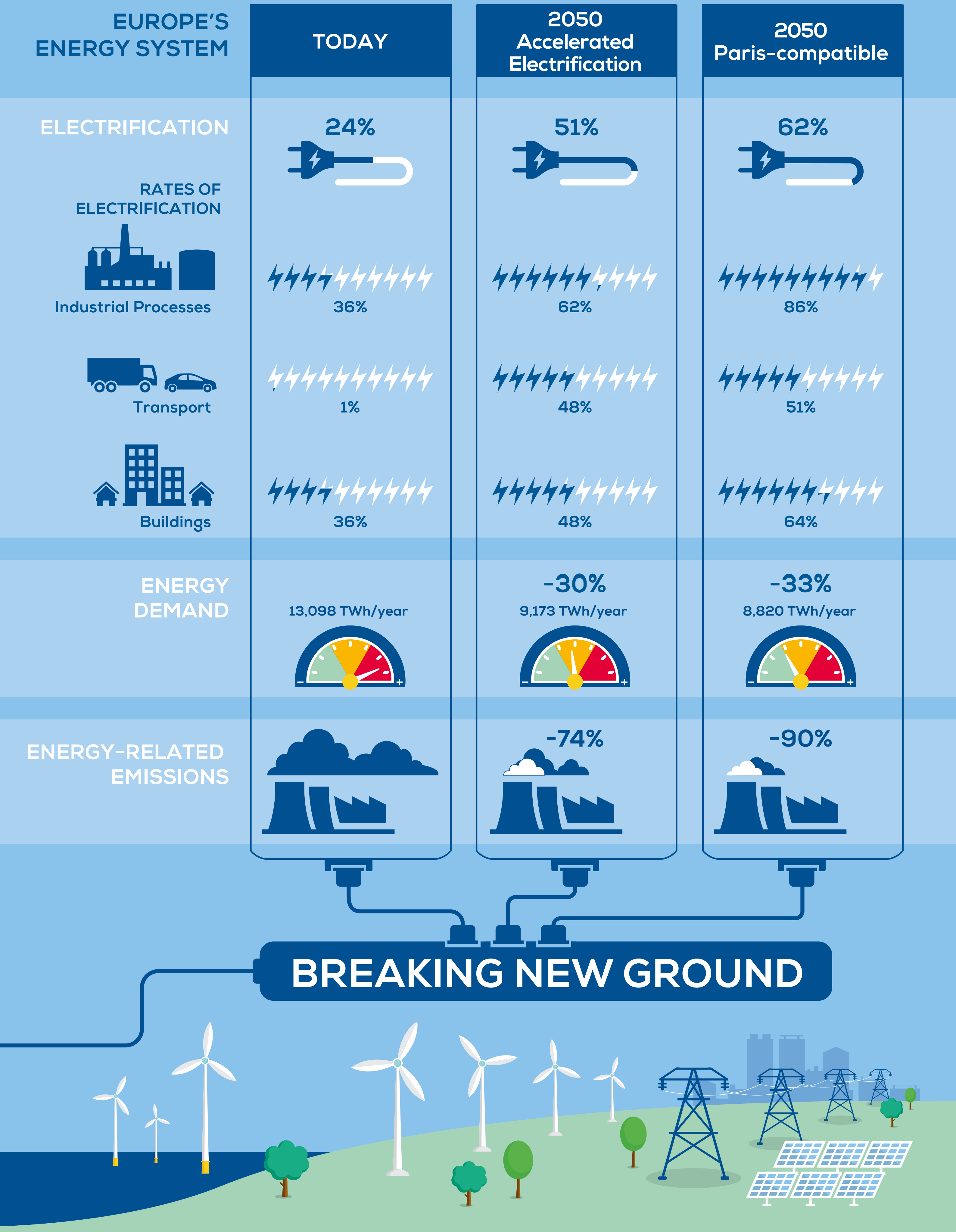
- Developing more and stronger power grids is a precondition of any electrification and decarbonisation pathway in Europe.
- Europe would need 12,000 GW-km/year of new power lines by 2050.
- Significant development of DC technologies and LV power lines will drive the expansion.

POLICY RECOMMENDATIONS

Europe must make a clear choice in favour of the renewables-based electrification of industrial processes, buildings and transport as the key driver of its decarbonisation strategy.

- The EU should **ramp up its emissions reduction objective for 2030 to 45%** now and use the 2023 ratchet-up mechanism to adjust its emissions reduction trajectory to its long-term decarbonisation objective.
- Member States should **adjust their energy tax regimes** for electricity and fossil fuels to incentivise decarbonised energy use.
- Market design rules should enable the use of dynamic electricity pricing contracts and time-responsive grid tariffs **to incentivise demand-side flexibility.**
- Market design rules should **avoid market exit barriers** for the most carbon intensive power generation assets.
- ENTSO-E's 10 Year Network Development Plan should **reflect the infrastructure needs of the Paris-compatible scenario** and accelerate the roll out of smart low voltage grid.
- The EU's **Connecting Europe Facility should prioritise electricity projects** and the deployment of ultra-fast vehicle charging infrastructure.
- The EU and Member States should adopt **zero-emissions vehicle sales targets** as part of the post-2020 CO_2 standards for passenger cars and light commercial vehicles.
- To unlock the massive potential of renewables-powered green hydrogen, Horizon Europe and national R&D programmes should **prioritise R&D funding for electrolysers.** Governments should also adopt network charge exemptions that enable electrolysers to benefit system operations.
- Member States should **spell out electrification measures as part of the National Energy and Climate Plans** to 2030 notably for industrial processes and buildings.
- The EU should **mainstream the electrification of industrial processes** as part of its strategy for a smart, innovative and sustainable industry

FIGURE 1
Main results of scenario analysis



INTRODUCTION

The decarbonisation of Europe's electricity sector has been one of the most transformative changes in the economy over the last two decades. Renewables have played a central role in this transformation, with 298 GW added to the power sector since 1995. And wind energy has been the largest single contributor, with 182 GW of capacity installed as of the end of June 2018. Wind energy now accounts for 12% of Europe's electricity and renewables in total account for 30%.

However, electricity is only about 24% of Europe's energy consumption. The vast majority of Europe's energy remains fossil fuel-based.

Transport, heating and cooling (H&C) use most of these fossil fuels. Transport accounts for 32% of Europe's final energy demand, and 94% of it is covered by oil products. Heating and cooling account for almost half (46%) of the final energy demand, and 80% of it comes from fossil fuels. Today renewables makes up only 18% of the supply in heating and a mere 8% in transport.

Considering Europe's success already in renewables and its remarkable potential for future growth, a rapid electrification of the most carbon-intensive energy uses is the best and most efficient way to simultaneously decarbonise and grow Europe's economy.

Integrating the power sector in heating, cooling and transport is the next big transformation in Europe's economy. Coupled with advances in digitalisation, machine learning and artificial intelligence, a renewables-based energy system could become an engine of growth and technological leadership.

With this report, WindEurope puts forward two pathways for the electrification of Europe's energy system, capitalising on the societal benefits of electrification.

The report sets out the trajectory and opportunities of an accelerated electrification scenario and a more ambitious Paris-compatible scenario aligned with the EU's commitments under the Paris Climate Agreement.

The report explores in particular the technical viability of increasing electricity shares in manufacturing beyond 80%. This challenge will be central to Europe's ability to deliver on its long term Climate and Energy objectives.

A European economy powered by renewable electricity will look different from today. Its success will rely on making the most of Europe's indigenous energy resources, on its skilled workforce and on its capability to innovate and stay at the forefront of nascent industries. This successful transition, based on European technology and expertise, must be at the core of the EU's industrial strategy.

BENEFITS OF RENEWABLES-BASED ELECTRIFICATION

Environmental considerations and climate change mitigation are important to the rationale for the electrification of Europe's energy system. But reducing fossil fuel import dependence, increasing energy efficiency, hedging future energy bills for consumers and quality of life for Europe's citizens are equally important.

Health-related economic costs of air pollution in the EU are between €330bn and €940bn annually, equivalent to 3-9% of the EU's GDP[1]. In 2017, 130 cities in 23 Member States have infringed European air quality rules and nine Member States have requested European Commission exemptions to exceed their emissions caps[2]. Displacing fossil fuels through higher use of electricity would reduce the exposure of large parts of the European population to dangerous pollutants such as SO_2, NO_x and other particles.

Second, 20% of all of the EU's imports are energy-related. The EU imports 90% of its crude oil, 66% of its natural gas, 42% of its coal and 40% of its uranium and other nuclear fuels. That accounts for 54% of all the energy it consumes, and costs EU citizens more than €1bn per day[3]. Heating and cooling commercial buildings, households and industrial processes is 80% fossil fuel-based, mostly with natural gas. Furthermore, 94% of transport is dependent on crude oil, whose import bill is around €187bn a year. Replacing fossil fuels with domestic renewable electricity would significantly improve the EU's security of energy supply and would translate into imports cost savings for consumers.

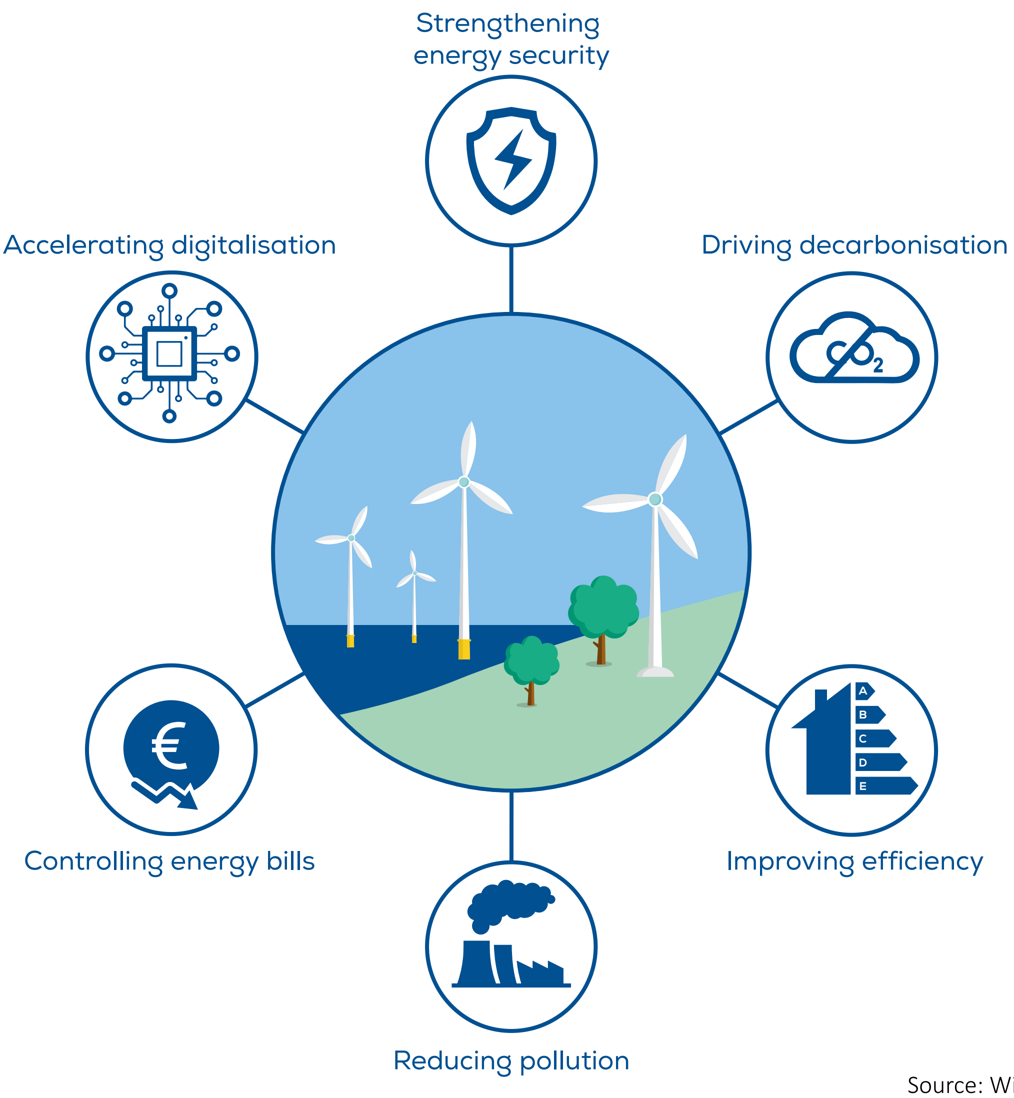
Third, savings would become even greater as the efficiency of the power system and of electrical end-use appliances increases. A renewables-based electrification of the economy would help to reduce final energy demand as the production of renewable electricity has no conversion losses and it can deliver equivalent services with less energy input. In addition, electrical devices are becoming more efficient than fuel-based combustion, even when accounting for power transformation losses. For instance, battery electric vehicles (EVs) have a conversion efficiency of 80-90% from tank to wheel, compared to internal combustion engines with an average efficiency of 20-30%. This allows EVs to drive three to four times the distance with the same amount of energy. In residential heating, common heat pump technology can heat space and water with high coefficients of performance (between 3 to 4), meaning that for each kW of electricity consumed about 4kW of energy is generated. And heat pumps have further potential for efficiency gains as the technology advances, whereas traditional gas boilers would struggle to surpass their current efficiency rates of 40-80%[4].

Finally, electrifying final energy uses also improves safety, comfort and living standards for Europeans. Synergies with digitalisation will enable consumers to take a more active role in managing their energy consumption, become prosumers and save costs.

All these benefits demonstrate that acting with urgency in the diversification of the energy supply for transport, industry and households must be part of the European vision for a sustainable, secure and affordable energy system.

1. European Commission Memo, 18 December 2013. http://europa.eu/rapid/press-release_MEMO-13-1169_en.htm
2. http://eeb.org/national-governments-must-not-use-legal-loopholes-to-hide-failure-on-air-quality/. National Emission Ceilings Directive sets absolute caps for the amount of pollution allowed by any one country within a year
3. Energy Security Strategy, European Commission, 2015. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52014DC0330&-qid=1407855611566
4. European Commission (2016), An EU strategy on heating and cooling. https://ec.europa.eu/transparency/regdoc/rep/1/2016/EN/1-2016-51-EN-F1-1.PDF

FIGURE 2
Benefits of Electrification



Source: WindEurope

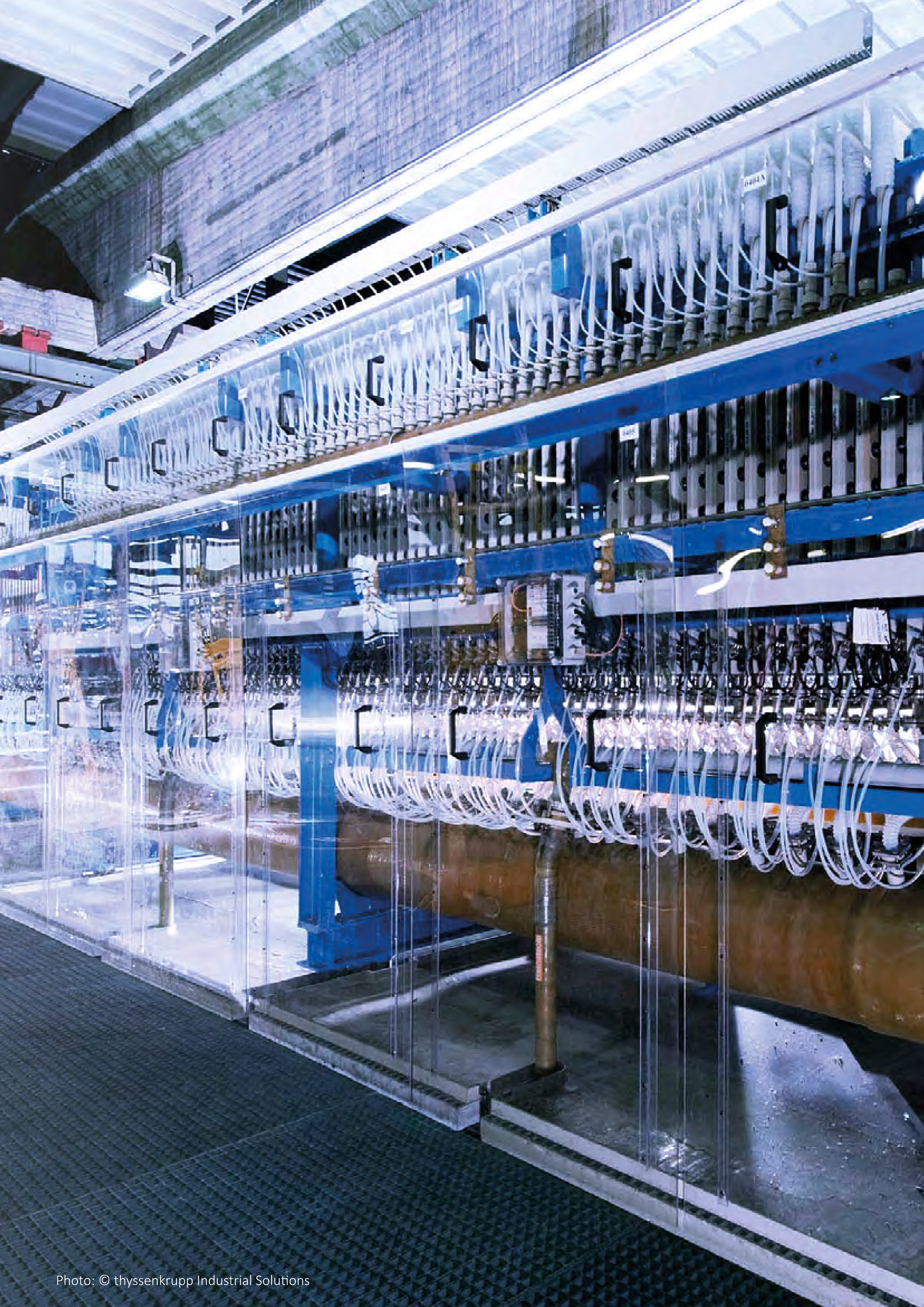


Photo: © thyssenkrupp Industrial Solutions

1. DECARBONISATION SCENARIOS & POLICY LEVERS

The EU has agreed a 32% renewable energy target to 2030, with an upward review clause in 2023. That equals around 55% of electricity coming from renewables in 2030. This means that wind will play an increasing role in Europe's energy mix and that Europe can stay at the forefront of global competitiveness in wind energy technology.

However, 2030 is only a milestone in the long-term transformation that Europe has to go through to limit dangerous temperature rises and other adverse effects from climate change. 2030 is also the minimum planning timeframe for some of the investments necessary to maintaining Europe's competitiveness and living standards. For most energy infrastructure however, with very long investment and economic cycles, planning beyond 2030 is crucial.

Thanks to the ongoing decarbonisation of the power sector, driven by a remarkable cost reduction in renewables, Europe's economic growth is decoupling from greenhouse gas emissions. However, Europe still relies largely on fossil fuels to satisfy its energy needs and is at risk of failing to capitalise on the global energy transition it initiated.

The direction forward is clear: if Europe is to decarbonise 80-95% of its economy by 2050[5], it will have to phase out fossil fuels and mainstream the use of clean electricity and energy efficiency in its most energy-intensive sectors, namely transport and heating in industry and buildings[6]. And it will have to do it with the same ambition and determination that it applied to transforming the power sector over the last two decades.

Integrating transport and heating into a renewables-based power system is the next challenge that will shape the future of Europe's energy system. If Europe wants a zero or close-to-zero emissions economy by 2050, it needs to start investing in zero emissions infrastructure in these sectors today.

5. The EU's long-term ambition of an 80-95% greenhouse emissions reduction in line with the recommendations of the IPCC include all sectors of activity in the economy. Energy-related emissions account for 80% of the EU's total emissions. The rest come from sources such as agriculture, land use, land use change and forestry (LULUCF).
6. According to the European Commission's Energy Roadmap 2050, the energy sector accounts for 31% of energy-related emissions, transport 19%, industry 13%, households 9% and other uses 7%.

1.1 DECARBONISATION SCENARIOS

WindEurope has commissioned DNV GL to assess the impacts of different policies on the long-term development of the European energy system. Using a model of the global energy system, we extracted Europe's (EU-28, EFTA and EETA) indicators and analysed the policy measures that will shape its future energy system.

WindEurope provided possible courses of policy action to DNV GL, who quantified Europe's energy transition. DNV GL's model is used generally to forecast the most likely outcome of the global energy transition. Hence, the model is able to capture interactions of Europe's energy system along with the rest of the world.

We describe the full methodology in Annex 1 and give an overview of the policy levers WindEurope provided to DNV GL in section 1.2.

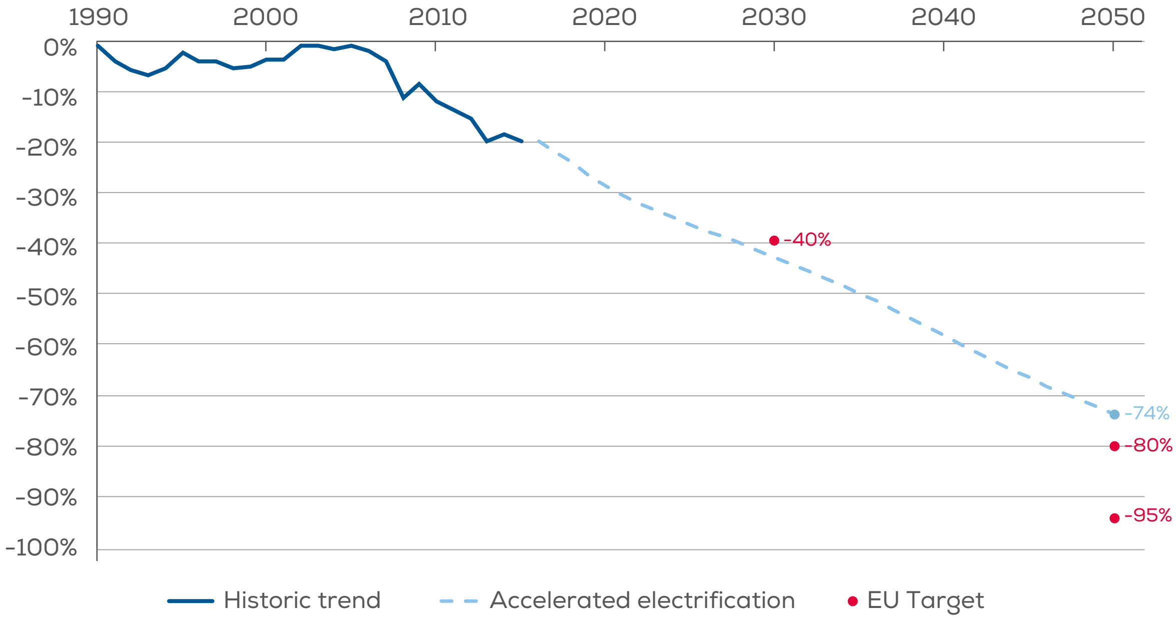
Here we present two scenarios, an *accelerated decarbonisation scenario* and a *Paris-compatible scenario*, each underpinned by three policy levers: 1) electrification uptake and energy efficiency, 2) CO_2 price and 3) the role of coal power generation. Each of these policy levers were translated into numerical inputs as summarised in Figure 3. We adjusted the level of ambition of each policy lever in order to assess the feasibility of a 90% reduction in energy-related CO_2 emissions to 2050, 5% more than the European Commission's 2050 Roadmap published in 2011.

FIGURE 3
Key input parameters to the scenarios

	SCENARIOS	
Policy lever	**ACCELERATED ELECTRIFICATION**	**PARIS-COMPATIBLE**
Energy Efficiency and Electrification Uptake:		
Buildings	1.0%/year	1.8%/year
Manufacturing	1.8%/year	2.6%/year
EV fleet of passenger vehicles	90% by 2050	90% fleet, 3.7% vehicles hydrogen-based
CO_2 price in 2050	€45/tCO_2	€90/tCO_2
Coal power	Plants retired as they reach their economic lifetime New plants built out where economic feasible	No new plants built after 2020 No generation after 2030

FIGURE 4

Energy-related CO_2 emissions trajectory - accelerated electrification scenario



Source: DNV GL for WindEurope

1.1.1 ACCELERATED ELECTRIFICATION SCENARIO

The accelerated electrification scenario yields a 43% reduction of energy-related CO_2 emissions by 2030, slightly above the current EU target of 40%, and a 74% reduction by 2050 (all percentages take as a base 1990 levels). While this is significant, it would fall short of the current climate goals for the mid-century. According to the 2050 Energy Roadmap, the EU requires an 85% reduction of energy-related CO_2 emissions, which would yield an 80% reduction in overall greenhouse gas emissions in the EU economy.

The CO_2 emissions reduction would be a consequence of lower energy demand and the incremental use of cleaner electricity. Under the accelerated electrification scenario, energy demand would reduce 30% from today. In parallel, the electricity share in such final energy consumption would more than double, from 24% today to 51% in 2050.

Our model shows that these changes would occur mainly through the electrification of the passenger vehicle fleet, a trend that is under way in many parts of the world.

Road transport, which represents about 80% of all energy demand in the transport sector, would undergo a radical transformation. Electric vehicles (EVs) are about to start their exponential growth phase and the urban population increasingly opts for car-sharing rather than ownership. In Europe, the light vehicle fleet has shrunk 30% since 2016, and the remaining fleet should be almost entirely electrified by mid-century, according to our model. Road transport electrification will be the main driver behind a five-fold decline in oil consumption in Europe by 2050. The remaining use of oil would go to international shipping and aviation, which would experience little change in energy use.

Because electric vehicles are 3 to 4 times more efficient than internal combustion engines, road transportation will be the main source of the decline in energy demand

and emissions in the accelerated electrification scenario, in spite of continued growth in passenger cars for the next decade.

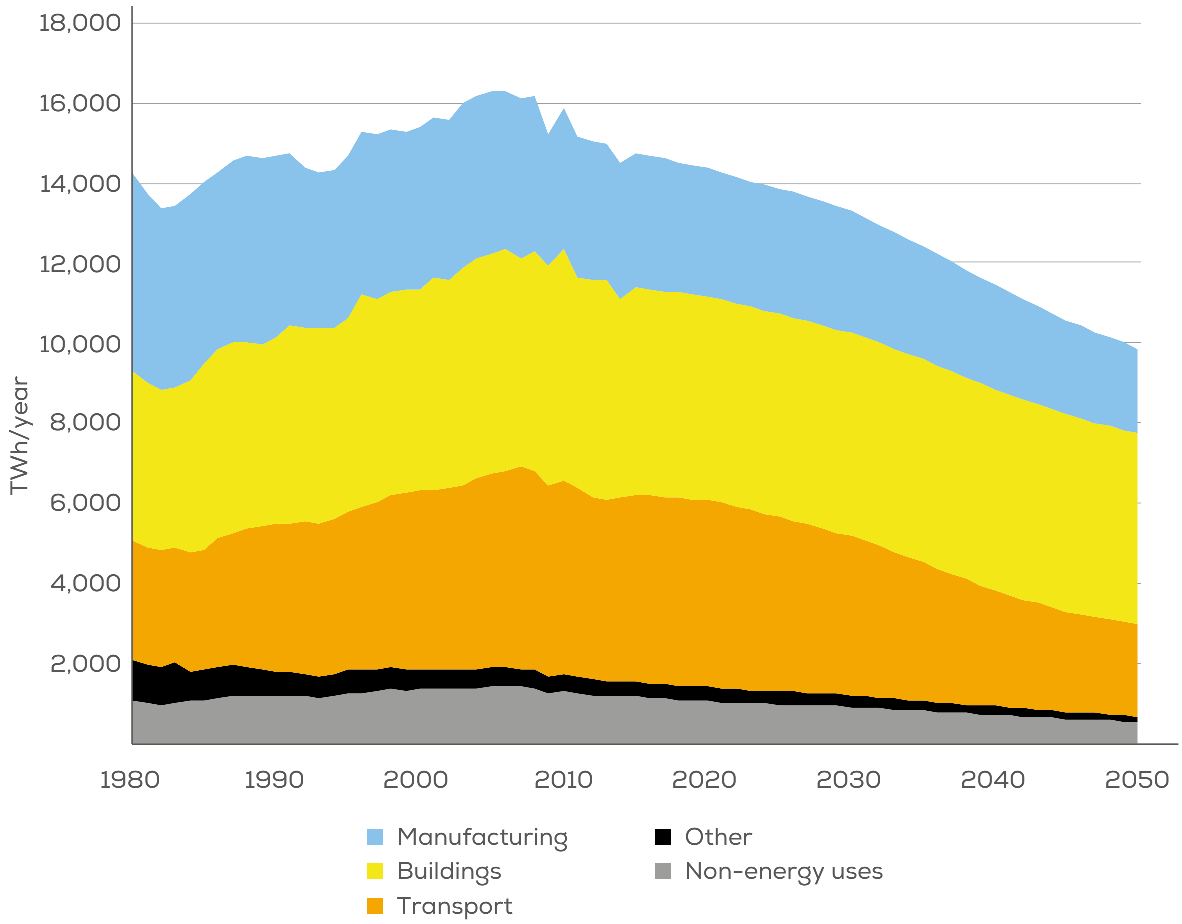
By contrast, the electrification rates of manufacturing and buildings would be far more limited. Consequently, their emissions do not reduce enough to reach an 80% decarbonisation of the economy by 2050.

Electrification in buildings would increase from 36% today to 48% in 2050. This would bring about a 50% reduction in direct carbon emissions from today, in spite of an almost 50% energy demand increase due to the expansion of the building stock.

The electricity share in industry's energy demand would increase from 36% today to 62% in 2050. However, this increase would be mainly due to a lower energy demand, which would decrease 36%. Unless specific policies are in place to safeguard manufacturing activity, this reduction in energy use would mainly be a consequence of the shift in advanced economies from manufacturing to services-oriented activities. With these trends combined, high electricity use and lower energy demand would reduce emissions by 71% from today.

FIGURE 5

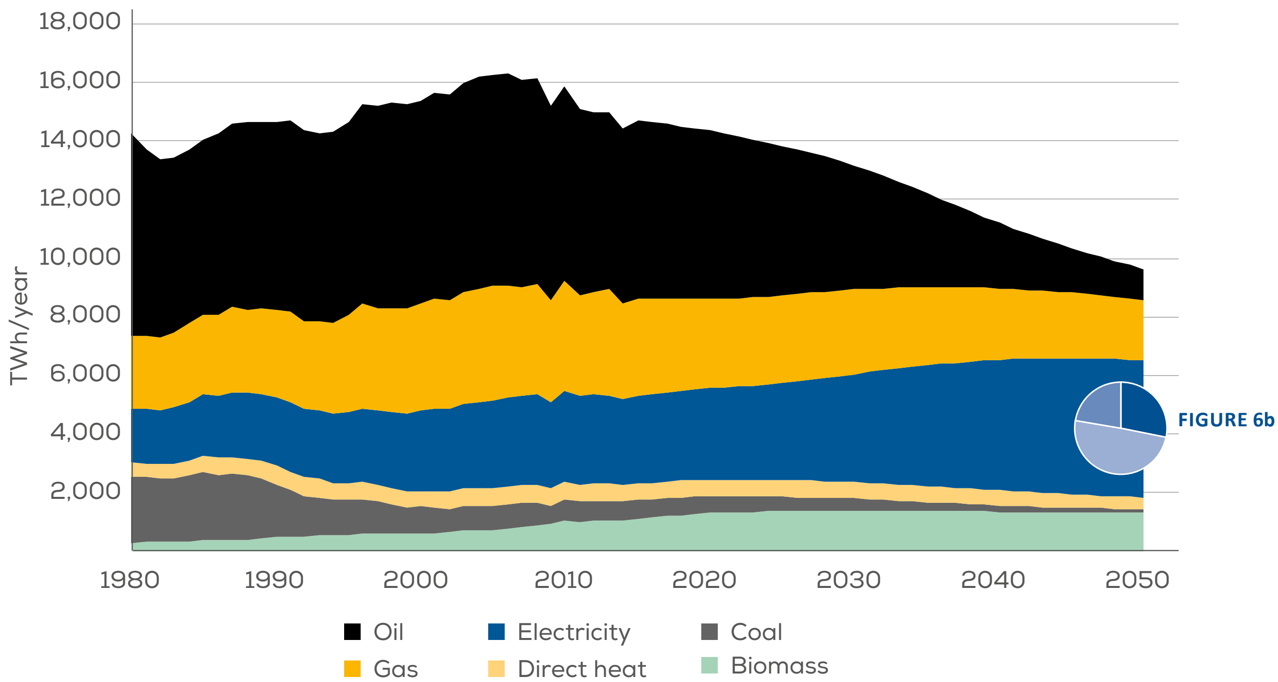
Final energy demand by sector of activity - accelerated electrification scenario



Source: DNV GL for WindEurope

FIGURE 6

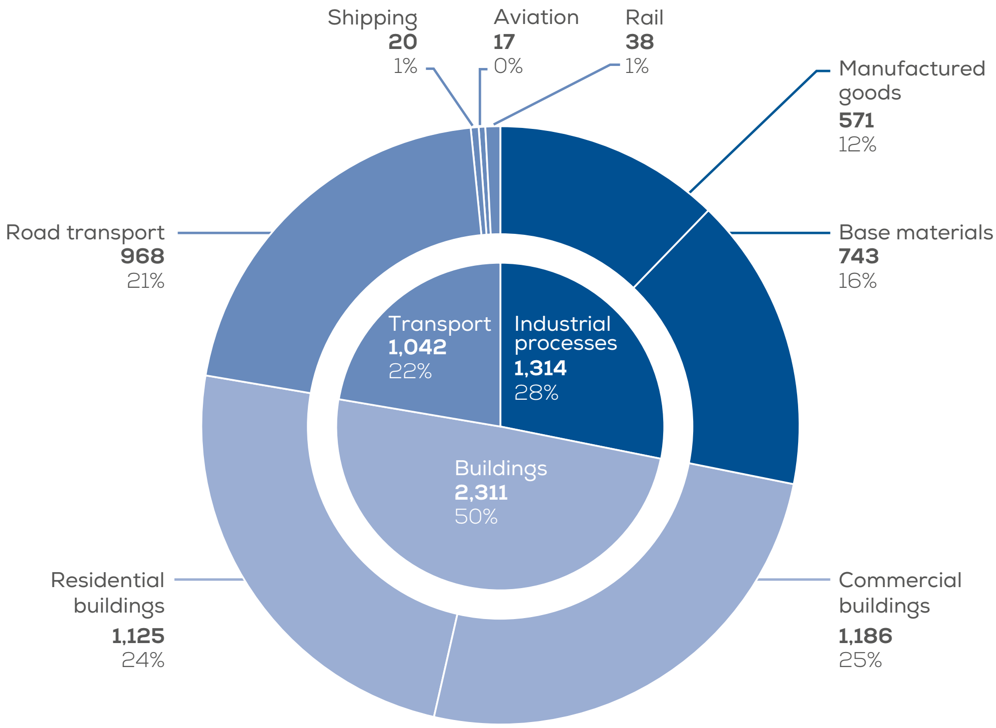
Final energy demand by fuel - accelerated electrification scenario (TWh/year)



Source: DNV GL for WindEurope

FIGURE 6b

Electricity use by user in 2050 (4,667 TWh/year)



1.1.2 PARIS-COMPATIBLE SCENARIO

Existing policies will not set the EU on course to meet its Paris Climate Agreement commitments. Failing to meet the global climate target of "well below 2 degrees" will inflict high societal costs across the economy in terms of infrastructure, health and social inclusion.

Our accelerated electrification scenario yields a high electrification of road transport, meaning the transport sector will have marginal additional decarbonisation potential. Achieving a 90% reduction of CO_2 emissions in the EU economy would require a combination of more carbon-free power generation and further electrification of heating in industrial processes and buildings.

In a Paris-compatible scenario, the share of electricity in final energy demand would reach 62% in 2050. This electricity would have to come mostly from carbon-free energy sources. Renewables would generate 78% of electricity in 2050, representing 66% of Europe's final energy demand.

Consequently, CO_2 emissions across the economy would reach a 90% reduction from 1990 levels.

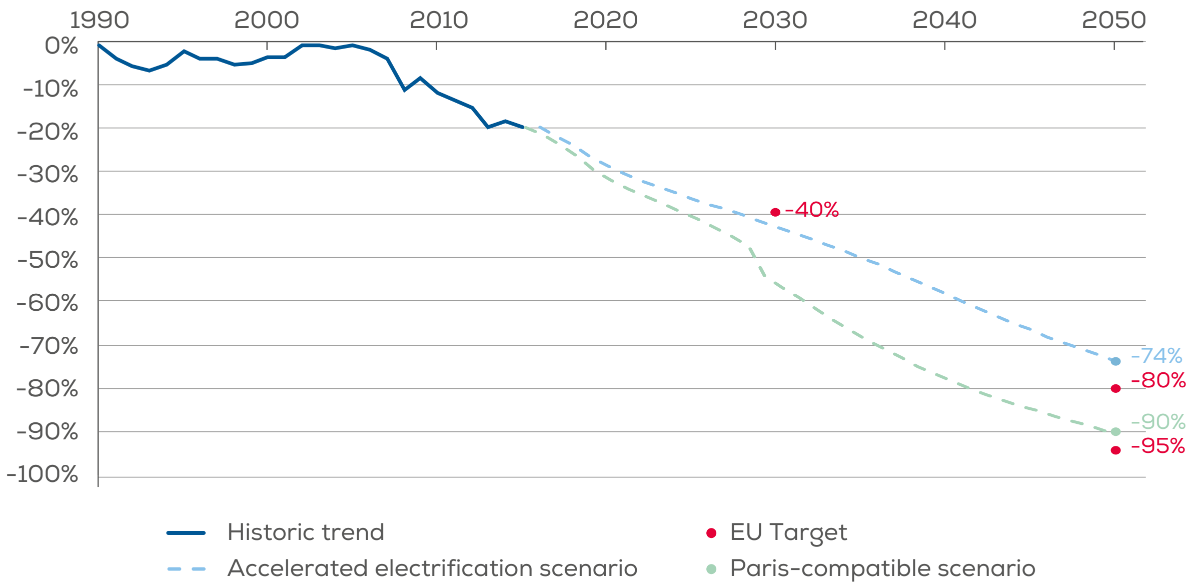
Such decarbonisation is possible, and is worthwhile in the long term. Pursuing policies towards Paris compatibility would not cost substantially more than the accelerated electrification scenario. The average annual energy costs would amount to 2.7% of Europe's GDP to 2050, 0.5 percentage points more than in the accelerated electrification scenario[7].

Moreover, such ambitious policies to limit a temperature increase below 2 degrees Celsius would yield savings in infrastructure repairs from an increasingly extreme climate, from 1.2% costs of GDP in the accelerated electrification scenario to 0.86% in the Paris-compatible scenario[8].

In addition, with more electricity and renewables in the energy mix import dependency would fall, reducing exposure to fossil fuel price volatility. Such volatility has a direct bearing on the energy bills of consumers.

FIGURE 7

Energy-related CO_2 emissions trajectory for Europe to comply with the Paris Agreement

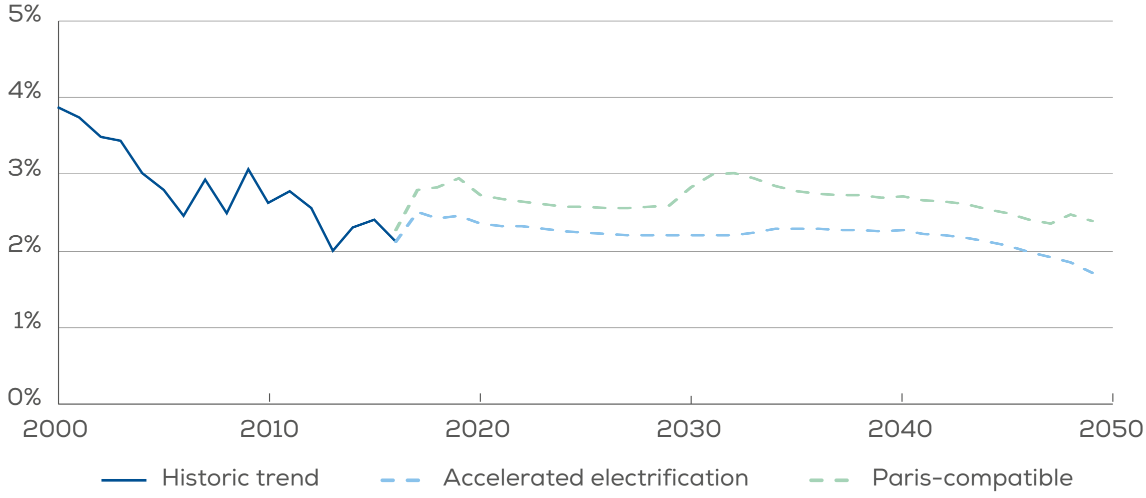


Source: DNV GL for WindEurope

7. Annual energy costs include OPEX and CAPEX for new power stations of all technologies, transmission and distribution grids, local production of oil, gas, coal and hydrogen, as well as LNG liquefaction and regasification. Costs excluded are energy imports, infrastructure costs beyond the distribution grid (e.g. EV charging stations), energy efficiency investments in buildings, manufacturing and transportation costs of any fuel not used in power generation such as oil and gas pipelines and shipping and oil refineries.
8. The DNV GL model does not allow direct estimation of costs for infrastructure repairs. Through a sister effort done in 2015, DNV GL quantified the concrete infrastructure ailment costs of a harsher climate. See Annex II for the full methodology and references.

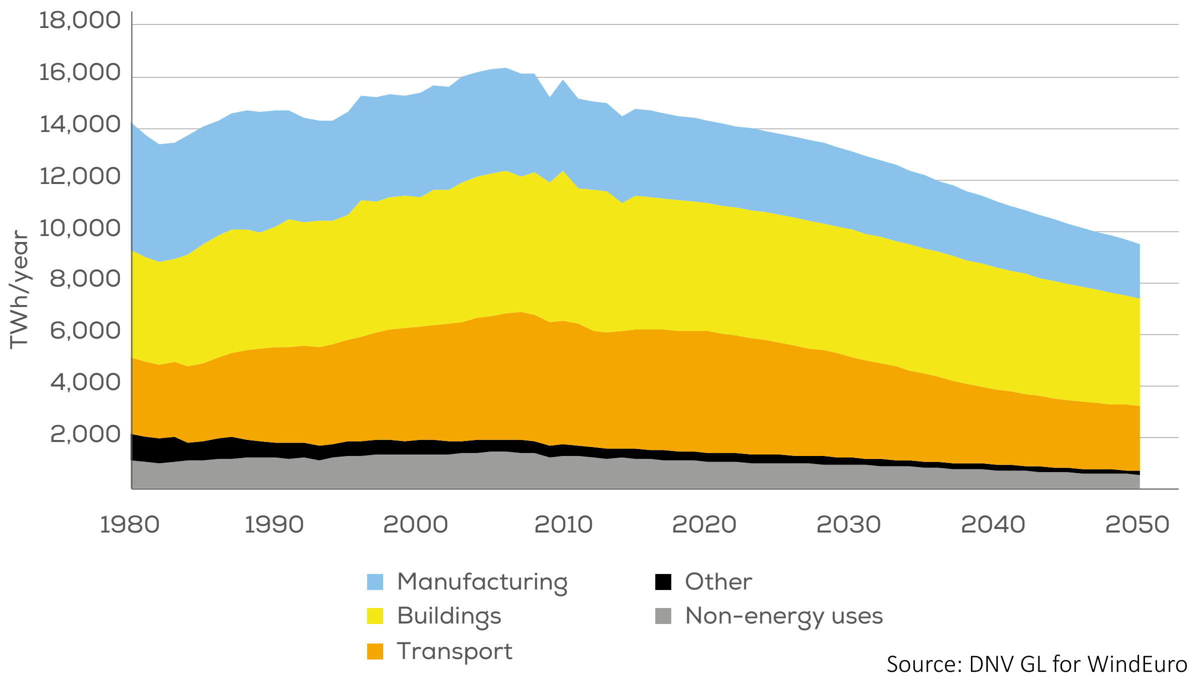
Moving away from fossil fuels would mean a transition from today's high fuel and operational costs to an energy system with higher capital expenditure, but lower fuel costs. This would not only be due to renewables, but also because almost all assets generating electricity today will reach the end of their economic lifetime by 2050. Replacing it with cleaner options would trigger investments that in turn would generate more GDP and technological competitiveness.

FIGURE 8
Energy expenditures as a share of GDP



Source: DNV GL for WindEurope

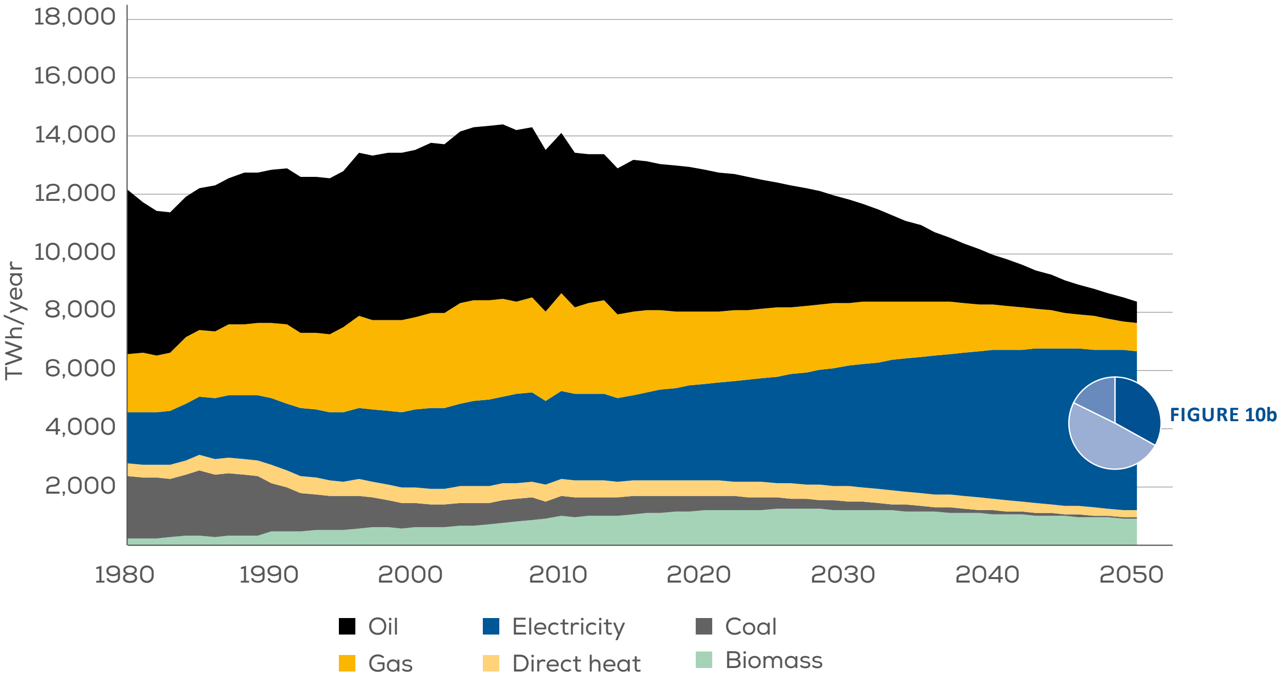
FIGURE 9
Final energy demand per sector - Paris-compatible scenario



Source: DNV GL for WindEurope

FIGURE 10

Final energy demand per energy carrier - Paris-compatible scenario (TWh/year)



Source: DNV GL for WindEurope

FIGURE 10b

Electricity use by user in 2050 (5,450 TWh/year)

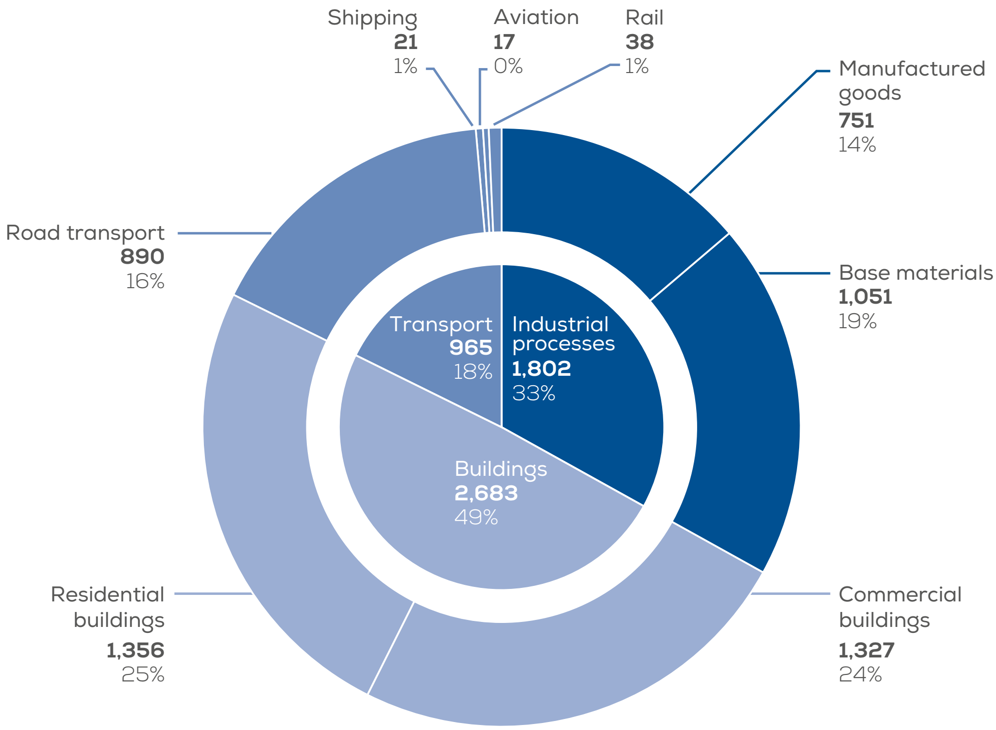
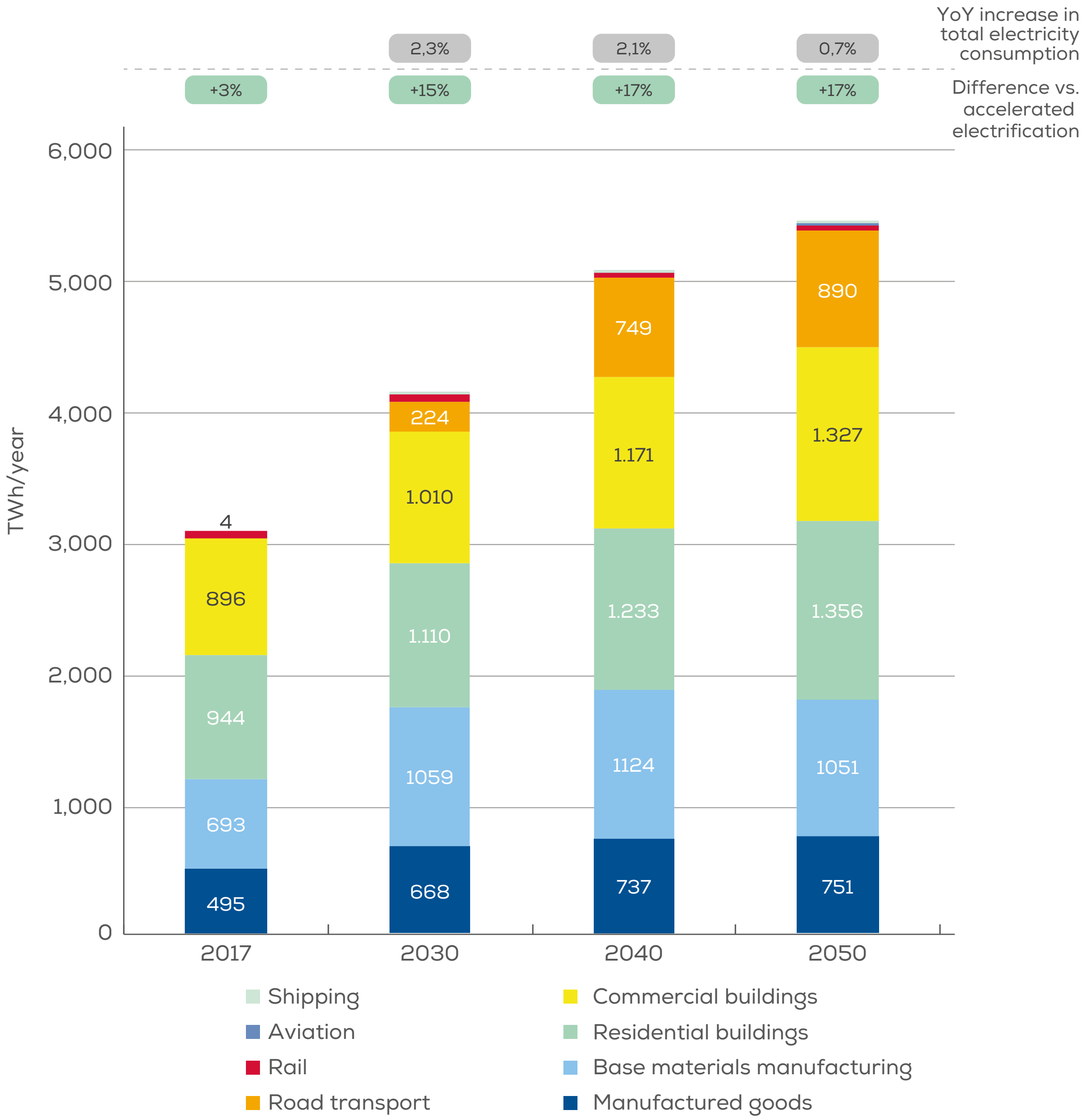


FIGURE 11
Electricity use by sector - Paris-compatible scenario



Source: DNV GL for WindEurope

1.2 POLICY LEVERS: MOVING FROM CURRENT POLICIES TO PARIS COMPATIBILITY

Decarbonising Europe's economy will require activating the right policy levers. Based on the societal benefits brought by electrification, we believe there are three broad categories of policy levers that could move the trajectory from the accelerated electrification scenario to the Paris-compatible scenario.

Activating these levers will require ambition at EU and national levels. EU Member States are preparing National Energy and Climate Plans to deliver on the EU's 2030 Climate and Energy objectives. These plans will be crucial in setting out timely and robust implementation measures for decarbonising the energy system.

1.2.1 ENERGY EFFICIENCY AND ELECTRIFICATION

ENERGY EFFICIENCY

The cheapest, cleanest and most secure energy is the energy not consumed. While renewable resources offer affordable and potentially inexhaustible energy, their efficient use across all stages of the energy chain, from transformation to end-use, will be critical to Europe meeting its long-term Climate and Energy objectives.

Traditionally efficiency has meant *'using less'*, but policies should pursue a goal of *'producing the same or more while using less'*. Minimising energy use per unit of economic output entails a genuine transformation of the European economy.

Policymakers can shape energy efficiency with two general levers: by setting obligations on energy savings or by promoting market-based instruments that incentivise users to optimise their energy consumption. Europe has combined both approaches, with the EU Institutions mainly setting the general framework of obligations[9], and individual Governments implementing market-based instruments such as auctions[10].

Last June, the EU agreed on a non-binding 32.5% energy efficiency target by 2030 with an upward review clause in 2023.

Policy makers will use a range of measures across different sectors in order to meet this 32.5% target. For example, the implementation of the Energy Performance of Buildings Directive (EPBD) agreed in May 2018[11] could have a significant impact in energy efficiency policies across countries. The Directive aims at boosting energy efficiency in buildings through ambitious long-term renovation strategies towards a decarbonised building stock by 2050. This would transform Europe's energy system; buildings account for 40% of Europe's energy consumption and two-thirds of Europe's buildings were built before energy performance standards were set up. Furthermore, the building renovation rate is only around 1% per year. Increasing this renovation rate has the potential to reduce between 5% and 6% of the EU's total energy consumption and to reduce CO_2 emissions by about 5%[12].

Energy efficiency in industry is more challenging to tackle due to the differences in energy uses depending on the specific industrial processes. Until now, the EU has addressed this by setting energy performance standards of manufactured products through the Eco-design Directive and energy labelling. These cover not only household appliances, but also industrial equipment, such as electric motors, water pumps, industrial refrigeration and power transformers.

However, energy efficiency in the production of base materials such as steel, cement and chemicals is far more complex and the EU has not tackled it directly with policies. The Eco-design and Ecolabelling policies focus on the amount of electricity machines use, rather than on the primary energy use. Whilst the European Commission estimates that Eco-design will deliver energy savings equivalent to the annual energy consumption of Italy by 2020[13], the transformation of Europe's energy system necessitates mining a greater fraction of the energy savings potential available in industry.

9. Energy efficiency obligations schemes for utilities of 1.5% per year to 2030. It is thought that this should attract investments and incentivise new business models. IEA (2017)
10. The 2012 European Directive on Energy Efficiency triggered policies and market based instruments. There are 12 market-based instruments for energy efficiency in the EU: AT, BG, DK, FR, IE, IT, LU, MT, PL, SL, ES, UK. Three more countries are to start shortly instruments: HT,HE,LT. IEA (2017)
11. http://data.consilium.europa.eu/doc/document/PE-4-2018-INIT/en/pdf
12. https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings
13. http://europa.eu/rapid/press-release_MEMO-16-3986_en.htm

In the transport sector, policy has focused on tax reduction incentives, stricter emissions and fuel efficiency standards, as well as charging infrastructure deployment. Most of these policies aim at passenger vehicles rather than heavy and long haul road transportation and shipping. Energy savings could be significant, as battery electric vehicles have higher energy conversion efficiency rates than internal combustion engines.

ELECTRIFICATION INCENTIVES

Energy prices often do not reflect true costs. This is partly because fossil fuels still benefit from subsidies and tax exemptions, in particular in the country of production, making them artificially cheaper than renewables[14]. Tax and subsidy regimes incentivise users to opt for fossil fuel-based heating and transport over electricity.

Policy makers hold a key lever to address market distortions through fuel and electricity pricing. For example, by revising taxes and levies in retail electricity prices, which average 30% of the final price to consumers. These taxes and levies are often unrelated to energy use as governments use them for wider tax collection.

Energy taxes could hinder the electrification of households and industries too. For example, the ratio between electricity versus gas and oil prices has remained quite stable over time, to the detriment of electric appliances.

Tax breaks could shape consumer demand towards low-carbon breakthrough technologies. Many countries have introduced tax reductions (Germany, Austria) or bonus payments/premiums for the buyers of electric vehicles (France, the UK, Norway), leading to a significant rise in sales[15].

Recent attempts towards a European approach to energy taxation have stalled. In 2011, the European Commission presented a proposal to revise the Energy Tax Directive with a view to supporting the EU's wider environmental and energy goals. The proposal was withdrawn in 2015 following unsuccessful negotiations in the Council of the EU.

1.2.2 CO_2 PRICING

For many years, the European Emissions Trading System (ETS) has been characterised by a structural imbalance between the demand and supply of allowances. This resulted in low carbon prices, which made the system unable to incentivise investments in Europe's energy transition. EU Member States and the European Parliament recently agreed a series of measures to address this. First, they introduced a Market Stability Reserve (MSR), which will remove some of the surplus allowances from the market. This will start operating in 2019. In addition, EU lawmakers adopted a broader reform of the ETS to bring it in line with the EU's 2030 greenhouse gas emissions reduction target of 40%. From 2021 onwards, the linear reduction factor will increase from 1.74% to 2.2%. This political deal also included a considerable strengthening of the MSR. EU lawmakers agreed to double the annual surplus permit take-out rate and cancel those that sit in the MSR from 2023 onwards. This should help to restore demand and supply balance in the carbon market, and push carbon prices up[16]. These new policies combined could see prices go up to €30/tCO_2 by 2030[18].

The EU ETS will remain the central EU policy instrument to regulate CO_2 emissions and deliver effective transition signals. The recently adopted reforms have sent a clear message to the market that scarcity is on the way. This is already resulting in a significant price uptick.

But further efforts are needed. An additional tightening of the ETS cap is essential to align the EU's CO_2 reduction trajectory with the Paris climate goals. A strengthened linear reduction factor will ensure the ETS can drive out Europe's most polluting assets more quickly. And bring the EU's CO_2 reduction trajectory in line with its long-term climate goals.

In addition to properly pricing CO_2 emissions, the ETS should ensure a fairer distribution of costs among energy users. Today, the ETS primarily covers electricity generation, some large industrial plants and emissions from flights between airports located in the European

14. According to Oil Change International, Friends of the Earth, WWF and the Sierra Club (2017), the G20 nations provide four times more public financing to fossil fuels than to renewable energy http://priceofoil.org/content/uploads/2017/07/talk_is_cheap_G20_report_July2017.pdf
15. 100,000 registered EVs in France in 2017 following the introduction of a 'superbonus' up to €10,000 in 2015.
16. Even when considering the solidarity mechanisms (in particular article 10c) which will continue to give free allowances to power utilities that rely heavily on coal
17. Carbon tracker

Economic Area. This puts electricity at a competitive disadvantage for energy use in sectors not covered by carbon pricing. For example, the electricity used for shore-side electricity (SSE) is more expensive than the tax-exempted fuel commonly used in the auxiliary engines of ships[18].

1.2.3 COAL POWER PHASE-OUT

Securing a low CO_2 power supply is paramount to extending the use of electricity to other energy uses. Whilst the carbon intensity of Europe's power supply has steadily declined from 0.84 tCO_2/MWh in the year 2000 to 0.72 tCO_2/MWh in 2015, it must reach 0.56 tCO_2/MWh by 2030 to meet Europe's climate targets[19].

However, coal-fired power still amounts to 21% of total generation in the EU. There are over 300 coal power plants in operation, 60% of which are operating with technology that is more than 30 years old. In 13 Member States, coal is the first or second source of electricity production[20]. And coal is responsible for 70% of the emissions in the sector and 18% of the emissions in the EU economy as a whole. Pollution from coal plants is responsible for about 23,000 premature death in the EU every year[21].

However, a number of Governments have made pledges to phase out coal power generation. The UK plans to do it by 2025, and the Netherlands by 2030. France, Italy and Finland have made similar pledges. In Germany, the Government has set up a Commission on Growth, Structural Change and Employment to set out a roadmap and agree an end date to phase out coal-fired power production in line with its Climate Action Plan.

18. Ecofys (2015), Potential for shore side electricity in Europe. Sweden asked for – and obtained – a derogation from the energy taxation directive, in order to make SSE tax-free. This would put electricity usage in ships on a level playing field with other fuels.
19. European Commission, 2016. Annex 2, PRIMES reference scenario
20. CAN Europe, 2017. Interactive coal map of Europe. www.coalmap.eu
21. http://www.caneurope.org/docman/coal-phase-out/3117-factsheet-coal-power-in-europe/file

1.3 SUMMARY OF SCENARIOS AND RESULTS

FIGURE 12
Summary of scenarios and results

	CURRENT BASE (2017)	ACCELERATED ELECTRIFICATION (2050)	PARIS-COMPATIBLE (2050)
CO_2 Emissions- Energy related	-22%	-74%	-90%
Final Energy Demand [a]	47,154 PJ/year	33,460 PJ/year	31,754 PJ/year
Final Energy Demand [a]	13,098 TWh/year	9,173 TWh/year	8,820 TWh/year
Renewables in final energy demand	20%	59%	66%
Renewables in power sector	34%	75%	78%
Energy costs as % of GDP	2.1%	2.2%	2.7%
Electrification of final energy demand [a, b]	24%	51%	62%
Manufacturing goods	46%	65%	86%
Base materials	34%	60%	85%
Households	29%	39%	59%
Commercial buildings	50%	62%	78%
Transport	<1%	46%	51%
Road transport	<1%	75%	80%
Shipping	0%	5%	6%
Aviation	0%	3%	3%
Rail	70%	96%	96%

a. Energy uses include demand in manufacturing, buildings and transport. It excludes other energy uses such as agriculture and military activities, which represented 2% of total final energy demand in 2017. It also excludes non-energy uses, which refer to use of other petroleum products such as white spirit, paraffin waxes, lubricants, bitumen and other products[22]. In 2017, non-energy uses represented 8% of total energy consumption.

b. Electrification includes both direct and indirect electrification (represented by the use of hydrogen as an energy carrier, mostly in transport and buildings)

22. http://www.interenerstat.org/definitions/results.asp?id=168&Type=Flows

Photo: Navee Sangvitoon

2. TRANSFORMING THE WAY WE CONSUME ENERGY

2.1 INDUSTRIAL PROCESSES

Decarbonising the EU economy by 2050 will require a widespread electrification of heat processes in industry. Heating and cooling represents approximately 75% of all energy demand in industry and 37% of the total heat demand in the EU. It comprises 85% for heat-consuming processes and 15% for space heating. While the energy savings potential is vast, electrifying heating in industry would require significant commitments from business and political leaders. The rewards would be considerable. Industry could reduce its CO_2 footprint by almost 90% from today under the Paris-compatible scenario, by a combination of electrification, energy efficiency improvements and, possibly, CO_2 capture and storage (CCS).

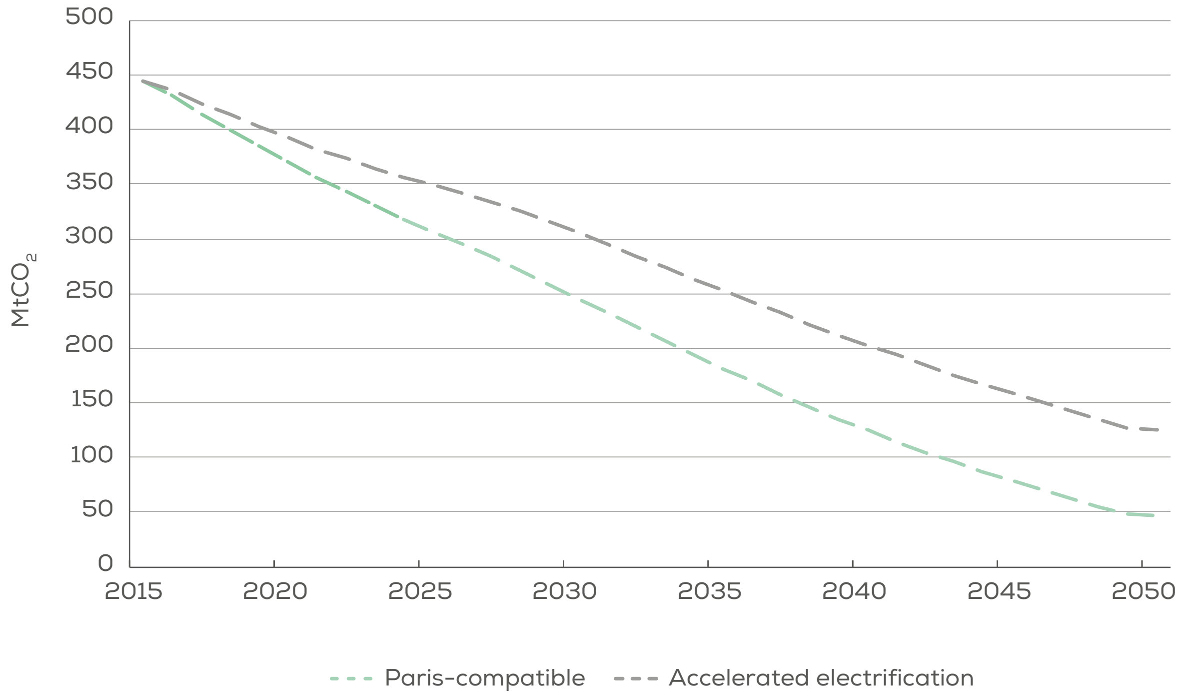
Our results are comparable with other studies assessing competitiveness of various CO_2 abatement potential options in industrial processes. McKinsey[23] concluded that energy efficiency improvements can reduce carbon emissions competitively, but cannot lead to deep decarbonisation on their own. In addition, at competitive electricity prices, zero-carbon electricity for heat or using hydrogen based on zero-carbon electricity becomes more economical than capturing CO_2 from industrial processes.

CCS is an abatement option we did not discard in our modelling, and it shows a contribution in 2050 to reduce emissions from large emitters. However, it would either be limited to regions with carbon storage locations or the compressed CO_2 would have to be transported to a suitable location. And CCS still needs strong support from local regulations and public opinion. Crucially, CCS imposes additional operational costs on industrial processes, which may hinder its viability. With the downward trend of costs in renewable electricity generation, investing in CCS might be an inadequate and costly choice in the long term. We provide a specific example for the decarbonisation of industry in the Netherlands with a contribution from CCS (see BOX 3).

23 Decarbonisation of industrial sectors: the next frontier, McKinsey, June 2018

FIGURE 13

Emissions in industrial processes, accelerated electrification scenario and Paris-compatible scenario



Source: DNV GL for WindEurope

In a Paris-compatible scenario manufacturing, where heat use is less significant, would increase its use of electricity from 46% to 86%. In other industrial processes for the manufacturing of base materials such as steel, iron, cement, aluminium and other metals, it means that the share of electricity would almost triple, from 34% today to 85% in 2050.

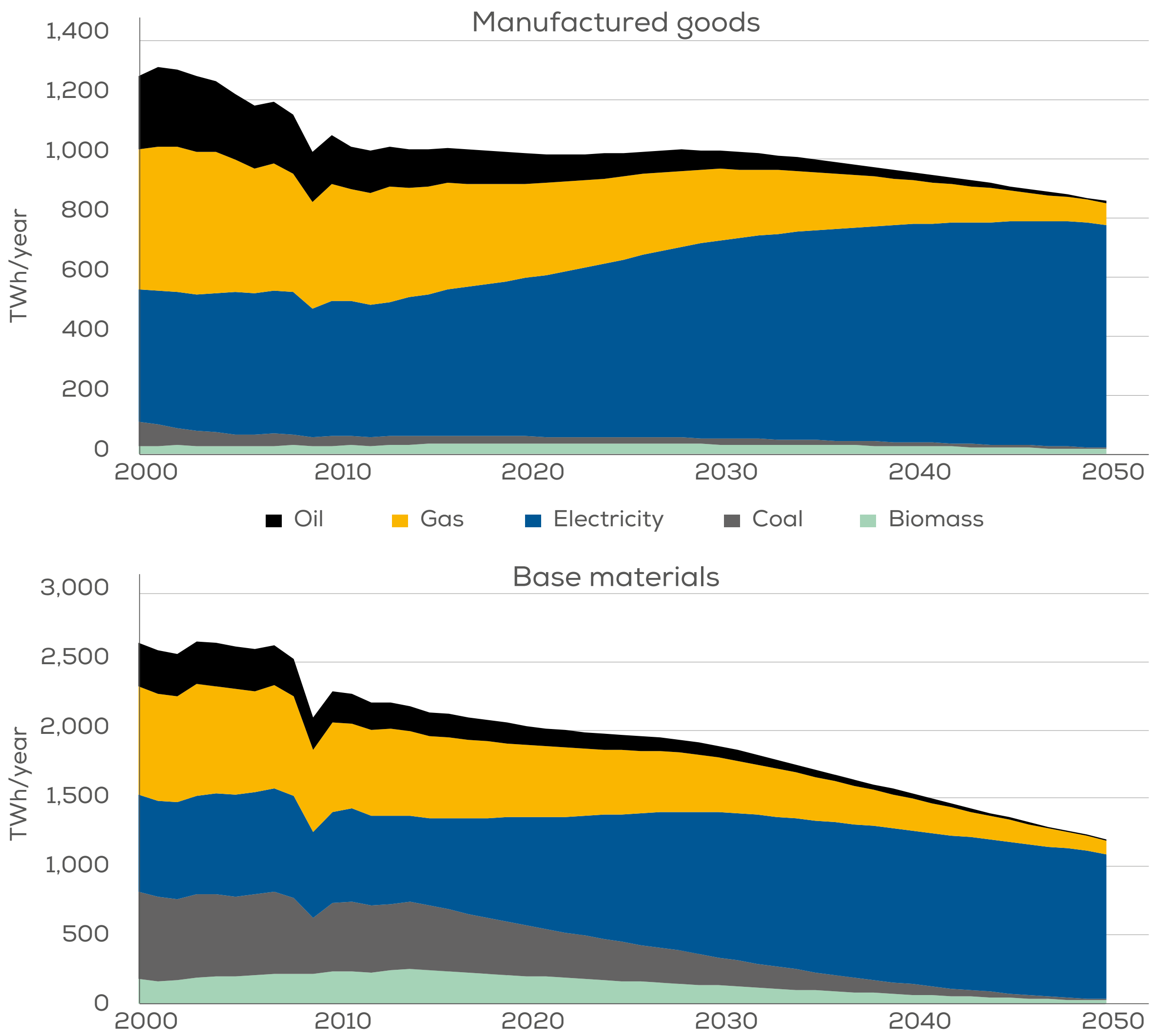
This increase in electricity use would require major transformations in processes, from technology upgrades[24] or replacements to operational practices and even business models. For example, gas burners currently dominate a large fraction of industrial heat loads because they can deliver higher temperatures, typically over 500°C. Replacing such technology would require sizeable investments, although technology solutions exist today[25].

In addition, industrial processes are typically highly integrated and changing one stage would require several other changes and retrofits. Nevertheless, this shift is possible as demonstrated by many industrial sectors, including the cement, steel, ammonia, glass and ceramic, which are already exploring direct electrification with renewables. Today, resistance, induction and infrared heating represent 80% of the available electric heating applications[26]. BOX 1 shows examples of direct electrification already undertaken by different manufacturing sectors.

Another key factor for electrification in industry is the fuel cost. The decreasing electricity prices driven by cost reductions in renewable technologies such as wind and solar could make them more attractive. However, this would depend on the level of taxes and levies and the distribution among fuels and energy consumers.

24. Electrification is traditionally associated with replacing steam- and gas-driven compressors, pumps and valves, of which many are still in use today.
25. There is a large number of electric technologies that provide heat and a substitute to fossil fuels (electric ovens, microwaves, induction, Foucault currents, heat pumps, mechanical vapour recompression (MVR), plasma torches, electron beams, radio frequencies, etc.), often with great ease of regulation, improved quality, and reductions of material wastes. As detailed in the European Commission's Strategy for heating and cooling (2016) and The IEA report Renewable Energy for Industry (2017), many of these are particularly efficient, exhibiting apparent efficiencies greater than 100%, such as heat pumps and MVR.
26. DecarbEurope

FIGURE 14
Energy use in manufacturing goods and industrial processes - Paris-compatible scenario (TWh/year)



Source: DNV GL for WindEurope

In addition to *direct* electrification, the transformation of renewable electricity into other energy carriers such as gas (e.g. synthetic gas, hydrogen) would become necessary. In some sectors such as cement, steel, fertilisers or refineries, Power-to-Gas is among the most promising CO_2 emissions abatement options available. This is also known as *indirect* electrification.

The use of hydrogen is widespread in many industrial processes, notably for the production of fertilizers (through the production of ammonia) and chemical products (through the production of methanol). Substituting this natural-gas formed hydrogen with green hydrogen from electrolysis (based on renewable electricity) would yield significant CO_2 savings. Green hydrogen and ammonia could also reduce CO_2 emissions in the production of iron and steel. The Swedish steelmaking industry is currently developing this option (see BOX 2).

Green hydrogen, blended with CO_2, can produce synthetic methane too. The required CO_2 could come from sustainable sources such as the surrounding air or from biogas plants. This would help into reuse CO_2 that would otherwise be released into the atmosphere.

BOX 1 DIRECT ELECTRIFICATION IN MANUFACTURING

INDUCTION HEATING IN CERAMIC PRODUCTION – SPAIN

At Porcelanosa in Spain, a GH induction ECOMOULD furnace improves the replacement and recycling process of so-called punches used in the press moulds for ceramic tile production. Punches—rubber or elastomer coatings on the steel plate—deteriorate and need to be replaced every certain number of tile cycles. With the innovative furnace, the ceramics manufacturer saved 75% on energy and tripled its production output. Where a traditional resistance furnace needed up to four hours to heat up 500 kg of steel moulds, the GH induction ECOMOULD technology achieves the same in just one hour. It is an environmentally friendly technology that improves labour conditions by avoiding contamination of burned elastomers.

Figure: innovative ECOMOULD furnace.
Source: GH Induction

INFRARED HEATING IN GLASS PRODUCTION – UK

A carbon infrared oven from Heraeus Noblelight is helping a UK company to achieve significant energy savings at its beverages plant. It has also saved factory space by allowing a single cold rinse line to be used for both juices and carbonated drinks. Since installation, the new medium wave infrared system has proved very successful, providing energy savings at the rate of £10,000 per year. As the manufacturing engineer comments: "Heraeus explained that medium wave infra-red was ideally suited for heating glass and then proved this in practice. Apart from helping us to save on energy costs, the new system also allows us to cold-rinse bottles before heating. This is important as it means that the rinse line can now be shared with the carbonated drinks line without major modifications and cost, as it is impossible to fill carbonated drinks into heated bottles."

Figure: Pre-heating of glass bottles prior to filling.
Source: Heraeus Noblelight GmbH, Infrared Process Technology

BOX 2 INDIRECT ELECTRIFICATION IN MANUFACTURING

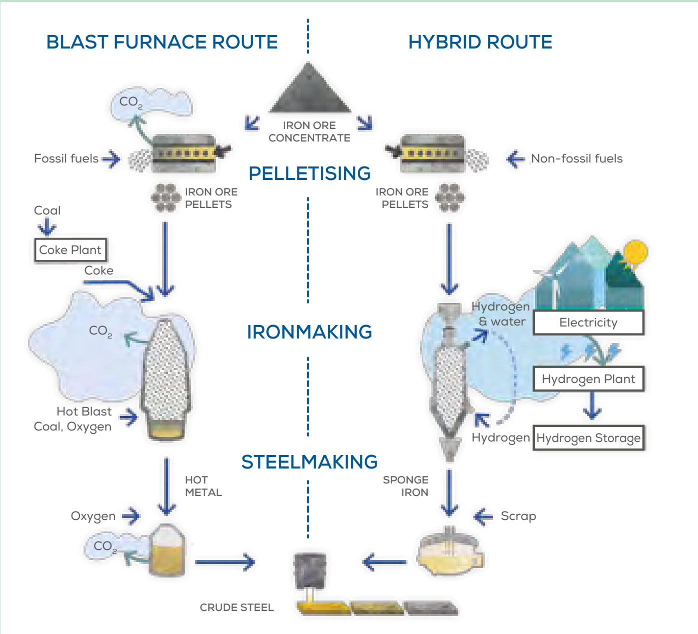
HYBRIT - GREEN STEEL IN SWEDEN

HYBRIT is a joint venture company, owned by three companies, SSAB, LKAB and Vattenfall, that aims to be first in the world to develop an industrial process for fossil-free, ore-based steel production. The project was initiated in spring 2016 and the goal is to have an industrial process in place by 2035. The objective is to replace coking coal, traditionally needed for ore-based steel production, with hydrogen from renewables-based electricity. The result will be unique: the world's first fossil-free steel production technology, with virtually no carbon footprint. The goal is to have a solution for fossil-free steel by 2035.

A pilot plant for fossil-free steel production is being designed in Luleå and the Norrbotten iron ore fields, 250 km north-west of Luleå. A successful HYBRIT would help reduce Sweden's CO_2 emissions by 10% and Finland's by 7%.

HYDROGEN-BASED METALLURGICAL PROCESS

In the HYBRIT- concept, specially developed iron ore pellets are reduced by hydrogen gas in a so-called direct reduction process. Reduction occurs in a solid state at a lower temperature than in the blast furnace process and produces an intermediate product – sponge iron or direct reduced iron – with water vapour emitted from the top of the furnace. This water vapour can be condensed and scrubbed before reuse in the plant. Hydrogen gas is produced by electrolyzing water using renewable electricity (e.g. from hydro or wind power plants), with oxygen gas as a by-product. Hydrogen storage of sufficient capacity is used to balance between the direct reduced iron-process and the electricity grid, allowing a significant amount of variable power generation by e.g. wind or solar power plants to be connected to it. The sponge iron can be used as hot direct reduced iron and melted immediately in an electric arc furnace, together with recycled scrap. The direct reduced iron can also be processed into hot briquetted iron, which can be stored and shipped to another site. The crude steel from the electric arc furnace goes through a similar process as in the blast furnace based route, i.e. alloying and refining before being cast into slabs, ready for rolling and further heat treatment before shipping to customers[27,28].



27. Source: http://www.hybritdevelopment.com/
28. Source of picture : https://www.oemoffhighway.com/engineering-manufacturing/press-release/20990971/ssab-ssab-lkab-and-vattenfall-to-build-pilot-plant-for-fossilfree-steel#&gid=1&pid=1

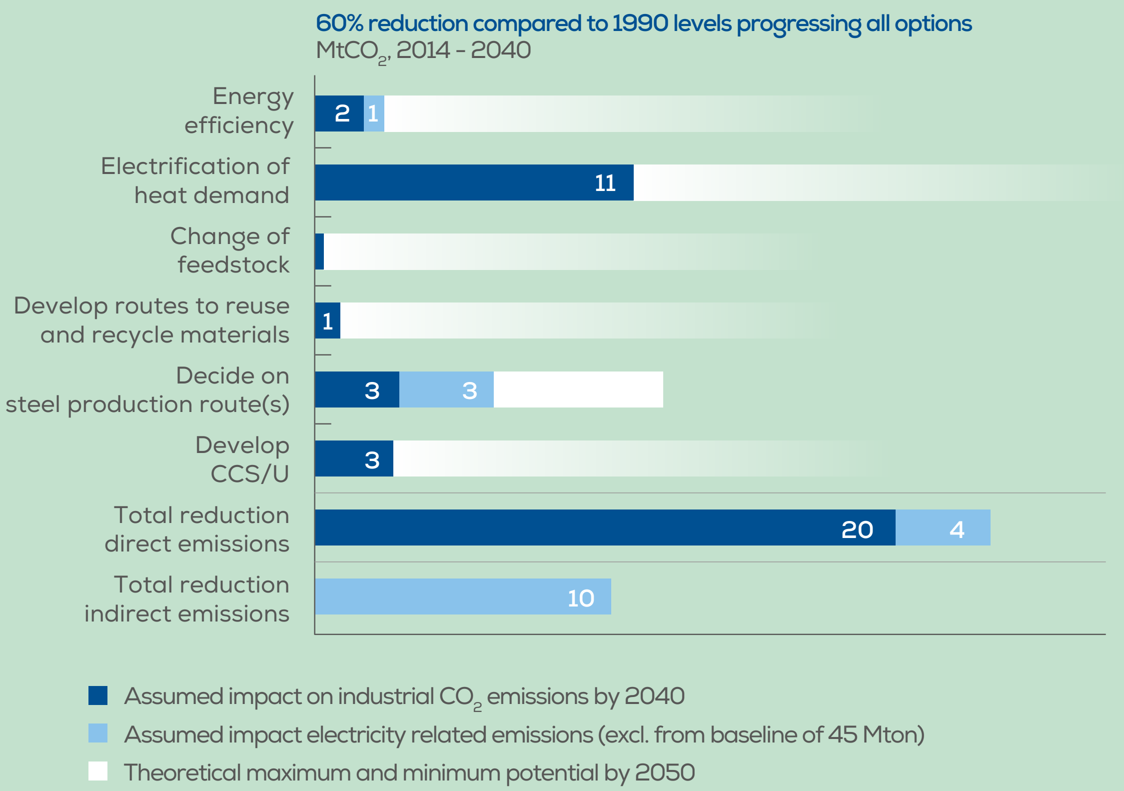
BOX 3 ELECTRIFICATON OF INDUSTRY

COUNTRY CASE - THE NETHERLANDS

The electrification of industry and society is a very important option to achieve the national emission reduction targets in the Netherlands. The concept behind this electrification is that renewable electricity, directly or indirectly, replaces the consumption of fossil fuels or feedstocks.

Industrial electrification offers huge growth potential for demand-response development, which can offer even more benefits:

- Electrified flexible industrial processes (e.g. the ones related to heat production) can offer improved absorption potential for the variable output of growing offshore wind capacities;
- Growing renewable electricity demand from the industrial sector will help to develop long-term economically sustainable business case potential for investors in renewable energy;
- The major industrial site locations in the Netherlands are on the coast, very close to landing points of offshore wind connections; Increasing the electricity demand and demand-response capacities in those locations offers important potential for deferral of onshore grid developments.



Source: Centraal Bureau voor de Statistiek (2014), "Energiebaland" and "Energieverbruik" databases, National Inventory Report (1990-2014)

2.2 BUILDINGS

The decarbonisation of energy use in buildings will be a key factor in Europe meeting its climate objectives. Population growth and standard of living conditions are the main drivers for energy demand in this sector, both of which we expect to continue growing to 2050. The breakthrough should come from cooking, space heating and water heating, currently dominated by gas. Appliances, lighting and space cooling are already generally electrified.

In our analysis, energy consumption in commercial buildings would stay flat, and electricity use will increase from 50% today to 78% by 2050, at the expense of natural gas. In households, energy efficiency gains will be more significant, with a decrease of 27% in energy consumption accompanied by a doubling of electricity use, from 29% today to 59% by 2050. The use of electric heat pumps will drive energy savings and emission reductions. Although they represent only 2% of the final energy demand for heating and cooling today, they are quickly spreading. The heat pumps stock at the end of 2017 exceeded 10.6 million units and, with a current annual market above 1 million units, their contribution could increase significantly in the next decade.

Particularly heat pumps used in district heating networks – which generate heat in central plants and pump hot water into homes via underground networks – will play a central role in driving the electrification in residential buildings. District heating accounts for just 9% of space and hot water heating in the European Union. These networks are mainly used in the energy systems in the Nordic countries and Germany. Switching these networks to use heat pumps instead of fossil fuels would tap into the increasing demand for heating in fast-growing cities like Berlin and Frankfurt.

Electricity will grow most where gas transmission and distribution lines require upgrading, triggering a replacement by electric cables. However, the conversion of a significant fraction of those gas pipelines could make it possible to transport hydrogen and/or synthetic methane. One third of the hydrogen demand (as energy carrier) would come from buildings in 2050, according to our model, representing about 3% of buildings' final energy demand.

However, hydrogen use for heating would compete against the emergence of heat pumps and their continued improvement. Grid expansion and renewal of the building stock could make cost-conscious customers switch to electricity for their heat demand, just as some had made the switch to hydrogen 10-20 years prior.

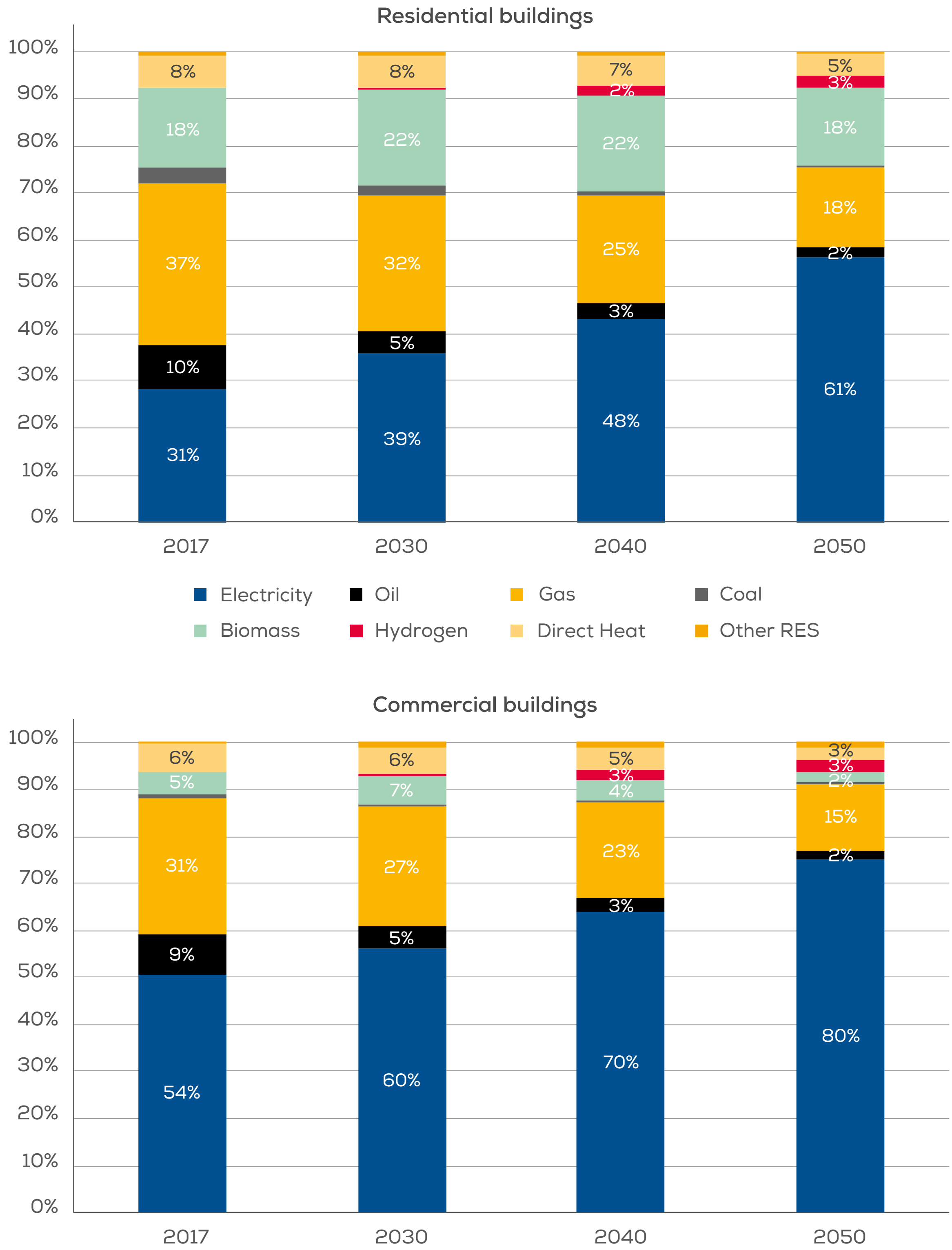
When looking at specific heating applications in buildings (cooking, space heating and water heating), the role of electricity is even more modest.

Buildings would reduce their direct emissions 70% from today, mostly by replacing gas and oil by electricity. In a Paris-compatible scenario, buildings would emit 160 $MtCO_2$ by 2050, compared to the 267 $MtCO_2$ that would be emitted under accelerated electrification.

The remaining unabated emissions will be due to the use of natural gas and, to a much lower extent, the use of oil in a very limited number of buildings.

FIGURE 15

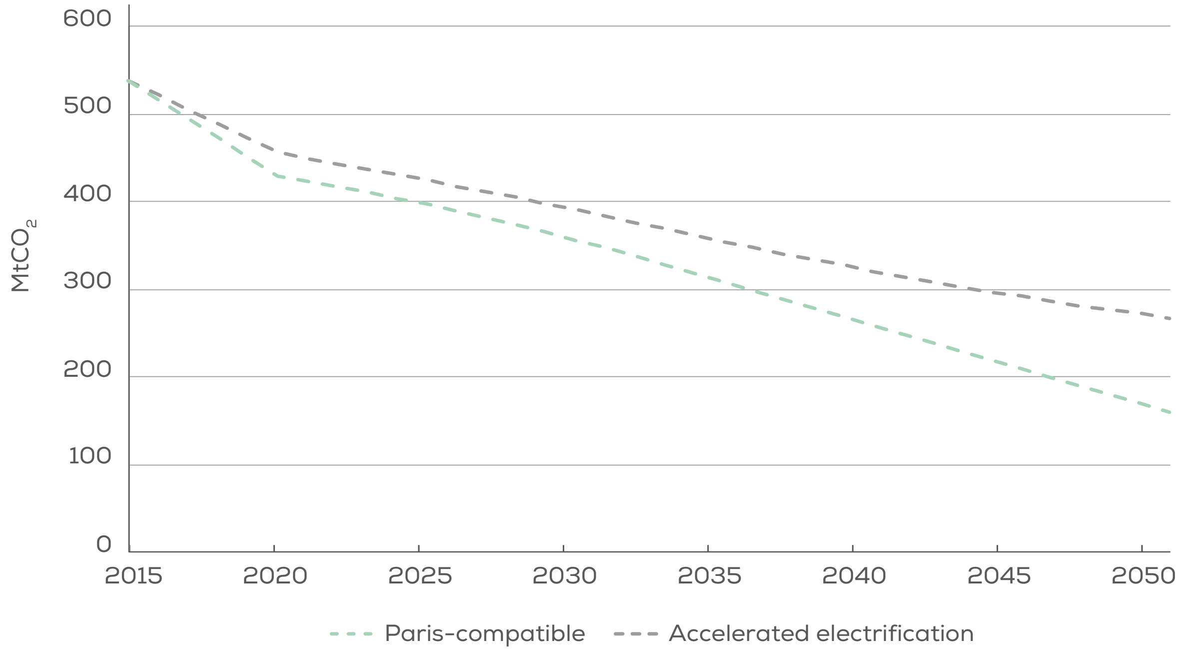
Energy use in residential and commercial buildings - Paris-compatible scenario



Source: DNV GL for WindEurope

FIGURE 16

Emissions in residential and commercial building - accelerated electrification scenario and Paris-compatible scenario



Source: DNV GL for WindEurope

2.3 TRANSPORT

Our accelerated electrification scenario yields a high electrification of road transport, meaning that it may have marginal further decarbonisation potential. Our analysis assumes continued tightening of emissions reduction measures and wide-spread zero emissions vehicle targets. These developments - combined with the sharply declining costs, improved range and versatility of new EVs - will relegate fossil-fueled vehicles to small niche applications in the next two decades. The major difference between the accelerated and the Paris-compatible scenarios is in the increased use of hydrogen for heavy-duty vehicles.

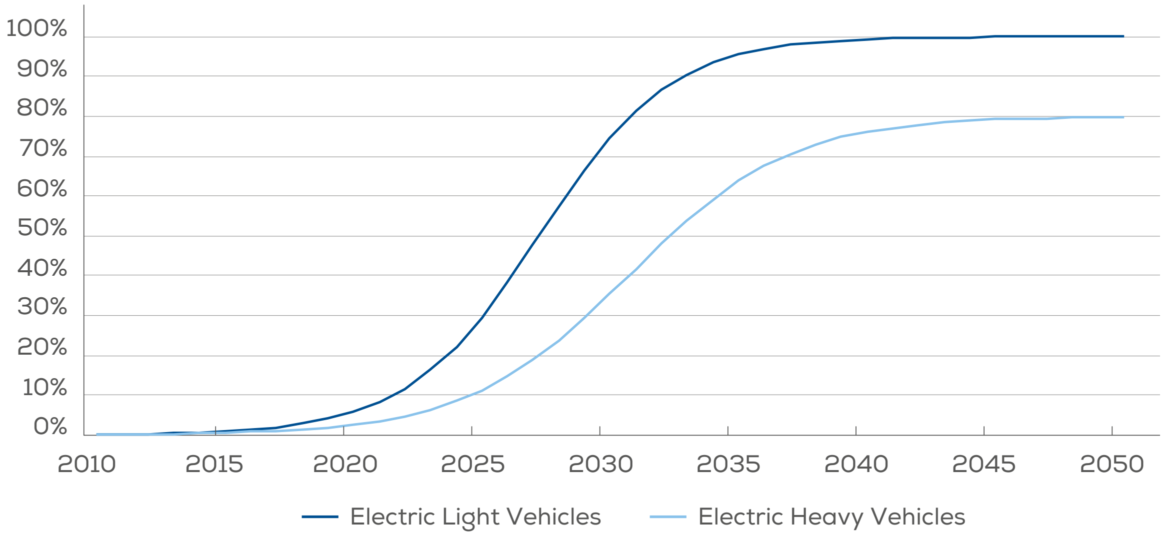
The electrification of the transport sector, in particular road transport, will be the main driver of energy savings and CO_2 savings, in spite of continued growth in passenger cars for the next decade.

The uptake of electric vehicles is expected to develop following an s-shape growth. If costs of EVs continue to decrease and are on a par with internal combustion engine vehicles by 2024 (light vehicles) and by 2027 (heavy vehicles), then half of all new sale vehicles will be EVs shortly after 2025 (for light vehicles) and shortly after 2030 (for heavy vehicles).

Nevertheless, stricter environmental regulations and a massive rollout of recharging infrastructure across the continent should sustain this uptake.

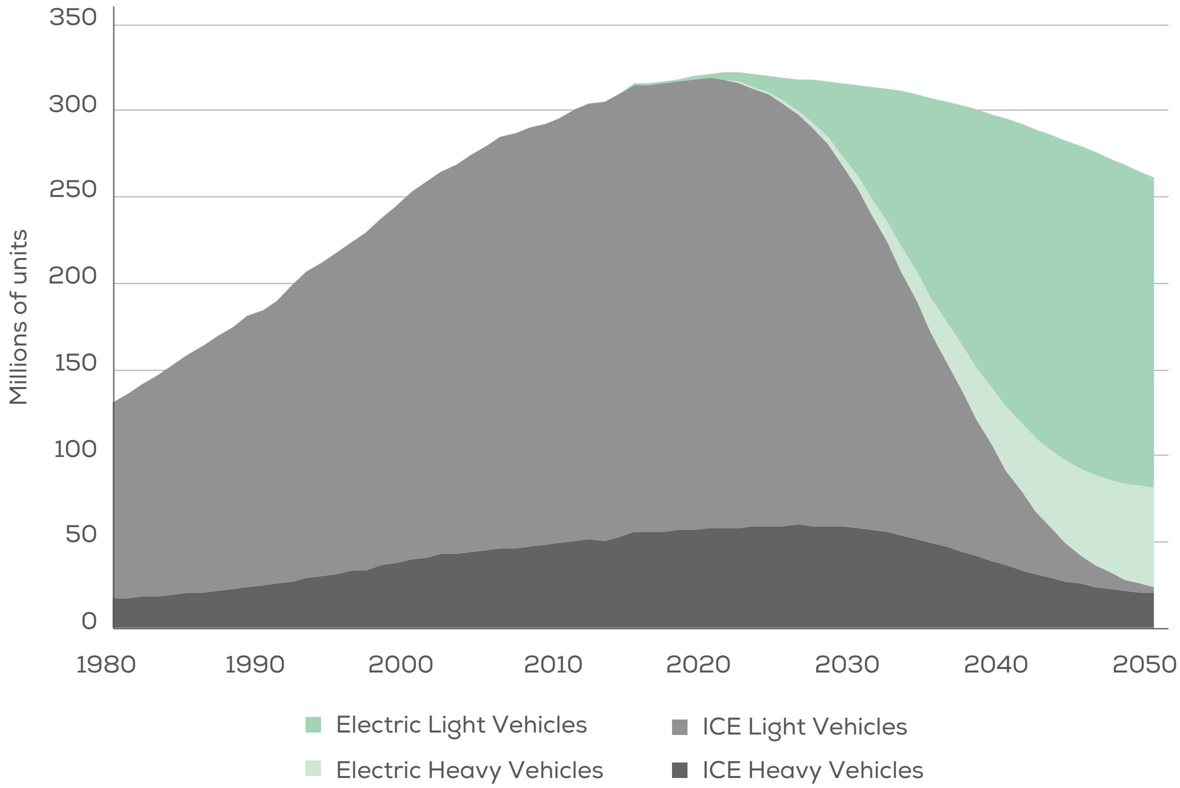
The world's light vehicle fleet propelled by combustion engines (ICE) is very likely to peak in 2025 as electric vehicles (EVs) have started their exponential growth phase and urban dwellers increasingly opt for car-sharing rather than car ownership. In Europe, the light vehicle fleet has shrunk 30% since 2016, and the remaining fleet will be almost entirely electrified.

FIGURE 17
EV share in new sales of light passenger and heavy vehicles



Source: DNV GL for WindEurope

FIGURE 18
Shifting drive train and vehicle fleet numbers - Paris-compatible scenario



Source: DNV GL for WindEurope

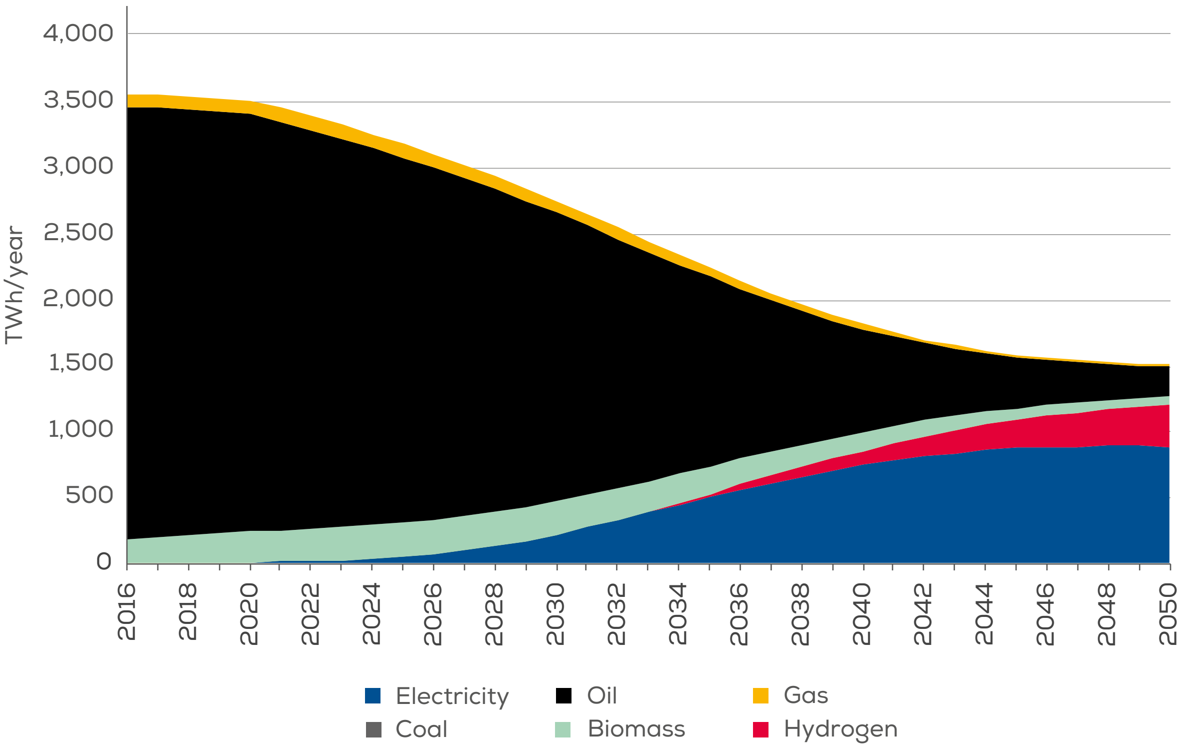
The role of hydrogen would become more relevant in locations with well-developed gas infrastructure. In such locations, hydrogen would serve not only buildings' heating demand, but also up to 16% of heavy trucks will run on hydrogen. The lower cost of variable renewables (making electricity cheaper) and their need for demand-side flexibility (as they are not "dispatchable") would improve the potential for electrolysis-based hydrogen production (hydrogen can be easily stored and transported in large quantities). However, direct electricity will still provide the vast bulk of propulsion for light vehicles, and a five times higher fraction of propulsion than hydrogen for heavy vehicles. By 2050, however, hydrogen will rival diesel as the most important fuel source for long-distance trucks.

Pursuing policies towards Paris compatibility would also require emissions reduction in shipping and aviation. Oil heavily dominates inland maritime and domestic aviation, each representing 11% of all transport demand in 2017. Both sectors would experience significant change of fuels until 2050, with larger contributions from biofuels and natural gas, but electrification would remain marginal with less than 5% in each case. In both sectors, energy consumption is expected to peak within two decades at levels about 15% higher than today, mostly thanks to increased efficiency of jet technology.

Shipping will see electrification of short-haul transport reducing its energy consumption by one quarter. Cruise segments will favour hydrogen. And air transport could see embryonic electricity propulsion by mid-century for the shortest haul flights.

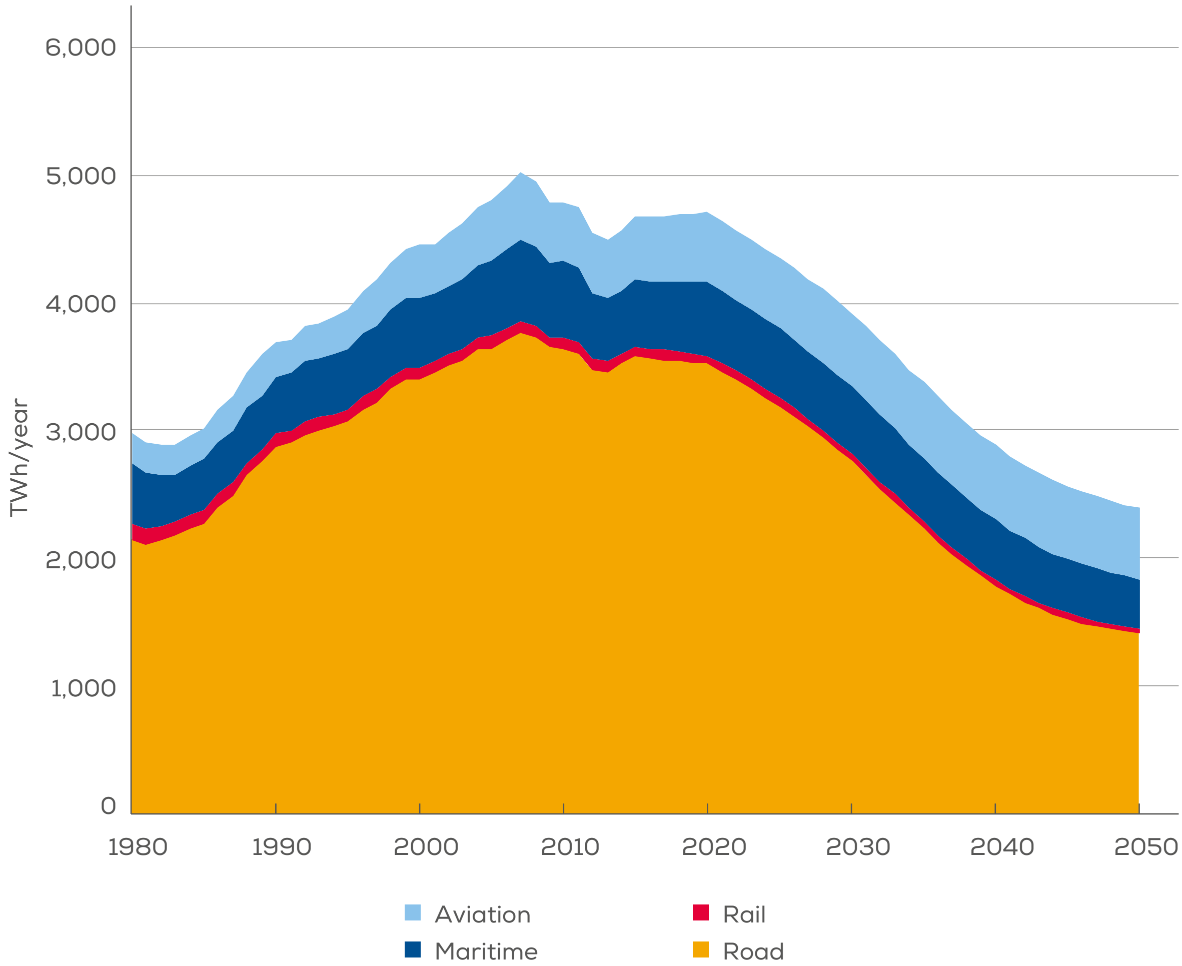
Rail is 70% electrified today, and would increase over 90% by 2050, although its share of total transport energy demand is a mere 2%.

FIGURE 19
Fuel use in road transport - Paris-compatible scenario



Source: DNV GL for WindEurope

FIGURE 20
Energy use in transport per sub-sector - Paris-compatible scenario



Source: DNV GL for WindEurope

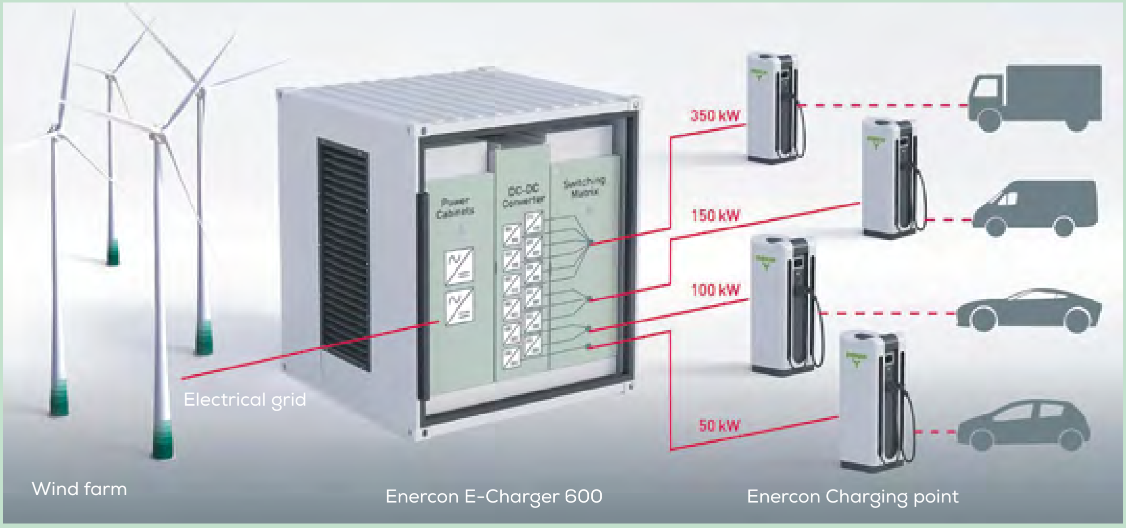
BOX 4 FAST CHARGING OF ELECTRIC VEHICLES

ENERCON has developed the E-Charger 600, which enables high power charging of next generation electric car and truck models. In an ideal scenario, the charger will take approximately 8 minutes to "refuel" an electric car with a range of 400 km.

Up to four charging columns, each with a maximum charging capacity of 350 kW, allow available space for charging at all times. This means charging an e-vehicle is becoming very similar to the familiar procedure of filling up at the petrol station. Such innovations are key to preparing e-mobility for the mass market and enabling battery-driven cars to be used as primary vehicles that can also make longer journeys.

One main challenge for the electrification of the transport sector is the integration of high power charging infrastructure into the existing grids. The new charging technology addresses this by leaving the grid completely balanced and can contribute to grid stability by providing reactive power as required. This is an important factor for the expansion of the rapid charging infrastructure.

With such innovations, the wind industry is increasingly developing solutions beyond its core products, with a view to accelerating the integration of wind energy as the core of a decarbonised energy system.



Source : Enercon

3.

BUILDING UP A RENEWABLES-BASED ENERGY SYSTEM

The electrification of the European economy would be a transformative shift, unlocking opportunities for innovation and competitiveness. Accelerating financing in infrastructure, system integration, sector coupling and digitalisation will be crucial to maintaining Europe's competitive edge while delivering secure, affordable and sustainable energy to consumers.

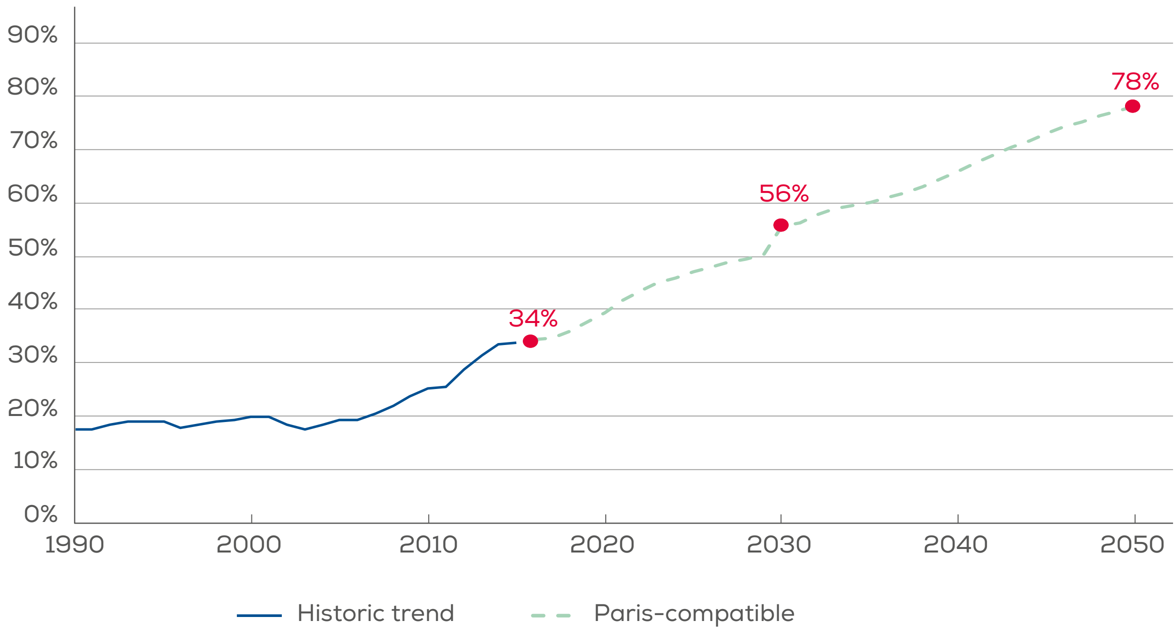
3.1 INFRASTRUCTURE NEEDS IN THE POWER SECTOR

3.1.1 THE POWER MIX AND WIND ENERGY

In the Paris-compatible scenario the share of renewable electricity generation in the power mix would need to grow from 34% today to at least 78% in 2050. Wind energy and, to a lesser extent, solar PV will be the main contributors, while biomass and hydropower will continue to play an important role. Increasing the share of renewables will be all the more significant, as the total power generation will grow from today's 3,500 TWh per year to up to over 6,000 TWh per year by 2050.

FIGURE 21

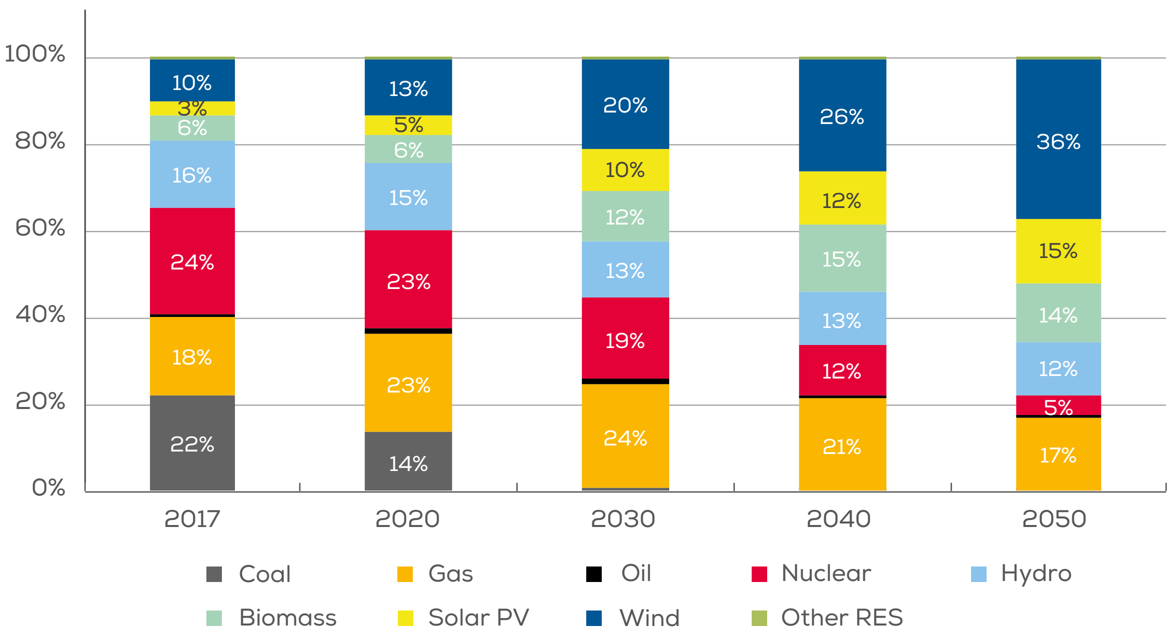
Share of renewable electricity generation



Source: DNV GL for WindEurope

FIGURE 22

European power mix - Paris-compatible scenario



Source: DNV GL for WindEurope

By 2050, variable renewables will represent 52% of all power generation, with wind energy leading the contribution, providing over a third of all power needs (2,223 TWh per year). In the context of a phase-out of coal-powered generation, thermal generation will significantly decrease. Gas-fired power plants will continue to have an important role until 2050 with a 17% share providing a certain amount of supply flexibility. The analysis shows that CCS would be economically attractive with CO_2 prices at €90 per tonne, allowing for the extended use of natural gas against other possible low-carbon alternatives. By 2050, CCS could abate both the remaining electricity production emissions from large power plants (about 50% of the emissions) and industry-related emissions.

Using hydrogen in the power sector is an alternative route to providing seasonal flexibility as well as short-term frequency reserves needed to integrate large shares of variable renewables. Hydrogen can be used to store electricity and then be injected back into the electricity grid through fuel cells or gas turbines. However, energy conversion losses are still high with efficiency around 40%, plus additional losses from the storage itself.

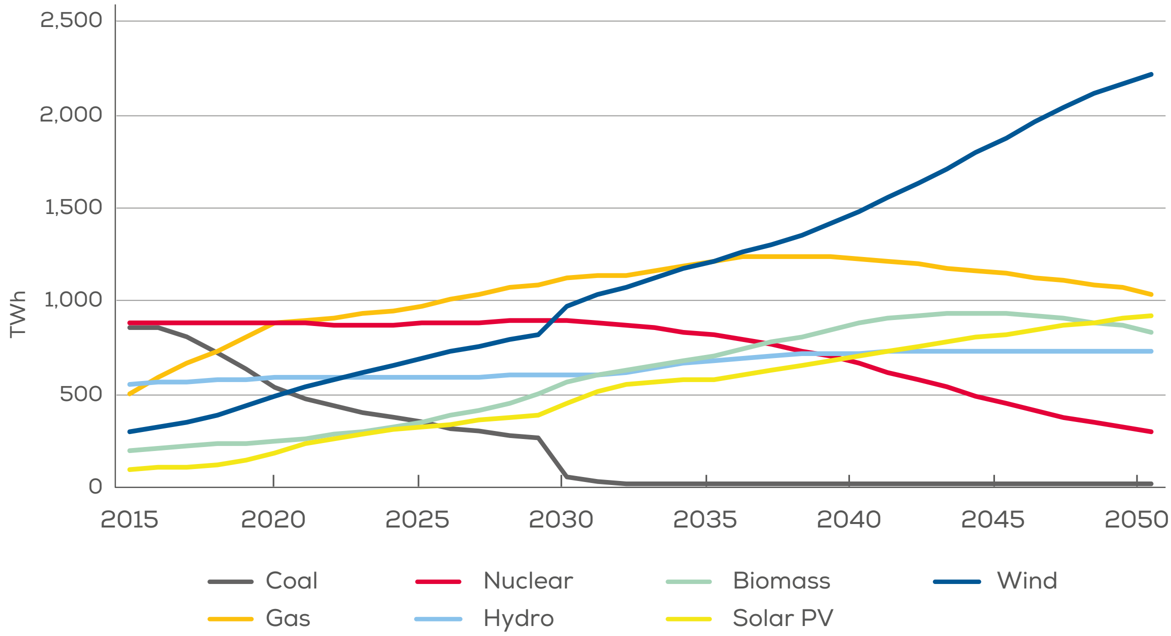
Our analysis show that this route is not cost competitive. Nevertheless, WindEurope believes that there will be favourable conditions in the long term to allow hydrogen use in the power sector as a complementary long-term seasonal storage solution.

Wind energy will become the first source of power generation in Europe by 2035, surpassing gas and taking a strong lead among all other renewable energy sources.

Corresponding costs for wind onshore will decline to €1.3m/MW by 2020 and further down to €1.1m/MW by 2050. For offshore wind, the CAPEX will decline to €2.3m/MW by 2020 and €2m/MW by 2050. The cost decrease is based on a learning rate of 16% for every doubling of capacity.

Assuming conservative capacity factors (see Annex II for more assumptions on wind energy technology) wind power capacity would need to grow four-fold, amounting to 342 GW of wind capacity by 2030 and up to 840 GW of wind capacity by 2050.

FIGURE 23
European power mix - Paris-compatible scenario



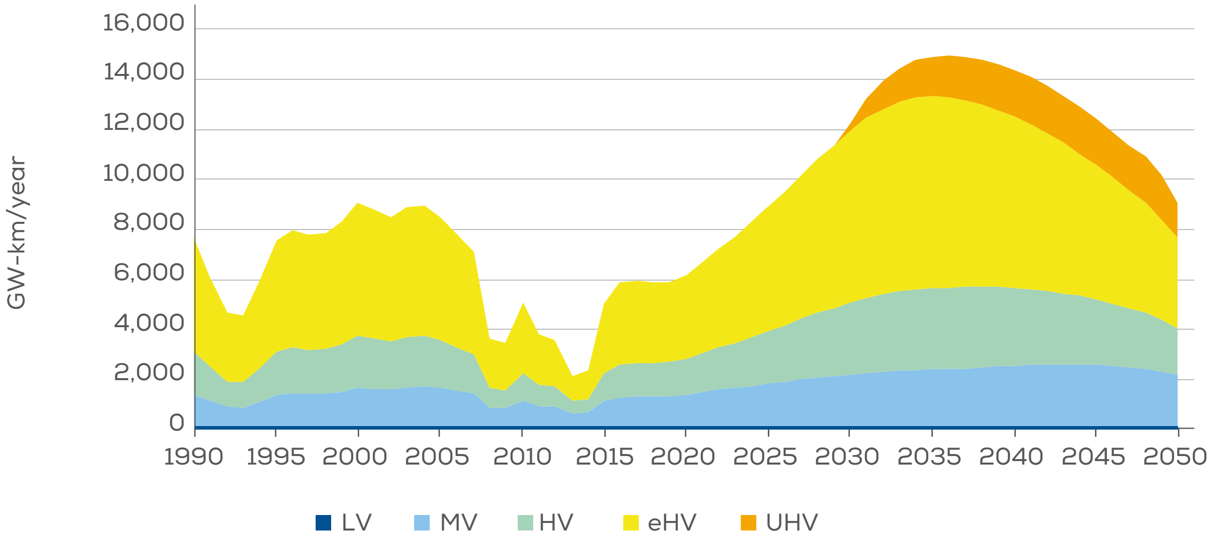
Source: DNV GL for WindEurope

3.1.2 ELECTRICITY GRIDS

Further development of the power grid infrastructure is a 'no regret' option, even in the less ambitious accelerated electrification scenario. Doubling the electricity share in Europe's energy mix would require larger and stronger grids. An estimated average of 12,000 GW-km/year of additional power lines would be needed to 2050. This is in stark contrast to what Europe has been building in the last 10 years, but is comparable to the rate of deployment in the 90s and early 2000s.

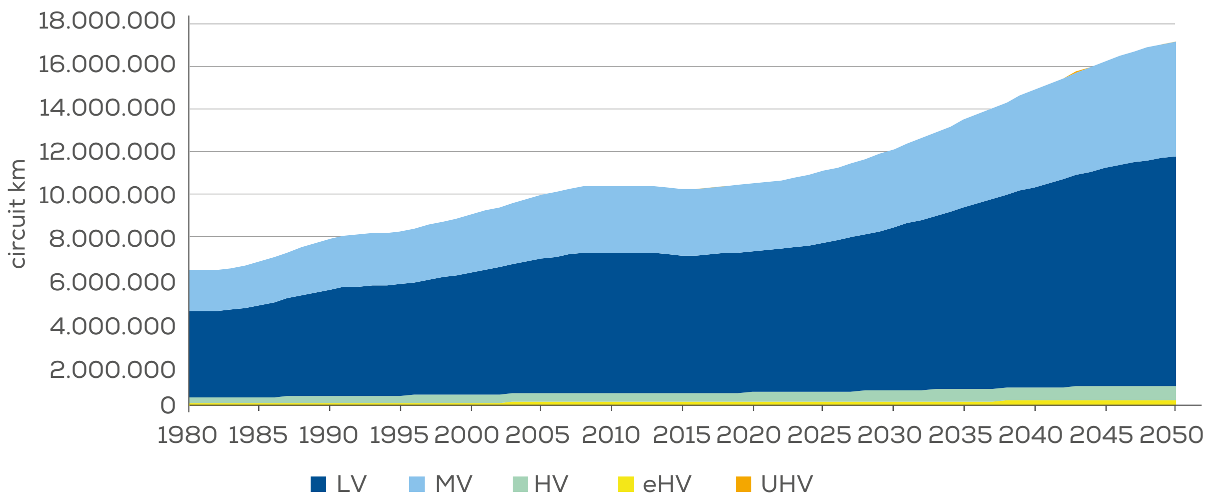
Distributed resources, including renewables, electric charging infrastructure and heat pumps would drive the build-out of low voltage grids around Europe, but the overall need for grid capacity would be driven by the total increase of demand from electrification and the need to optimise system operations at regional level.

FIGURE 24
Grid capacity additions by voltage class



Source: DNV GL for WindEurope

FIGURE 25
Grid length in circuit kilometres by voltage level



Source: DNV GL for WindEurope

3.1.3 CHARGING INFRASTRUCTURE FOR ROAD TRANSPORT

A reliable and comprehensive coverage of charging infrastructure for all vehicles (cars, vans, trucks and buses) is a prerequisite for the transition to a decarbonised road transport sector. It provides certainty for electric vehicle users and potential adopters, as well as for transport operators and authorities willing to deploy electric heavy-duty vehicles.

Public charging (regular power charging in urban areas or high power charging along corridors) represents about 20% of passenger car charging, while the majority of charging is done with private chargers in buildings (at home or at work). Infrastructure development both in public and private points will need to incorporate smart meters and focus on smart charging methods to accommodate the increased needs of flexibility. Public charging points in highways will require focus on fast-charging infrastructure.

Our scenarios also assumes a significant share of fuel cell vehicles (16% of heavy trucks will run on hydrogen) while in the Paris-compatible scenario there is an uptake of light fuel cell vehicles. For these to be attractive, the hydrogen refuelling infrastructure will need to be developed across Europe. When it is not produced on-site through electrolysers, hydrogen will be transported to the refuelling stations. This can be done in gas or liquid form, in trucks or via pipelines, from a nearby hydrogen plant or refinery. Currently, one of the most economical ways to provide hydrogen for fuelling stations is by truck, with hydrogen as a compressed gas. But liquid hydrogen has a relatively higher density so it could be transported for larger distance at moderate prices.

The deployment of a sustainable grid (as mentioned in the previous section) and charging infrastructure should address the challenge of both public and private charging while public funding should aim at providing market certainty, long term stability and sharing the risk of uncertainty of market uptake speed.

3.1.4 SECTOR COUPLING: BRIDGING THE GAS AND POWER GRIDS

Power to gas (P2G) technology converts electrical power into hydrogen using electrolysis. This hydrogen can be used directly and locally as a fuel for transport, for heat in buildings and industry, as a chemical feedstock or converted back to power. Our analysis shows that an increasing fraction of variable renewables would lead to a fast growth of electrolysis-based hydrogen in a near future. However, our analysis has not included electrolysis as a chemical feedstock or its conversion back to power.

Electrolysed hydrogen is generally very dense (because of the associated energy needs for compression and later decompression), which makes its storage and transportation in most cases expensive. However, the hydrogen can also be injected into the natural gas networks and be stored or transported over long distances, enabling its use in any gas application connected to the grid. The percentage of hydrogen that can be injected into these systems is dependent on various factors (such as the nearby applications of gas, the type of network, the minimum annual demand).

Hydrogen can also be blended with sequestered CO_2 in a methanation process, producing synthetic methane (also called synthetic gas or syngas). This synthetic gas has the same characteristics as natural gas and can be used in the same way with the natural gas grids.

P2G is a proven technology that promises to enable a very large share of variable renewables, since it offers an excellent demand flexibility and storage alternative. In areas with high grid congestion and significant curtailment of wind, where the electrical grid expansion is not happening as fast as it should, and where the gas grid infrastructure is available, P2G could become a competitive system solution in the near future. A number of studies have looked into the economics of different business cases for an early update of power-to-hydrogen[29].

The European Power to Gas Platform[30] provides an overview of ongoing demonstration projects, and the European FCH JU[31] is putting considerable resources and efforts into bringing this technology to the next level. Since 2012, there has been a sharp increase in the number of demonstration plants, with Germany leading the way. In the first quarter of 2017, about 70 power-to-gas projects were realised or underway in Europe, all having a strong research or demonstration dimension. The large number of research and application projects helps the new technologies to outgrow laboratory conditions and brings them closer to commercial deployment. BOX 5 shows specific examples in Germany.

29. Early Business cases of Power-to-hydrogen, Tractabel Engie and Hinicio, June 2017
30. http://europeanpowertogas.vps1.clean-fresh.nl/projects-in-europe/
31. A public-private partnership supporting research, technological development and demonstration (RTD) activities in fuel cell and hydrogen energy technologies in Europe.

BOX 5 NEW 4.0 NORTHERN GERMAN ENERGY TRANSITION

The ‘NEW 4.0 – Norddeutsche EnergieWende’ (Northern German Energy Transition) is an interdisciplinary and innovative network of around 60 partners in Hamburg and Schleswig-Holstein, covering the entire value chain in the energy sector to demonstrate the feasibility of the energy transition within 100 individual projects. It is sponsored by the Federal Ministry of Economics and Energy (BMWi) as part of the “Smart Energy Showcases – Digital Agenda for the Energy Transition (SINTEG)”.

The project, with an investment of almost 125 million euros, covers eight topic areas: grids, load management, generation management, information and communications technology, market conditions and regulatory framework, utilisation and acceptance, education and training and holistic system design. Below two examples in the field of Power to gas and wind energy.

BRUNSBÜTTEL: MULTI-MW HYBRID STORAGE PROJECT

Wind to Gas Energy GmbH & Co. KG is connecting an electrolyser and battery accumulator a directly to wind turbines in the surrounding area. With a peak output of 2.5 MW, 450 Nm^3 of hydrogen can be produced per hour. The hydrogen produced is fed into the city‘s gas network, but is also intended to be used by other customers, for example at gas filling stations. The objectives of the project are, on the one hand, providing system services through a multi-MW battery storage facility and, on the other, innovative marketing of wind power in the electricity and gas accounting circuit.

HAURUP H2 PROJECT: GREEN HYDROGEN FROM EXCESS WIND POWER

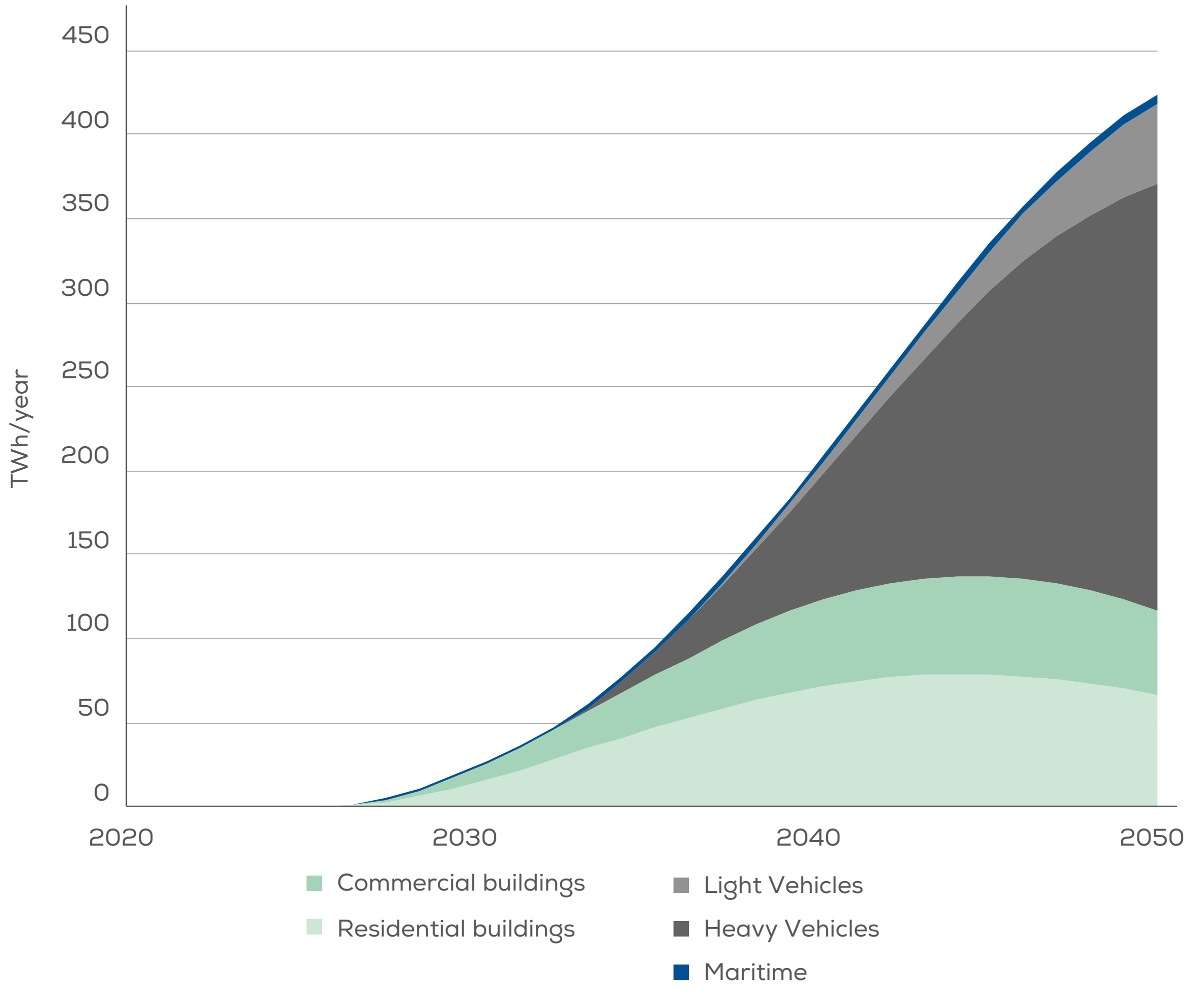
This project consists of constructing an electrolyser (1.25 MW electric, 225 Nm^3/h hydrogen) for combining the electricity, gas, heat and mobility sectors and simultaneously integrating them into the system network. If possible, the plant is to be operated with surplus, renewably produced wind power in order to demonstrate how energy grid shutdowns work can be used purposefully. The plant is to be used for feed-in (admixture) into the existing gas pipeline network, and for constructing and operating a hydrogen filling station.

Figure: Battery storage power plant, Wind to Gas Energy
Photo: Wind to Gas Energy GmbH & Co. KG[32]

32. Source: https://new4-0.erneuerbare-energien-hamburg.de/de/downloads.html?file=files/new40/upload/downloads/2018/04/NEW%204.0%20Broschu%CC%88re%20englisch.pdf

The Paris-compatible scenario foresees the demand for hydrogen (as energy carrier) to reach 426 TWh/year - equivalent to 4.8% of energy demand in 2050 - mainly to heat buildings and as fuel for road transport. However, there is a need for policy measures to make it a reality. P2G is not yet competitive with gas-fired boilers for large-scale heat production in Europe. This is mainly because of differences in commodity prices: gas prices, in the case of conventional boilers, and electricity prices, which are exposed to very high taxes and fix charges. Policy needs to focus on CO_2-price measures and energy tax revision, shifting energy taxes from electricity to gas and oil.

FIGURE 26
Hydrogen demand - Paris-compatible scenario



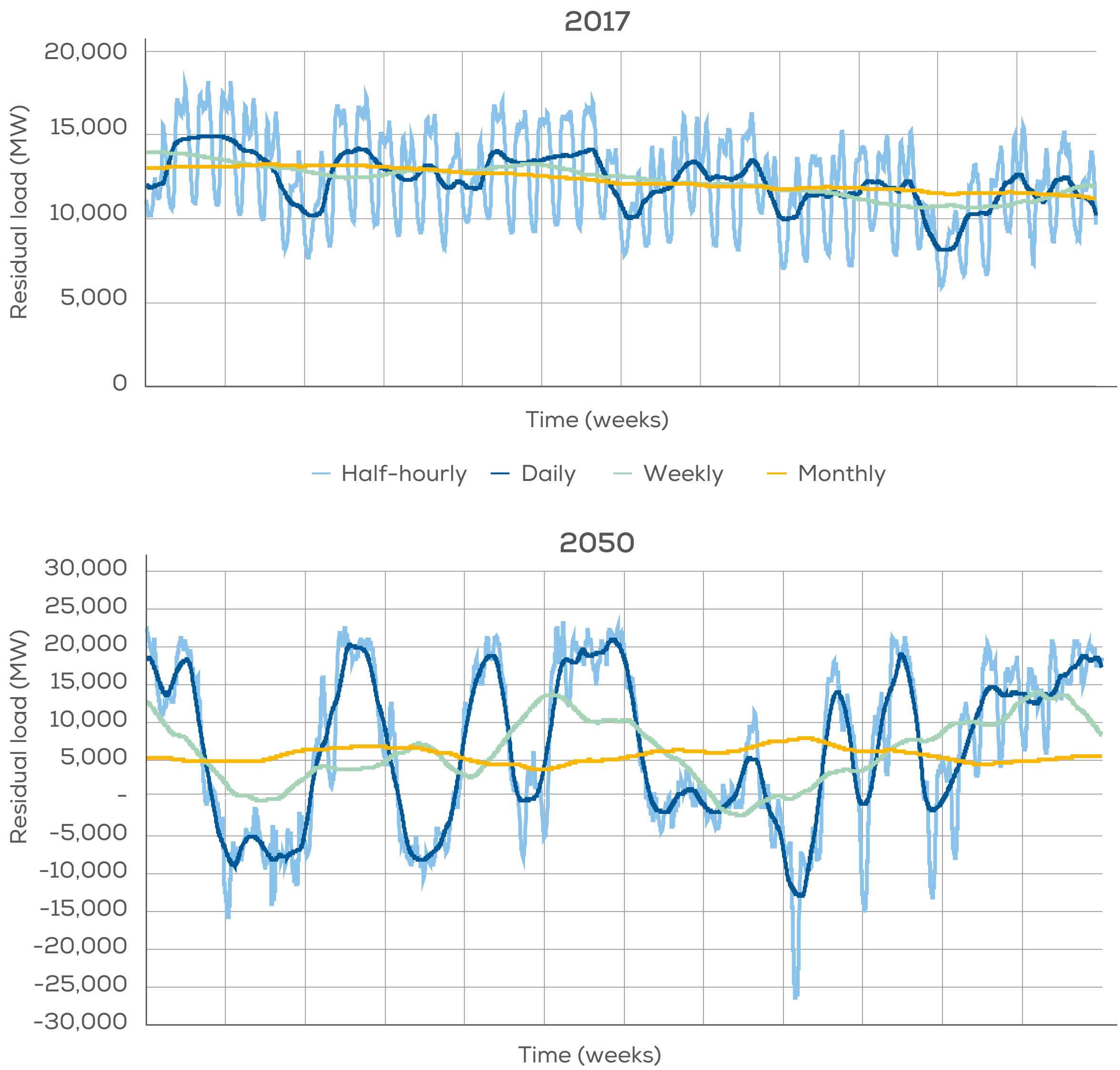
Source: DNV GL for WindEurope

3.2 SYSTEM INTEGRATION

Europe will need a highly flexible energy system to operate the very large shares of wind and solar energy in the Paris-compatible scenario. It can get this flexibility through smart electrification and sector coupling. These will enable the demand response required to match renewables generation with energy demand. In this way, the power capacity needed to provide a reliable system would be optimised, keeping the reserves for balancing to affordable levels. In addition, electrification and sector coupling would help to minimise the curtailment of valuable renewable energy.

FIGURE 27

Residual load over 6 weeks in 2017 and 2050 in the Netherlands



Source: DNV GL for WindEurope

3.2.1 FLEXIBILITY NEEDS

Flexibility is important to manage variability from demand and supply in the power system at different time scales. For example, where solar energy varies with the day and night rhythm, wind energy varies by slowly moving low-pressure areas (at a time scale of multiple days). Furthermore, solar and wind energy show variability on both hourly and shorter time scales (minutes down to sub seconds), due to wind variations, wind gusts and cloud coverage. Hydropower, while being dispatchable in most cases, also presents important seasonal and inter-annual variability. Demand is generally predictable at aggregated scale, but sudden changes need to be addressed too (e.g. half-time break during the final of a major sporting event). This is why flexibility solutions need to cover the whole spectrum, from the sub-second to hourly, monthly and yearly variations.

For example, an analysis done for the Dutch power system by DNV GL assessed the variability of the residual load (this is the demand minus the variable generation) at different time scales during a 6-week period today and the projected variability over the same period in 2050, but with a very high share of wind and solar power of 83%.

The analysis showed that the half-hour variability is very predictable, with peaks and valleys characterised by load patterns between day and night and the peak of solar generation. Despite the fact that the 2017 daily variability has a difference of about 7 GW between the highest and lower demand, the changes are smooth, with peaks and valley spread over several days. Weekly and monthly load changes are very small too. In contrast, in 2050 half-hour variability becomes far less predictable, with significant quick changes that would require fast reserves. Daily residual load would also experience strong changes, with differences over 20 GW within one day, while weekly and monthly load changes are large but relatively smooth.

It would be very difficult to analyse with this level of detail the implications of the Paris-compatible scenario at European level, but further investigations[33] into the Dutch system conclude that, in a system with high amounts of power-to-heat and electric vehicles, wind curtailment will be as low as 1% in 2040 and 9% in 2050. The situation would be almost identical in the German power system.

Flexibility needs can be broadly categorised under three heading challenges with their respective timeframes. For each need, market mechanisms exist. A large pool of resources can be used in each case.

TABLE 1
Flexibility needs by timeframe

Challenge	TIMEFRAME	MARKET MECHANISM
Adequacy	Weeks to months (seasonal)	Capacity mechanisms, strategic reserves
Balancing	Hourly/Daily	Day-ahead market (for predicted variability) Intra-day (to correct forecast error)
Stability	Real time (sub-hourly)	System reserves, balancing markets

Source: WindEurope

33. Using DNV GL's European Market Model (version 2017) in PLEXOS. Note that curtailment refers here to system-wide dynamics, when supply is larger than demand at any given hour, not reflecting the real situation of the local grid, interconnectors use, etc. This is generally referred to as a constraint and might appear much earlier due to the lack of adequate infrastructure and/or local voltage stability problems.

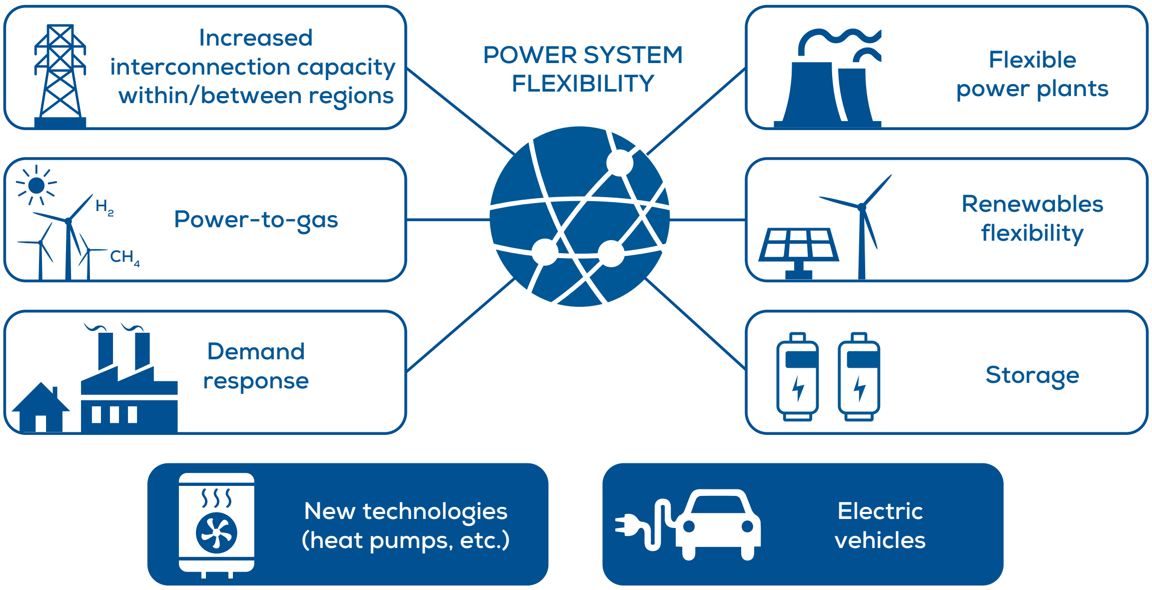
3.2.2 FLEXIBILITY SOURCES

Existing flexibility comes from flexible generation (both conventional and renewable), demand response (both consumption patterns and smart technologies), interconnectors, storage and sector coupling.

While a number of technologies focus on improving the flexibility they can provide, other technologies look at reducing the need for flexibility (for instance, improved forecasting of renewable sources). Flexibility may also come from improved market design, e.g. intraday trading is a clear example of how to adapt the market to the new realities, significantly reducing balancing and reserves costs. Bringing the gate closure time in these markets near to real-time can also reduce the system dependency on balancing reserves. Other examples include the possibility of aggregating generation at larger geographical areas and/or aggregating different technologies when bidding in the market.

The most significant element of system flexibility will come from new electric loads such as heat pumps, electrolysers, smart charging infrastructure and storage solutions.

FIGURE 28
Sources of flexibility



Source: DNV GL for WindEurope

HEAT PUMPS

Heat pumps can help to integrate large shares of wind energy, especially when combined with an electrical resistance heater or a gas boiler at home, or with other heat supply technologies at local level. Such hybrid systems allow for switching from one device to another when the power system is under stress or in the case of price variations. However, the potential of hybrid systems for shift load depends mostly on the heat demand, climate, building type and whether a single heat pump is used rather than a hybrid system (where the heat pump provides the baseload and another source provides the peak load). This may be direct electric heating or storage.

If a building has little mass (like wood-based buildings), load shifting is very limited since shutting off the heat pump leads to a rapid reduction of the indoor temperature and comfort level. A heavy stone or concrete building could perhaps do without heating for half a day.

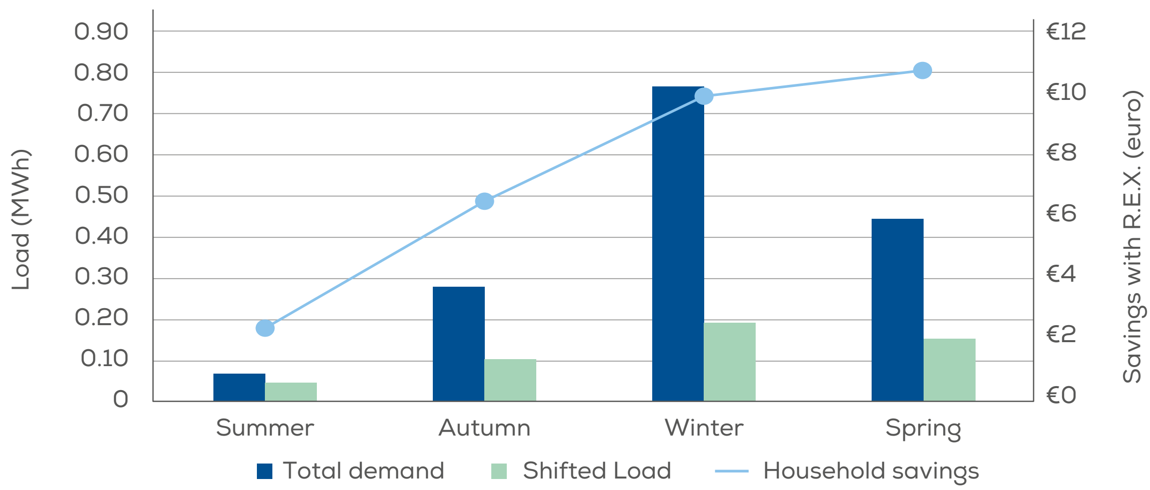
The charts below illustrate the potential load shift depending on the season.

Heat pumps can also be used for the heating of domestic water, for cleaning, cooking, etc. The potential load shift is daily, normally with a large potential to shift load from the peak hours to the off-peak hours.

High temperature heat pumps are mainly used for industrial processes. The potential shift highly depends on the process, but it may be limited since the capacity of the heat pumps is designed for the process and the load is often base load. Here the trade-off will be increasing cost of production and saving on electricity cost. Heat storage may be a good solution to increase the potential shift.

A number of studies have investigated the load shifting potential from heat pumps. For instance, a report[32] recently commissioned by the UK's department for Business, Energy & Industrial Strategy found that heat pumps sized to today's standards could provide significant electric load-shifting potential. While load-shifting potential is negligible in summer, it is significant during the winter and the shoulder seasons. Heat pumps proved capable of providing direct-control positive balancing power at winter peak demand times (i.e. shifting the consumption of the heat pump) and to provide negative balancing power on summer peak supply times (i.e. shifting the consumption of the heat pump to times of oversupply, for example by PV). The report found that load shifting was achievable in both cases and that, even without a buffer tank, air-to-water heat pumps offer a load-shift potential that meets the daily peak demand and could avoid future curtailment of variable renewables.

FIGURE 29
Seasonality of potential load shift[34]



Source: Max van Etten

34. Heat Pumps in Smart Grids, IEA HPT Programme Annex 42, Delta Energy & Environment, 2018

ELECTROLYSERS: POWER-TO-X

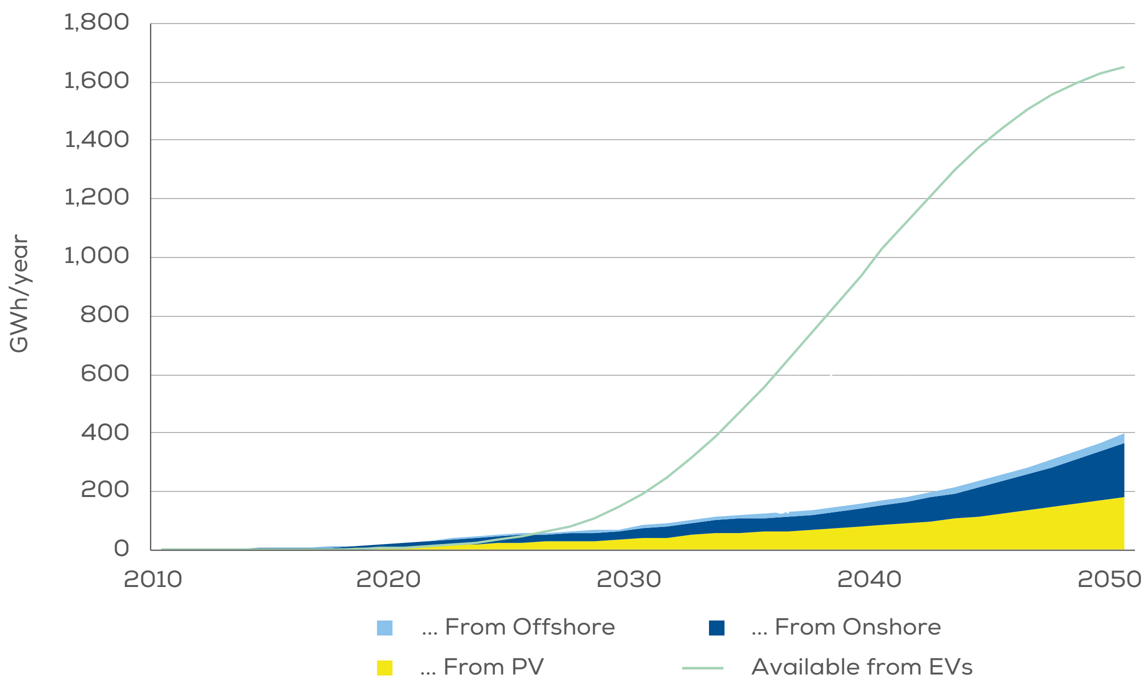
Power-to-gas has a large potential to shift electric load. The electrolyser could serve as large flexible load if the hydrogen produced is used in heating in buildings or industry as a feedstock (replacing fossil fuel-made hydrogen and/or mobility). If the hydrogen is transferred back to electricity (through a fuel cell or a gas turbine), it will also act as an energy storage source. Also, heat produced from power could be stored at very high temperatures and then converted back to electricity (e.g. in a steam turbine).

The common concept of power-to-x is that storage is on the X side, not on the electrical side, and that the electric power input does not need to be constant, but may vary according to requirements from the network or supply/generation side without jeopardising the production process downstream. Power-to-gas (P2G) and Power-to-liquids (P2L) are particularly interesting due to their potential for long-term storage to overcome weekly and even seasonal variability.

ENERGY STORAGE

Balancing a system dominated by variable RES, as foreseen in the Paris-compatible scenario, will require increasing amounts of storage, complemented by the available capacity from fossil-fuelled peaking plants, and a reinforced power grid on all levels and for all voltage classes. The additional battery storage coming from the deployment of EVs would be able to provide more than sufficient storage capacity, even with the conservative assumption that only 10% of the EV fleet's battery storage is made available for the grid. This relies on the deployment of smart charging schemes. This battery storage would be suitable for addressing the challenges of stability and balancing in the hourly/daily timeframe (see Table 1). In order to address the adequacy challenge (providing a buffer for seasonal variability in supply), our analysis relied on a mix of dispatchable hydro power and peaking capacity combined with CCS. But other solutions, such as large storage of gas/liquid (made from Power-to-gas), could be envisaged. Possibly some heat storage could also work for shorter periods.

FIGURE 30
Battery storage capacity available for Electric Vehicles compared to capacity required for managing variable RES - Paris-compatible scenario



Source: DNV GL for WindEurope

3.3 DIGITALISATION

Digital technologies will make power systems around the world more connected, intelligent, efficient, reliable and sustainable. Today, smart grids are already improving the safety, productivity, accessibility and sustainability of power systems, allowing utilities to deliver energy at the right time, in the right place and at the lowest cost. In the next few years, emerging technologies like data analytics, artificial intelligence and mobile- and cloud-based systems will add layers of software and applications to the smart grid. This brings more predictability, scalability, new business models and services to grid operators while also driving change in markets, businesses and employment. As new business models are emerging, others may be on their way out.

Digitalisation will lower costs of monitoring and control of energy generation in general, but it is easier to digitalise new technologies like renewables than old fossil fuel assets. In transmission and distribution networks, digitalisation will help realise efficiency gains and a lower level of losses, for example through remote monitoring of assets, allowing them to be operated closer to their optimal conditions. Finally, digitalisation will also have an impact on energy use, as demand response through variable pricing will enable a better and more effective match between supply and demand of energy.

In the asset-intensive energy value chain, digitalisation will drive improved commitment and maintenance of assets, leading to lower investment levels and more efficient (predictive) asset maintenance.

FIGURE 31
State of play and next steps of digitalisation in the energy industry

	GENERATORS	TRANSMISSION	DISTRIBUTION	UTILITIES	PROSUMERS	TRADING
State of play	Early stage	Advanced	Early stage	Pilot projects	Pilot projects	Early stage
Next steps	Modernising power plants, automating grid controls	Advanced algorithms for optimised operations	Full automation for grid stability optimisation	Fast-acting aggregated demand response	VPP aggregated balancing	Automated platforms using machine learning

Source: Bloomberg

ANNEXES

ANNEX I.

METHODOLOGY

The Energy Transition Outlook (ETO) is the publication wherein DNV GL forecast global energy demand, supply and trade within and between ten regions. Europe is one of them. The forecast is termed as the 'most likely' future (henceforth referred to as baseline), and encompasses DNV GL's best judgement on policy changes, or lack thereof. Energy demand has been in decline in Europe for a decade, and this decline will most likely continue.

ETO depicts the most likely global energy future, and represents shift from the past. While GDP will continue to grow to reach about 230% of the current level by 2050, energy supply will soon depart from a history of following GDP growth.

Only solar PV and wind will grow significantly after Primary Energy Supply has peaked in 2032. While coal has already started its decline, and oil will do so in a few years, natural gas will peak a decade later. The result is that global energy-related carbon emissions will also peak in the next decade.

However, this remarkable departure from history is not enough to ensure a safe and sustainable future, as it implies a stabilisation at around 2.6 degrees, a full degree warmer than the "well below 2 degrees" of the 2015 Paris climate agreement.

Table 2 breaks down these emissions in ten regions. Europe, including EEA and EFTA, will see emissions cut by more than 2/3 to 2050. In addition, carbon emissions from land use change will grow from about 2 ½ Gt/y today to about 3 ½ Gt/y in 2050.

DNV GL sees Europe as the region with the strongest relative decline in emissions of any region. This decline follows an ambitious path, reaching 43% decline by 2030 – in line with current EU discussions of upping the 2030 target above the present 40% ambitions, to reach perhaps 45%. Yet this pales to the stated EU ambition of an "80-95%" reduction (from 1990).

Though under revision to be tightened, current EU climate goals imply an emissions reduction of 40% to 2030, to be achieved by at least 32% renewables in the energy mix. The ETO 2018 implies that these goals will be fulfilled and that a 32% renewable share of the economy will be achieved, using the EU definition. However, this will not be enough to fulfil Europe's commitments under the Paris Agreement. Therefore, DNV GL was tasked to investigate how to achieve the 2050 EU direction of 80-95% decarbonisation of the economy. For this study, WindEurope requested to aim at 90% decarbonisation and provided the policy levers depicted in Figure 3.

The Accelerated scenario is identical to the baseline scenario in the DNV GL Energy Transition Outlook for its EUR (Europe) region, with the exception of updated capacity factors for offshore wind for the 2016-2025 period. This scenario unfolds entirely in line with, and as a continuation of, current ambitious EU climate target setting. Such a scenario is far more benign to the environment, and implies stronger electrification and energy efficiency than commonly termed "central scenarios" by major oil companies and the IEA (DNV GL, 2018).

TABLE A-1

Global Energy-related emissions by region [Gt CO_2/year]

REGION	1990	2000	2010	2020	2030	2040	2050
Greater China	2,4	3,6	8,7	10,6	10,5	6,6	3,5
EUROPE	4,3	4,1	3,9	3,1	2,4	1,7	1,1
Indian subcontinent	0,6	1,1	1,9	3,2	4,1	4,0	3,3
Latin America	0,9	1,2	1,6	1,6	1,5	1,4	1,1
Middle East and North Africa	0,9	1,4	2,3	2,8	3,3	3,2	2,4
North America	5,4	6,4	6,1	5,0	4,2	2,9	2,0
North East Euroasia	3,6	2,2	2,4	2,0	1,6	1,4	1,0
OECD Pacific	1,7	2,0	2,2	2,0	1,5	0,9	0,5
South East Asia	0,4	0,7	1,1	1,7	2,1	1,9	1,3
Sub-Saharan Africa	0,4	0,5	0,7	0,9	1,1	1,2	1,3
TOTAL	**20,6**	**23,3**	**30,9**	**32,8**	**32,2**	**25,4**	**17,5**

Policy levers to input the ETO model

	SCENARIOS	
Policy lever	ACCELERATED ELECTRIFICATION	PARIS-COMPATIBLE
Energy Efficiency and Electrification Uptake:		
Buildings	1.0%/year	1.8%/year
Manufacturing	1.8%/year	2.6%/year
EV fleet of passenger vehicles	90% by 2050	90% fleet, 3.7% vehicles hydrogen-based
CO_2 price in 2050	€45/tCO_2	€90/tCO_2
Coal power	Plants retired as they reach their economic lifetime New plants built out where economically feasible	No new plants built after 2020 No generation after 2030

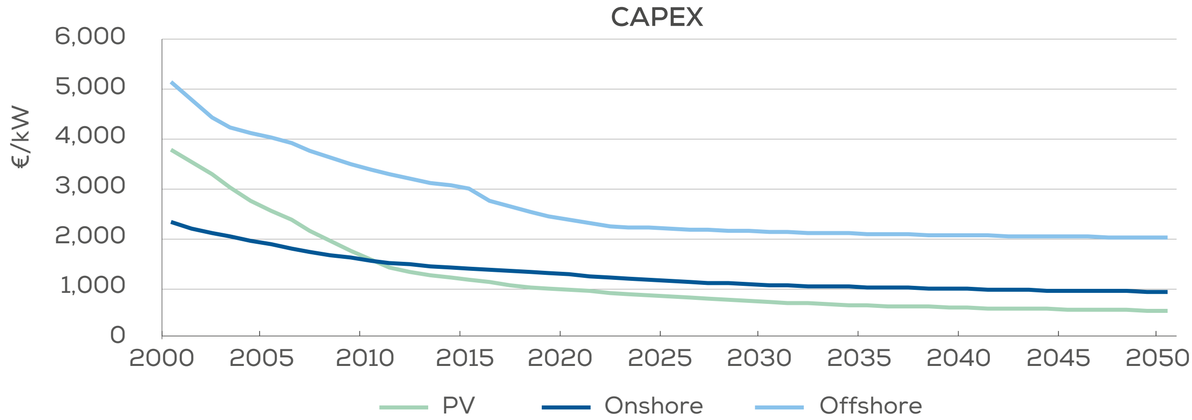
ANNEX II.

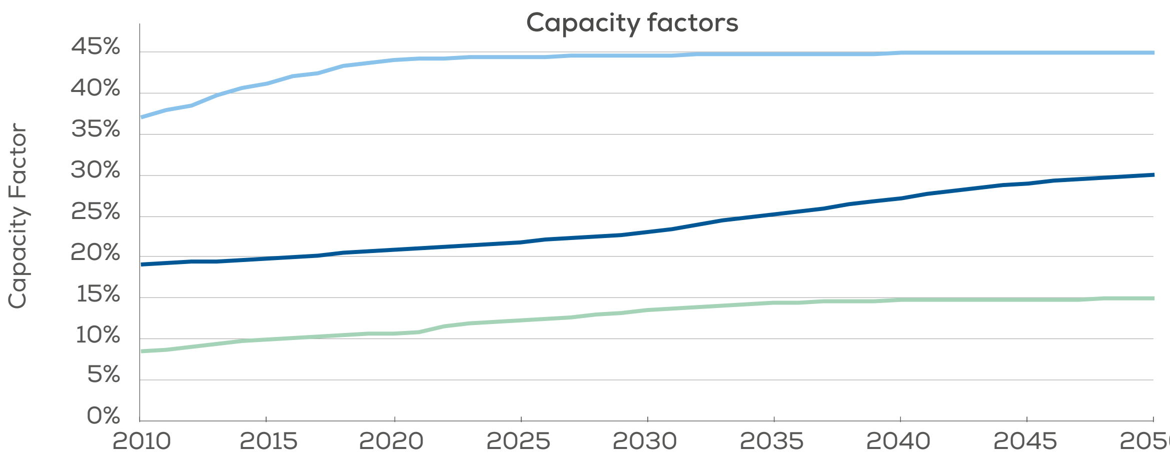
WIND ENERGY TECHNOLOGY ASSUMPTIONS

Corresponding costs for onshore wind will decline to 1300 Eur/kWp by 2020, and to 1100 by 2050. Corresponding costs for offshore wind will decline to 2,300 by 2020 and 2,000 Eur/kWp by 2050. The cost decrease is based on a learning rate of 16% for every doubling of capacity, while PV declines with an 18% rate.

While we are aware of lower CAPEX already achieved in ongoing auctioning processes, these are average figures, and each installation will have lower or higher costs than these. We have chosen conservative values. The CAPEX also depend on turbine design. In low-wind resource sites, a developer might choose to develop higher turbines with larger rotors and relatively lower power ratings. These turbines are characterised by higher CAPEX, but they also improve the capacity factor, reducing the penalty of poorer resources. The model, however, uses a single CAPEX per technology and average capacity factors. Capacity factors can vary significantly, due to climate change, local climate, and technology factors. On average, the model assumes that onshore capacity factors will plateau at 0.32 for onshore and 0.45 for offshore installations within the next decades[35].

FIGURE A-1
CAPEX and capacity factors for wind energy technologies





Source: DNV GL for WindEurope

35. WindEurope is currently working on getting a better understanding of the evolution of capacity factors and how these affect LCOE and total system costs

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.

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