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The Quest to Decarbonize Europe

2020 Strategies towards 2050

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REI – Renewable Energy Institute

Renewable Energy Institute is a non-profit organization which aims to build a sustainable, rich society based on renewable energy. It was established in August 2011, in the aftermath of the Fukushima Daiichi Nuclear Power Plant accident, by its founder Mr. Masayoshi Son, Chairman & CEO of SoftBank Corp., with his own private resources. The Institute is engaged in activities such as; research-based analyses on renewable energy, policy recommendations, building a platform for discussions among stakeholders, and facilitating knowledge exchange and joint action with international and domestic partners.

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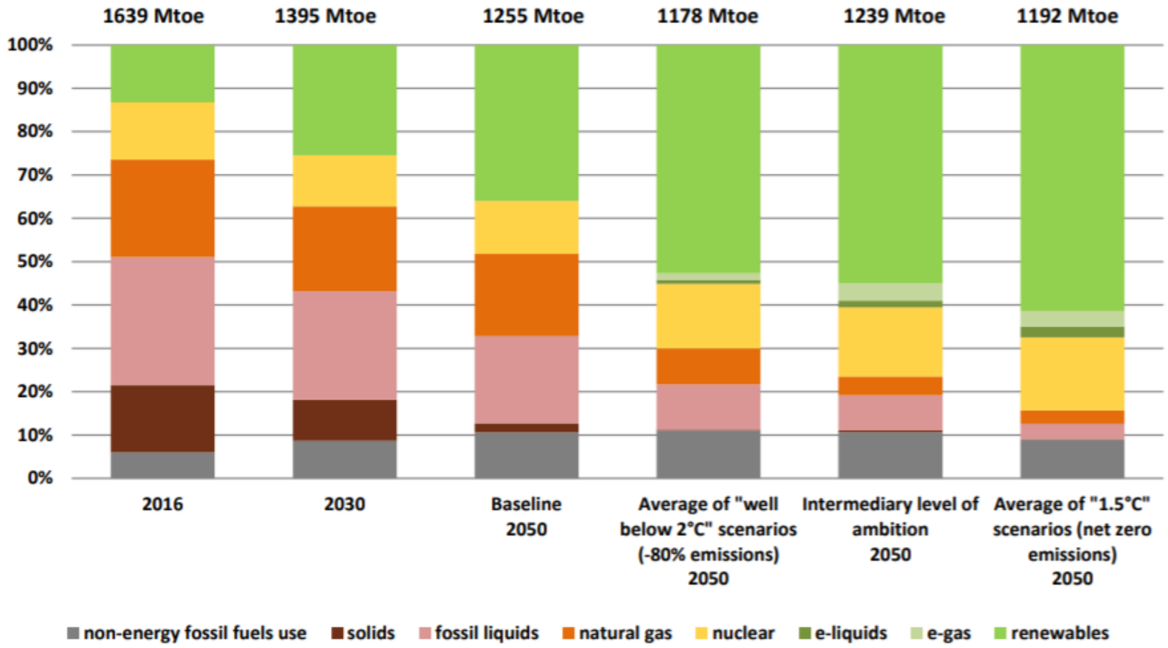
Executive Summary

Europe and its five largest economies: France, Germany, Italy, Spain, and the United Kingdom are now all aiming for carbon neutrality by 2050. A common, ambitious and necessary objective.

At the European Union level, to achieve this goal, the European Green Deal has been launched in December 2019. It is the European Union's main instrument to realize its "strategic long-term vision for a prosperous, modern, competitive and climate neutral economy" advanced in November 2018. This vision, up to 2050, identifies energy efficiency and renewable energy, particularly in the power sector, as the two key pillars of decarbonization. In addition, to the decarbonization of the power sector, the electrification of the heating & cooling and transport sectors will be significant.

EU Energy Consumption Fuel Mix



Source: European Commission.

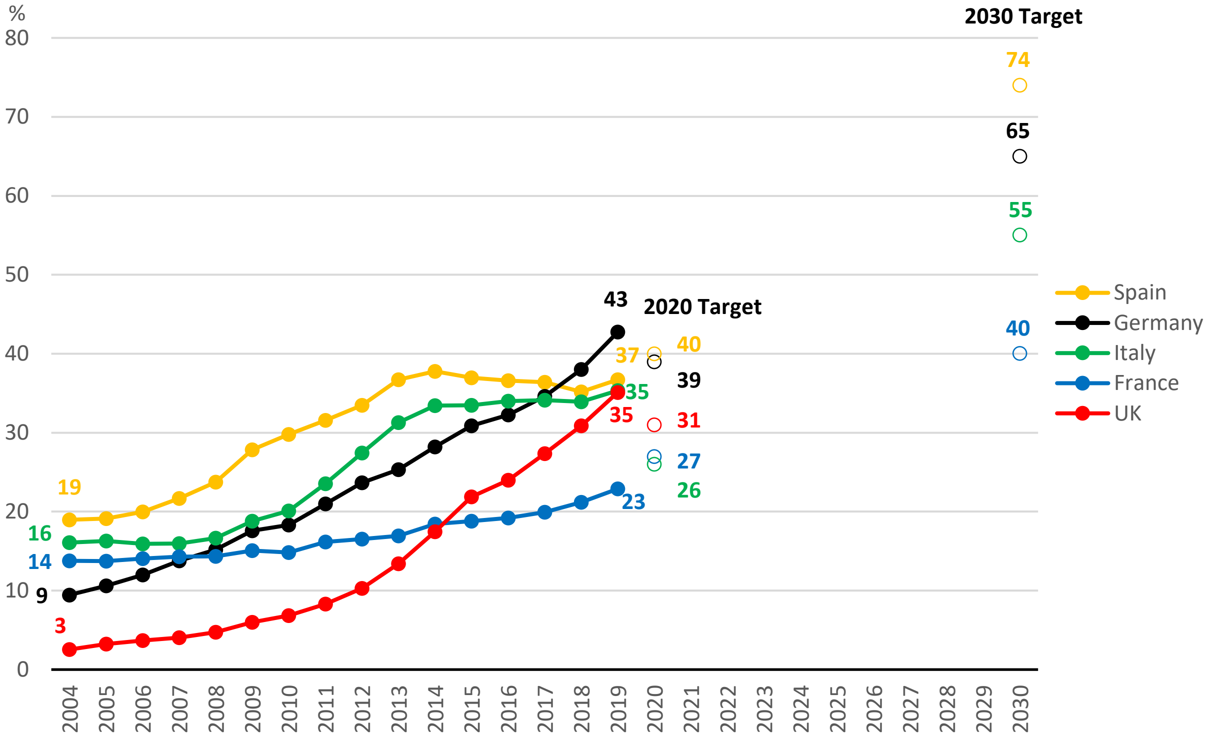
In the European decarbonization strategies, intermediate objectives are set to pave the way towards the final goal. In this regard, by 2030, the European Union targets a minimum 40% reduction in greenhouse gas emissions (compared to 1990) – which could soon be increased to 60% as currently being negotiated, a 32% share of renewable energy in total energy consumption (including electricity, heating & cooling, and transport), and a 32.5% improvement in energy efficiency.

Latest achievements towards the initial 2020 targets – upon which the 2030 targets have been built – have been rather remarkable. For instance, the greenhouse gas emissions reduction target of 2020 was already exceeded in 2018; against a decrease of 20% sought, a decrease of 23% had been achieved. This is notably thanks to renewable energy which share in electricity reached 32%.

Moreover, the European Union is determined to ensure that the COVID-19 pandemic will not slow down progress towards decarbonization. Green recovery plans presented until now; especially the adoption of a huge stimulus package of almost €2 trillion (out of which 30% is earmarked for climate protection projects and all spending must contribute to the EU emissions-cutting goals) through the EU budget for 2021-2027 and the COVID-19 recovery fund, show this resoluteness.

At the country level, similar approaches have been adopted by Europe's five largest economies with intermediate targets for greenhouse gas emissions reduction, renewable energy expansion and decrease in energy consumption. Based on these plans, it is clear that decarbonization is to take place through renewable energy electricity – mainly cost competitive solar and wind power – and that there is no place at all for coal power, which will be phased out in all the countries studied – as soon as 2022 in France, at the latest by 2038 in Germany.

Europe's Five Largest Economies RE Electricity Expansion 2004-2019 and 2020 & 2030 Targets



Note: No 2030 target for the UK.

Sources: Eurostat, International Energy Agency, and European Commission.

In the heating & cooling sector, alongside continued reliance on bioenergy, the significant deployment of heat pumps is expected to play a key role in renewable energy contribution to decarbonization by replacing the existing facilities using fossil fuels. Green hydrogen, based on renewable energy electricity, will increasingly be used in the industry (e.g. steel, chemicals). In the transport sector, thanks to costs reductions in batteries, road electrification for light passenger light-duty vehicles is forecasted to be decisive. Advanced biofuels and green hydrogen are projected to help decarbonization in other transport means (i.e. heavy road transport, trains, ships and airplanes).

Finally, from a technological perspective, three options are emerging as decarbonization enablers: offshore wind, road transport electrification, and green hydrogen. The United Kingdom is leading offshore wind developments with a remarkable track record; already 10 GW of installed capacity in 2019 – accounting for nearly 10% of the country's electricity, and aggressive objectives; 40 GW to be installed by 2030 to account for one-third of its electricity. Road electrification, essentially for passenger light-duty vehicles, is ongoing with dramatic costs reductions in batteries and support policies (e.g. purchase subsidies and/or tax reductions). And thanks to ever cheaper renewable energy and costs reductions in electrolyzers, green hydrogen is starting to take off, which will be critical for hard to decarbonize activities in the industry (e.g. steel or chemicals) and transport sectors (other than passenger light-duty vehicles). Green hydrogen is the less mature of these thee enablers and requires more policy support. France and Germany both recently advanced inspiring strategies in this direction.

Though it is too early to assess the successfulness of these comprehensive and progressive plans, they can definitely serve as examples to learn from for countries like Japan which are lagging behind both in terms of achievements and vision.

Introduction

Europe and its five largest economies: France, Germany, Italy, Spain, and United Kingdom, have all recently announced their ambitions to achieve carbon neutrality by 2050.

These new commitments are built upon continuous climate change mitigation actions implemented over the past few decades – which have already resulted in significant progresses, particularly in the power sector where the share of renewable energy reached 32% in the European Union in 2018.

The long-term shared objective of carbon neutrality is pursued to deliver additional economic, environmental, and social benefits. It is widely supported by societies who not only recognize the inevitable necessity to adopt sustainable lifestyles, but also the advantages coming with it (e.g. better air quality, new economic opportunities…). Reaching carbon neutrality will, however, be the realization of important efforts and deep transformations in all sectors of the economy.

For instance, the energy supply industries (essentially the public electricity and heat production) and transport sectors which together account for about half of total greenhouse gas emissions of the European Union need to reinvent themselves.

Confronted to economic difficulties due to their initially slow adaptation to this new reality, Europe's biggest power companies, EDF, Enel, ENGIE, and RWE are changing by embracing renewable energy as demonstrated by the additions of gigawatts of wind and solar projects to their generating portfolios in the past few years.

In the automotive industry, this shift of paradigm consists in leaving the internal combustion engine behind. Some European countries have already announced or are looking to establish zero-emission zones or bans on internal combustion engine vehicles. In response, car manufacturers are moving forward with electrification which is increasingly affordable as the costs of batteries decrease. Electric vehicles sales are now growing fast; for instance, the stocks of electric cars increased by more than 300% in France, Germany, and the United Kingdom in the past five years, to reach about 230-260 thousand in each of these three countries in 2019.

It is not always perfectly clear yet how carbon neutrality will be completely accomplished. Nevertheless, plans laid out for the coming decades and past and current developments certainly highlight the key roles of renewable energy, energy efficiency, electrification, and energy storage. In this future, coal power is condemned to extinction, the weight of nuclear power is often reduced, and solutions to replace fossil fuels in the heating & cooling and transport sectors are advanced.

This report aims at constructively presenting Europe and its five main countries' decarbonization respective strategies towards carbon neutrality by mid-century and achievements since 1990.

Learning from these leading economies' inspiring successes and challenges should effectively contribute to dynamic discussions in Japan where progresses are also ongoing, but at a slower pace.

CHAPTER 1: EUROPE GOING CARBON NEUTRAL BY 2050

The European Union (EU) and the United Kingdom (UK) are targeting carbon neutrality by 2050. This means having a balance between emitting carbon and absorbing carbon from the atmosphere in carbon sinks. The latter are designated systems by humans on which activities are carried and which absorb more carbon than they emit as for examples, soil, forests, and oceans. An example of carbon sink optimization is increasing the forest area through reforestation or afforestation of non-forest land.

To reach this ambitious and necessary common objective, both the EU and the UK have advanced mid-century visions and set intermediate goals. This chapter focuses on the EU only, the UK's plans and progresses are described in CHAPTER 2 which focuses on Europe's largest economies' decarbonization strategies, including France, Germany, Italy, and Spain in addition to the UK.

Map 3: Europe Including the EU Member States and Other Countries

Source: Maproom, Map of EU Countries after Brexit (accessed August 13, 2020).

I Long-term Vision (2050)

Building upon years of decarbonization progresses, the European Commission unveiled its landmark European Green Deal in December 2019. The European Green Deal is the EU roadmap to prepare its economy for climate neutrality by 2050. It provides an action plan to boost the efficient use of resources by moving to a clean, circular economy, and restore biodiversity and cut pollution. It outlines investments needed and financing tools available, and explains how to ensure a just and inclusive transition (Chart 1).

Chart 1: Overview of the Actions of the European Green Deal

- Increasing the EU climate ambition for 2030 and 2050.
- Supplying clean, affordable and secure energy.
- Mobilizing industry for a clean and circular economy.
- Building and renovating in an energy and resource efficient way.
- A zero-pollution ambition for a toxic-free environment.
- Preserving and restoring ecosystems and biodiversity.
- From "Farm to Fork:" a fair, healthy and environmentally friendly food system.
- Accelerating the shift to sustainable and smart mobility.

Source: European Commission, The European Green Deal (December 2019).

More concretely, the European Green Deal is a proposal force to shape the EU energy and climate policy making. The EU legislation is to be transposed into Member States' legislations triggering the adoption of appropriate national policies.

The European Green Deal is dynamically engaged in all strategic dimensions of the decarbonization: economic, environmental, political, social, and technological.

In this framework, among its key actions so far have been: in January 2020, the presentation of the European Green Deal Investment Plan and the Just Transition Mechanism. In March 2020, the proposal of a European Climate Law. And in July 2020, the adoption of the EU strategies for energy system integration and hydrogen.[1]

The European Green Deal Investment Plan is the investment pillar of the Green Deal. It will mobilize at least €1 trillion (half of which will be financed through the EU budget) in sustainable investments over the coming decade. Part of the plan, the Just Transition Mechanism, will be targeted to a fair and just green transition. This mechanism will mobilize at least €100 billion over the period 2021-2027 to support workers and citizens of the regions most impacted by the energy transition.[2]

The European Climate Law proposal is to turn the political commitment of carbon neutrality by 2050 into a legal obligation and a trigger for investment. It also provides for the conditions to set out a trajectory leading to climate neutrality, regular assessment of progress, and mechanisms in case of insufficient progress or inconsistencies with the climate neutrality objective.[3]

The EU strategies for energy system integration and hydrogen pursue on the one hand an energy system that is planned and operated as a whole, linking different energy carriers, infrastructures, and consumption sectors, on the other hand the development of hydrogen. These are complementary because the former prioritizes electrification and the latter hydrogen which can energize sectors that are not suitable for electrification and provide storage to balance RE power flows.[4] Road electrification and green hydrogen are described in CHAPTER 3 which focuses on key technological enablers.

Moreover, the adoption in June 2020 of the taxonomy regulation – a key piece of regulation that will help create the world's first-ever "green list" (a classification system for sustainable economic activities) – will contribute to the European Green Deal. This regulation is a tool to help investors from all types of institutions (e.g. policy and business decision-makers) to understand whether investments are meeting robust environmental standards and are consistent with policy commitments related to climate change mitigation. It should thus boost investment in green and sustainable projects.[5]

The taxonomy regulation provides an exhaustive list of sectors and activities currently considered as making substantial environmental contributions to climate change mitigation. The inclusion or not of nuclear energy as a sustainable economy activity remains unresolved for now because of the potential environmental impacts of nuclear waste (Table 1).[6]

Table 1: List of All Sustainable Economic Activities under the EU Taxonomy Regulation

Sector	Activity
Agriculture and forestry	(1) Afforestation, (2) rehabilitation, (3) reforestation, (4) existing forest management, (5) conservation forest, (6) growing of perennial and non-perennial crops, and (7) livestock production
Buildings	(1) Construction of new buildings, (2) building renovation, (3) individual renovation measures, (4) installation of renewables on-site, (5) professional, scientific and technical activities, and (6) acquisition and ownership of buildings
Electricity, gas, steam and air conditioning supply	(1) Production of electricity from RE (bioenergy, geothermal, hydro, ocean, solar, and wind) and gas, (2) transmission and distribution of electricity, (3) storage of electricity, (4) storage of thermal energy, (5) storage of hydrogen, (6) manufacture of biogas or biofuels, (7) retrofit of gas transmission and distribution networks, (8) district heating & cooling distribution, (9) installation and operation of electric heat pumps, (10) cogeneration of heating & cooling and power from RE (bioenergy, concentrated solar power, and geothermal) and gas, and (11) production of heating & cooling from RE (bioenergy, concentrated solar power, and geothermal), gas, and using waste heat
Information and communication technologies	(1) Data processing, hosting and related activities, and (2) data-driven climate change monitoring solutions
Manufacturing	(1) Manufacture of low carbon technologies, (2) cement, (3) aluminum, (4) iron and steel, (5) hydrogen, (6) other inorganic basic chemicals (carbon black, disodium carbonate, and chlorine), (7) other organic basic chemicals, fertilizers and nitrogen compounds, and (8) plastics in primary form
Transport	(1) Passenger rail transport, (2) freight rail transport, (3) public transport, (4) infrastructure for low carbon transport (land and water), (5) passenger cars and commercial vehicles, (6) freight transport services by road, (7) interurban scheduled road transport, (8) inland passenger water transport, and (9) inland freight water transport
Water, waste and sewerage remediation	(1) Water collection, treatment and supply, (2) centralized waste-water treatment, (3) anaerobic digestion of sewage sludge and bio-waste, (4) separate collection and transport of non-hazardous waste in source segregated fractions, (5) composting of bio-waste, (6) material recovery from non-hazardous waste, (7) landfill gas capture and utilization, (8) direct air capture of CO2, (9) capture of anthropogenic emissions, (10) transport of CO2, and (11) permanent sequestration of captured CO2

Notes: In the cases of "Manufacturing" and "Transport," though the document of reference does not specify "low carbon" for the manufacture of (2) to (5) and the different transportation means, it is understood that to be sustainable these economic activities need to be low carbon. The threshold for energy generation from gaseous or liquid fossil fuels is set at below 100 grams of carbon dioxide per kilowatt-hour, requiring the use of carbon capture and storage technologies.

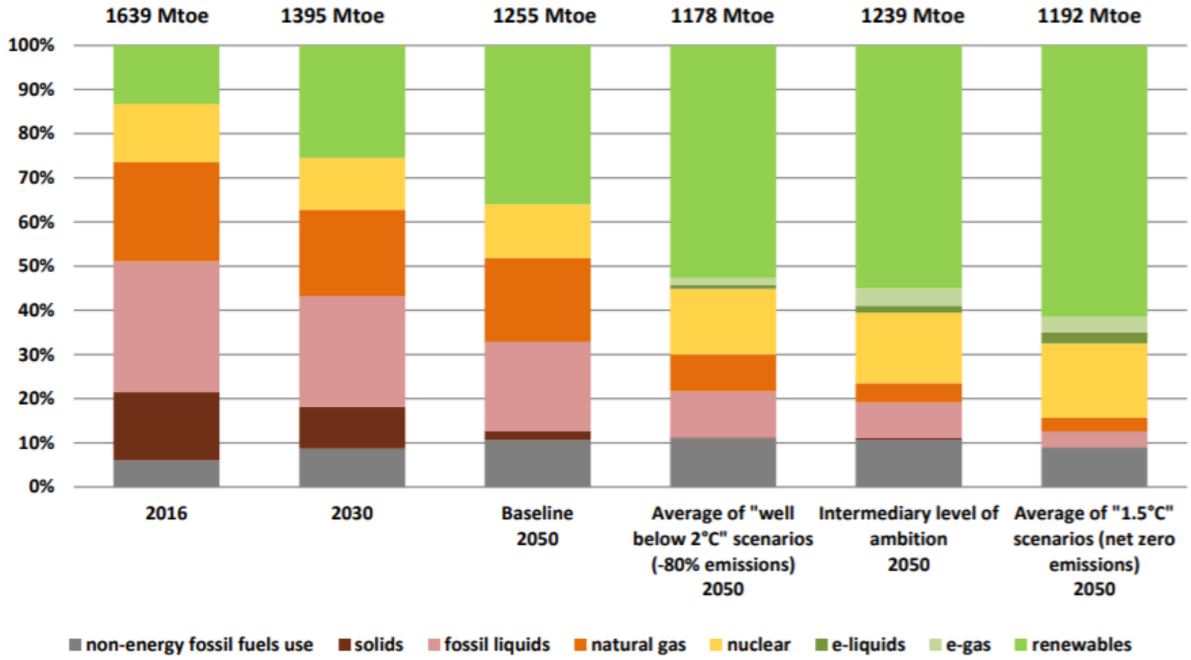
Source: European Union Technical Expert Group on Sustainable Finance, Taxonomy: Final Report of the Technical Expert Group on Sustainable Finance (March 2020).

The European Green Deal is currently the main instrument to realize EU “strategic long-term vision for a prosperous, modern, competitive and climate neutral economy.” In this 2050 vision, advanced in November 2018, energy efficiency and renewable energy (RE), particularly in the power sector, will be the two key pillars of Europe’s decarbonization. In addition to the decarbonization of the power sector, the electrification of the heating & cooling and transport sectors will be significant.[7]

For instance, thanks to energy efficiency measures, the EU projects to reduce its 2050 energy consumption by as much as half compared to 2005. It is envisioned that much of the reduced energy demand will occur in buildings, in both the residential and services sectors. Given that most of the housing stock of 2050 exists already today, this will require higher renovation rates, fuel switching with a large majority of homes that will be using RE heating (electricity, district heating, renewable gas or solar thermal), diffusion of the most efficient products and appliances (e.g. LED lights and other electrical devices…), smart building/appliances management systems (e.g. smart meters, smart thermostats…), and improved materials for insulation.

As for RE in decarbonization scenarios, it is forecasted to account for more than half of the EU total energy consumption in 2050, a tripling from the current level (Chart 2). It may also be noted that the share of nuclear may remain stable or slightly increase; 14-17%. This is not the result of an expansion of nuclear, which consumption is projected to either decrease or remain stable despite/thanks to permanent shutdowns, lifetime extensions, and new-builds (little specific details on these various issues are provided), but of a significant reduction in total energy consumption.

Chart 2: EU Energy Consumption Fuel Mix 2016-2050

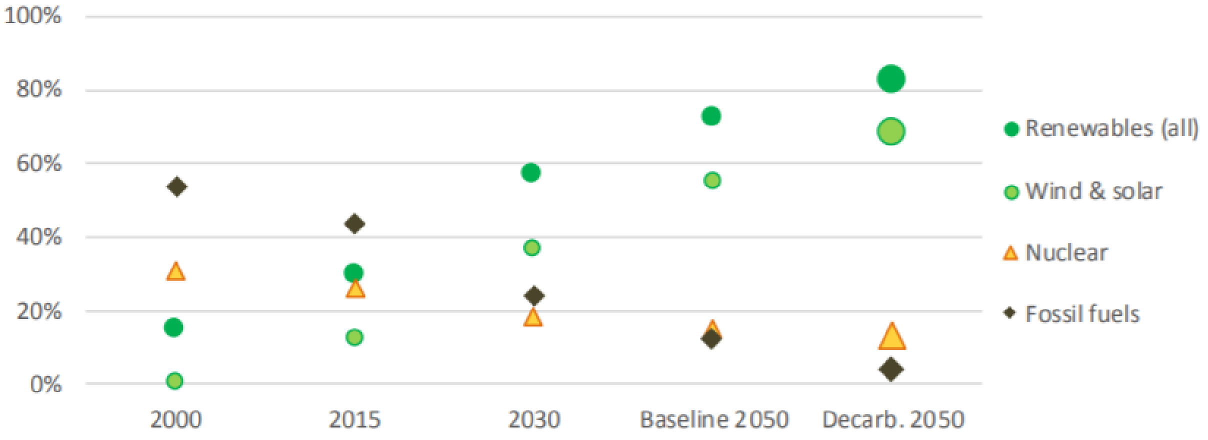


Source: European Commission, A Clean Planet for All: A European Strategic Long-term Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy (November 2018).

In the power sector only, in the 2050 decarbonization scenarios, the share of RE is estimated at 81-85%, against a current level of above 30% (Chart 3 on next page). The combined shares of wind and solar power will be 65-72%, up from about 15%. And the shares of nuclear and fossil fuels will be 12-15% – down from 25%, and 2-6% – down from around 40%, respectively. Contrarily to its share in total energy consumption, the share of nuclear in electricity decreases because while nuclear consumption either decreases or remains stable, as aforementioned, electricity consumption in total energy consumption significantly increases (see below). The very small share of fossil electricity underlines the fact that carbon capture and storage (CCS) technologies will almost not contribute in decarbonizing the power sector.

This new electricity generation mix would reduce the carbon intensity of power generation to nearly 0 gram of carbon dioxide per kilowatt-hour (gCO2/kWh) in the EU, against about 270 gCO2/kWh in 2019.[8] In comparison, the CO2 intensity of power in Japan was a little below 500 gCO2/kWh in 2019 or 80% higher than that of the EU.[9]

Chart 3: EU Electricity Generation Mix 2000-2050



Note: The “Decarb. 2050” points are the averages across all the decarbonization scenarios.
Source: European Commission, [A Clean Planet for All: A European Long-term Strategic Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy: In-Depth Analysis](#) (November 2018).

In this framework to support the expansion of RE electricity, the European Commission presented the EU strategy on offshore RE in November 2020. This strategy proposes to increase Europe’s offshore wind capacity from its current level of 12 GW to at least 60 GW by 2030 and to 300 GW by 2050. It also aims for 40 GW of ocean energy and other emerging technologies such as floating wind and solar by 2050. To realize this massive scale-up, long-term strategies from Member States, will need to include planning for new sites, public acceptance, stakeholder engagement, cross-border coordinated grid planning, and a ramp-up in the value chain. Among the European Commission’s key actions to support Member States’ efforts to significantly expand offshore wind are: the development of a framework for the Member States to formulate a joint long-term commitment for the deployment of offshore RE per sea basin up to 2050, and the publication of guidance on how to coordinate the sharing of costs and benefits across borders for electricity transmission projects combined with the development of electricity generation projects.[10]

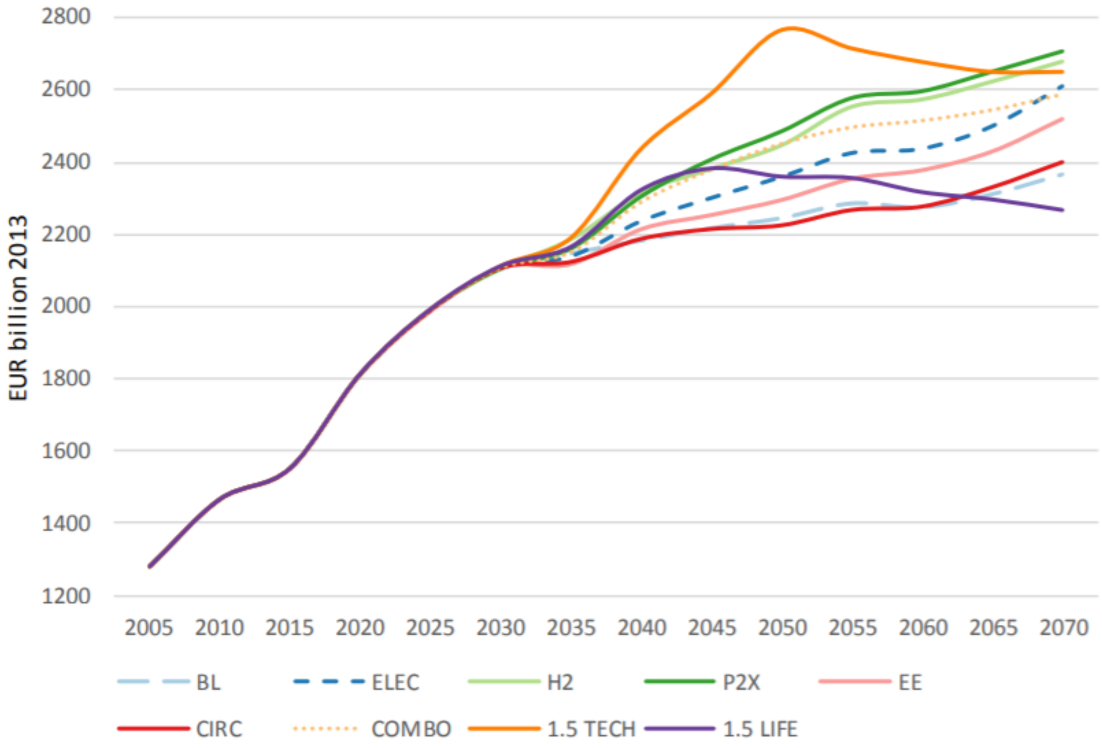
In addition, by 2050, the share of electricity in final energy demand will at least double, reaching more than 50% – compared to less than 25% in 2018 (while the share of fossil fuels, excluding electricity and heat, was over 60%).[11] Large-scale electrification is supported by cost competitive solar and on- & off-shore wind power. The deployment of RE electricity provides a major opportunity for the decarbonization of the heating & cooling and transport sectors, either through direct use of electricity, or indirectly through the production of electricity-based fuels (e-liquids and e-gas) through electrolysis (e.g. hydrogen) when direct use of electricity or sustainable bioenergy is not possible.

This future will require a smarter and flexible system, based on consumers' involvement, increased interconnectivity, improved energy storage deployed on a large-scale, demand side response, and management through digitalization.

Achieving it will require substantial investments €520-575 billion annually. It will, however, reduce pre-mature deaths caused by fine particulate matter by more than 40% and health damage by around €200 billion per annum. It will also reduce the risks of weather-related disasters and their costs. For example, annual damages due to river floods in Europe could reach €112 billion, from the current €5 billion. Finally, it will positively impact the EU trade and geopolitical position as it will result in a sharp reduction of fossil fuel import expenditures (currently €266 billion). The cumulative savings from a reduced import bill will amount to €2-3 trillion over the period 2031-2050.

Regarding the EU total energy system costs more specifically, between today and 2070 these will increase in all scenarios regardless of decarbonization efforts (Chart 4). This is especially because of an increase in capital costs (for energy installations such as power plants and energy infrastructure, energy using equipment, appliances and vehicles) on the one hand to modernize the EU energy system, on the other hand to decarbonize it (in the case of decarbonization scenarios).

Chart 4: EU Total Energy System Costs 2005-2070



Note: The nine scenarios above consist of one business as usual scenario ("BL" standing for "Baseline" and reflecting the current EU decarbonization trajectory) and eight decarbonization scenarios, out of which; five target an 80% greenhouse gas emissions reduction by 2050 compared to 1990 – excluding natural carbon sinks ("ELEC" standing for "Electrification" and focusing on electrification in all sectors, "H2" standing for "Hydrogen" and using hydrogen in industry, transport, and buildings, "P2X" standing for "Power-to-X" and using electricity based fuels in industry, transport, and buildings – compared to the "H2" scenario, hydrogen is mainly used as an intermediate feedstock for the production of other electricity based fuels, "EE" standing for "Energy Efficiency" and pursuing deep energy efficiency in all sectors, and "CIRC" standing for "Circular Economy" and focusing on increased resource and material efficiency), one targets a 90% greenhouse gas emissions reduction by 2050 compared to 1990 – including natural carbon sinks ("COMBO" standing for "Combination" and cost-efficiently combining the 80% greenhouse gas emissions reduction scenarios), and two target carbon neutrality ("1.5 TECH" standing for "1.5°C Technical" based on the "COMBO" scenario with more carbon capture and storage, and "1.5 LIFE" standing for "1.5°C Sustainable Lifestyles" based on the "COMBO" and "CIRC" scenarios with lifestyle changes).
Source: European Commission, A Clean Planet for All: A European Long-term Strategic Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy: In-Depth Analysis (November 2018).

The projected trajectories of the EU total energy systems costs will, however, differ depending on decarbonization efforts pursued as well as the technological choices made and behavior changes adopted. Decarbonization efforts typically require more capital costs than business as usual "BL" (standing for "Baseline") because of additional investments in power plants, power grid, and new fuels for examples. Interestingly, only in the carbon neutral scenarios – the most aggressive decarbonization scenarios – "1.5 TECH" (standing for "1.5°C Technical" and relying more heavily on the deployment of biomass associated with significant amounts of CCS) and "1.5 LIFE" (standing for "1.5°C Sustainable Lifestyles" and assuming a drive by EU business and consumption patterns towards a more circular economy) total energy system costs increase and then decrease thanks to more pronounced energy consumption and fossil fuel savings. It may also be highlighted that by around 2065 the total energy system costs of the "1.5 LIFE" scenario will be the lowest of all scenarios. This important finding means that reaching carbon neutrality may temporarily increase costs, but can ultimately result in lower costs – while improving people's health, reducing weather-related disaster risks, and strengthening energy security.

How all this will concretely be done remains, however, to be seen. Some countries have already advanced their national long-term strategies to 2050 (among Europe's largest economies, only France and Germany). Though instructive, these documents lack of practical insight to capture today's most dynamic trends which are already decisively shaping tomorrow.[12]

To better understand how the EU is now proceeding towards carbon neutrality, the most useful complementary information are its 2030 intermediate goals and latest developments until now.

II Intermediate Goals (2030)

In its long decarbonization journey, the EU has set itself medium-term targets to be reached by 2030. These objectives bring more clarity to what upcoming changes are to be expected, and really pave the way towards the bigger goal of carbon neutrality by 2050.

The priority is given to greenhouse gas (GHG) emissions reduction, renewable energy expansion, and energy efficiency improvement (Table 2).

Table 2: EU Key 2030 Minimum Decarbonization Targets

Topic	Target
GHG emissions	40% reduction (compared to 1990)
RE	32% share in final energy consumption (no sectoral target except for transport; 14%)
Energy efficiency	32.5% improvement

Source: European Commission, 2030 Climate & Energy Framework (accessed August 4, 2020).

It must be noted that as a part of the European Green Deal the GHG emissions reduction target could be revised more ambitiously to 60% as voted by the European Parliament in October 2020, following the proposal of the European Commission to increase it to at least 55%.[13] Member States now need to agree with this new target to finalize it, which could be done by the end of this year. In a recent past, 2018, the EU already increased its 2030 targets for both RE and energy efficiency to 32% and 32.5%, respectively, from originally 27% each.

Except for transport, there is no RE sectoral target. However, it may be indicated that Europe's largest economies typically target between about 40% and 75% of their electricity to come from RE by 2030.

In more details; France 40%, Germany 65%, Italy 55%, and Spain 74%. The UK, which already reached 35% in 2019, does not have a target for total RE electricity for 2030, but ambitiously aims for one-third of its electricity to come from offshore wind alone at this date – compared to close to 10% last year.

The EU aims at achieving its intermediate goals thanks to efforts led both at the EU and national levels. In this regard, the three key policy tools implemented are the EU Emissions Trading System (ETS), the binding national emission reduction targets, and the 2030 national energy and climate plans (NECPs).

At the transnational level, the EU ETS is a mean to internalize the negative externalities of economic activities emitting GHG. It is done by putting a penalty price on the GHG emissions of activities which harm the environment and the lives depending on it (polluter pays principle).

Established in 2005, it was the world's first international ETS, and it remains the biggest one. It covers carbon dioxide (CO2) emissions from electricity and heat production, energy-intensive industries (e.g. oil refineries, iron and steel, chemicals…), and commercial aviation, as well as nitrous oxide emissions from the productions of nitric, adipic and glyoxylic acids and glyoxal, and perfluorocarbons emissions from the production of aluminum. Altogether these activities account for approximately 45% of the EU GHG emissions. By 2030, these emissions will have to be cut by 43% emissions (compared to 2005).[14]

After years of emission allowances oversupply and low prices – below €10 per ton (/t) of CO2, the introduction of a mechanism called "market stability reserve," removing surplus allowances in circulation from 2019 onwards, resulted in much higher prices; mostly about €20-30/t CO2 – a level unseen since the international financial crisis of the late 2000s (Chart 5). In Europe, this level of price starts to be meaningful enough to benefit to technologies which GHG emissions are close to zero; RE and nuclear, or lower; gas (when competing with coal for electricity generation for example).

Chart 5: EU Allowance Price April 2008-October 2020

Source: Ember, EUA Price (accessed October 15, 2020).

Domestic carbon tax may complement participation in the EU ETS in scope (i.e. CO2 emissions from the industry, buildings and transport sectors in France, and fluorinated GHG emissions only from all sectors in Spain) or price (carbon price floor in the UK). Among Europe's five largest economies, France, Spain, and the UK are using this tool. In 2020, the amount of this tax is the highest in France;

€45/t CO2, up from €7/t CO2 when introduced in 2014. The amount of this tax has been increased multiple times to enhance the effectiveness of the measure. Spain's carbon tax is lower at €15/t CO2. The UK relies on a slightly different mechanism called "carbon price floor," which supplements the EU ETS by requiring power generators to pay a minimum carbon price of around €20/t CO2, as of 2020 (up from €17/t CO2 when introduced in 2013).[15]

At the national level, to meet the EU 2030 decarbonization targets Member States need to respect binding national emission reduction targets and establish 10-year integrated NECPs.[a]

The former covers the GHG emissions of activities not subject to the EU ETS: housing, agriculture, waste, and transport (excluding aviation). Altogether these activities account for around 55% of the EU GHG emissions. By 2030, these emissions will have to be cut by 30% emissions (compared to 2005).[16]

In total the GHG emissions covered by the EU ETS and those covered by the binding national emission reduction targets are thus targeted to be reduced by 36% compared to 2005 (or by 40% compared to 1990). In comparison, Japan targets to reduce its GHG emissions by 25% in the same timeframe (or by 18% compared to 1990).[17]

The NCEPs notably outline how Member States intend to address GHG emissions reduction, RE, and energy efficiency.[18]

In terms of process, for the period 2021-2030, Member States had to submit their draft plans to the European Commission by the end of 2018, and their final plans taking account of the Commission's assessment and recommendations on the draft plans by the end of 2019. In 2020, the final plans will be assessed before their execution starts in 2021. To better develop and implement NECPs, the Member States had to consult citizens, businesses and regional authorities both in the drafting and finalization periods. Progress reports must be submitted every two years.

The approach of setting up NECPs requires a coordination of purpose across all government departments and it provides a level of planning that ease public and private investment. For instance, when it comes to RE, Member States are not only required to set a target for the share of RE in total energy consumption, but also for the shares of RE in electricity, heating & cooling and transport. All sectoral contributions are thus effectively assessed to reach the designated overall goal.

CHAPTER 2 focusing on Europe's largest economies' decarbonization strategies explores the NECPs of France, Germany, Italy, and Spain in greater details.

This energy and climate policy planning process is not a novelty in the EU. Indeed, in the past ten to fifteen years already, the EU has led its first experience in this field, and it is now possible to evaluate progresses.

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[a] Compared to a country like Japan, the EU Member States did not submit individual nationally determined contribution (NDC). The EU submitted one single NDC covering all its Member States without specifying the contribution of each country to GHG emissions reduction. The EU NDC is consistent with its 2030 GHG emissions reduction target.

III Progresses (as of 2018)

At the end of the 2000s, the EU enacted its 2020 Climate & Energy Package setting three key targets for reduction of GHG emissions, energy consumption from RE, and improvement in energy efficiency – already (Table 3).

Table 3: EU Key 2020 Decarbonization Targets

Topic	Target
GHG emissions	20% reduction compared to 1990
RE	20% share in final energy consumption (no sectoral target except for transport; 10%)
Energy efficiency	20% improvement

Source: European Commission, 2020 Climate & Energy Package (accessed August 5, 2020).

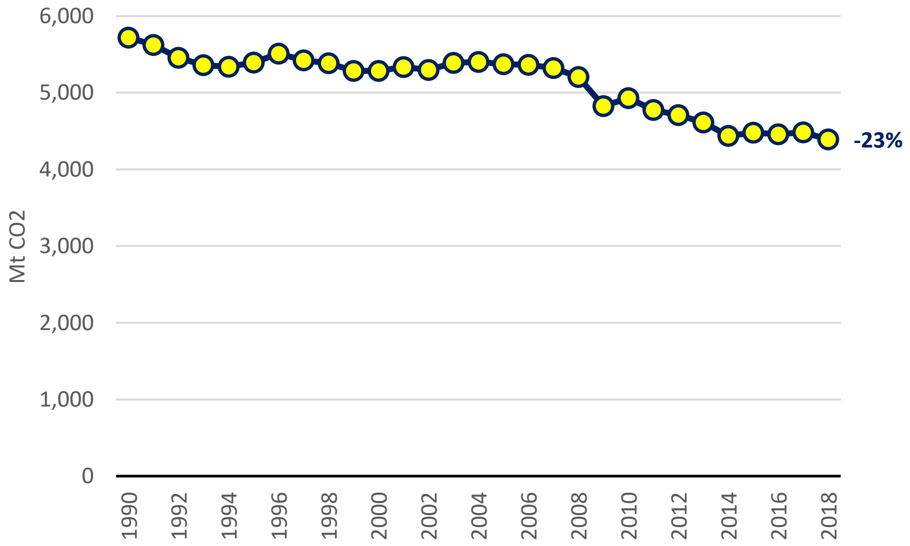
As for 2030 targets, except for transport, there is no RE sectoral target. For information purposes however; Europe's largest economies typically target between around 25% and 40% of their electricity to come from RE by 2020.

This original initiative has served as a policy planning cornerstone to build upon and has resulted in unprecedented decarbonization efforts which have been rather successful.

For instance, today's NECPs are yesterday's National Renewable Energy Action Plans (NREAPs). Advanced at the turn of the past decade, NREAPs indicated Member States' overall RE goals (i.e. share in final energy consumption) and by sector (electricity, heating & cooling, and transport) by the year 2020. The potential of energy efficiency was also taken into account.[19]

Regarding results, between 1990 and 2018, the EU reduced its GHG emissions by 23% exceeding its 2020 target by 3 percentage points (Chart 6). These decarbonization progresses have mainly been made in the energy sector – primarily in the energy supply industries, and especially public electricity and heat production.

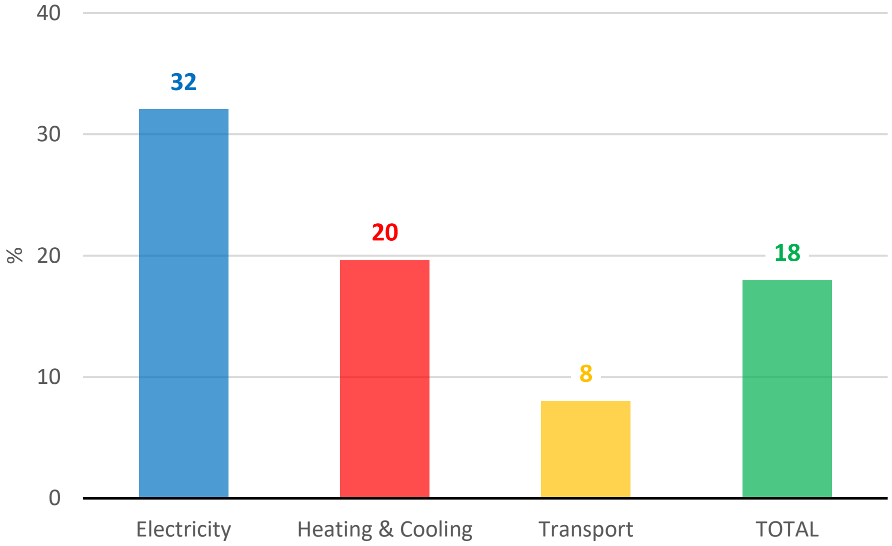
Chart 6: EU GHG Emissions 1990-2018



Source: Eurostat, Greenhouse Gas Emissions by Source Sector – updated June 9, 2020 (accessed August 8, 2020).

In 2018, the share of RE in total energy consumption reached 18% in 2018 – a doubling since 2004. This is very close to the 2020 target of 20%. By sector, the share of RE was 32% in electricity, 20% in heating & cooling, and 8% in transport (Chart 7).

Chart 7: EU RE Shares 2018



Source: Eurostat, [Share of Energy from Renewable Sources – updated August 27, 2020](#) (accessed September 2, 2020).

As for energy efficiency improvement (based on a comparison with a projected reference value for 2020), it reached 16-17% in 2018, which is also not very far from the 2020 target. Since 2005, the EU energy consumption decreased by 6-10%.[20] This reduction was mainly the result of the combination of two key factors; the slow economic recovery following the international financial crisis of the second half of the 2000s and a more aggressive promotion of energy efficiency as a major climate change mitigation action.

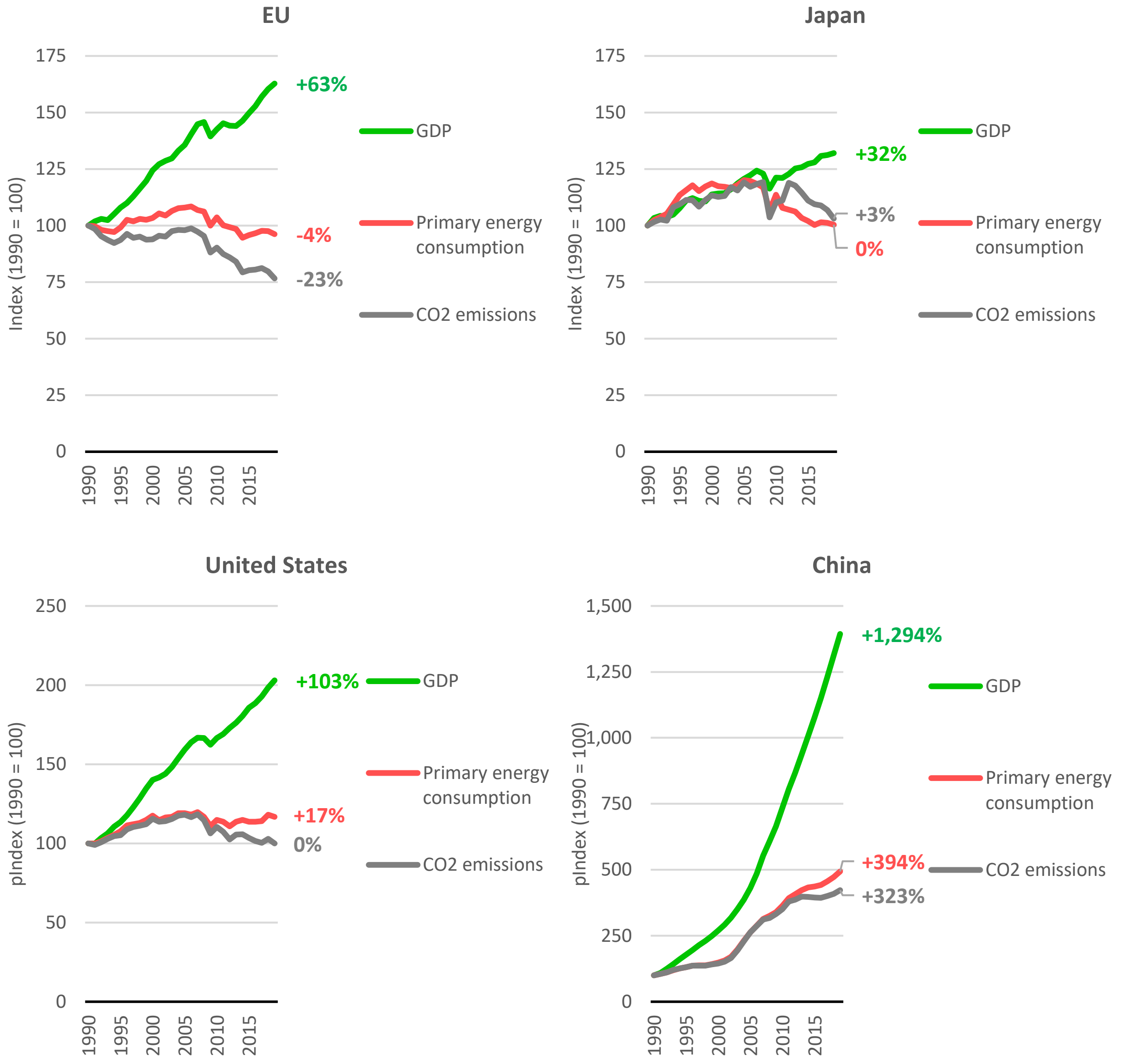
Thanks to these various progresses the EU has demonstrated that decoupling is possible, which is probably its biggest success in the past thirty years. This decoupling is actually a double decoupling. Indeed, the EU has managed to decouple both its energy consumption and economic growth, and its GHG emissions and energy consumption.

The decoupling of energy consumption and economic growth means that the EU has succeeded in creating more wealth while consuming less energy thanks to energy efficiency & savings. The decoupling of GHG emissions and energy consumption means that the EU has managed to reduce the amount of GHG it emits per unit of energy it consumes thanks to greater adoption of technologies emitting less GHG emissions, RE especially. Developing a prosperous and sustainable economy in a GHG and resource constrained world is a remarkable and critical achievement.

More specifically (Chart 8 on next page), between 1990 and 2019, the EU has managed to increase its gross domestic product (GDP) by 63%. At the same time, it managed to decrease both its primary energy consumption and carbon dioxide (CO2) emissions by 4% and 23%, respectively, a performance which no other world's leading economy (i.e. Japan, the United States, and China) has achieved.

In comparison, in this period, Japan's economy grew by 32% "only" – half the growth rate of the EU. Worse, Japan's CO2 emissions slightly increased by 3%, and its primary energy consumption was in 2019 at the same level than in 1990. This means that admittedly decoupling is also happening, but at a much slower pace than in the EU. On a more positive note, it must be noted that following Fukushima nuclear accident, CO2 emissions increased in Japan, but have been decreasing continuously since 2012-2013 mostly thanks to energy efficiency & savings and RE.

Chart 8: Decoupling in World's Leading Economies 1990-2019



Sources: CO2 emissions and primary energy consumption from BP, Statistical Review of World Energy 2020 (June 2020), and GDP from the World Bank, GDP (constant 2010 US$) – updated October 13, 2020 (accessed October 16, 2020).

Thus, the EU has not only succeeded in creating more wealth with less energy, but also with cleaner energy, which is the right path to a successful decarbonization.

In 2020, the world has been struck by the COVID-19 pandemic. This pandemic is not derailing the EU decarbonization progresses, neither in terms of observable energy trends nor in terms of political action.

The COVID-19 pandemic is negatively impacting energy consumption. In the power sector, for example, this decrease in electricity consumption is happening at a time when RE electricity are the most competitive technologies for electricity generation. Not only in terms of marginal costs, but also

– and more importantly – in terms of levelized cost of electricity (LCOE). Therefore, the main casualties of the crisis are coal, gas, and nuclear power, not RE (for more information see the Box 1 “Impacts of the COVID-19 Pandemic on the Power Sector of Europe’s Five Largest Economies” on page 37).

In addition, in response to the COVID-19, the EU leaders agreed on a “green” recovery deal in July 2020. This deal is a huge stimulus package comprising a €1,074 billion EU budget for 2021-2027 (part of which will finance the European Green Deal Investment Plan) and a €750 billion COVID-19 recovery fund, almost €2 trillion in total. Of the entire package, 30% (about €550 billion) is earmarked for climate protection projects and all spending must contribute to the EU emissions-cutting goals. No precise guidelines on how the money can be spent have been settled yet. Still, this powerful response is the largest climate funding pledge in history.[21]

CHAPTER 2: EUROPE'S FIVE LARGEST ECONOMIES' STRATEGIES

I Medium & Long-term Decarbonization Goals and Progresses

- Greenhouse gas emissions reductions

When it comes to GHG emissions reductions the message from Europe's five largest economies cannot be any clearer: carbon neutrality by 2050. This very ambitious goal indeed makes a consensus in France, Germany, Italy, Spain, and the UK regardless of where each country stands today with regard to its GHG emissions level. This commonly shared objective means substantially reducing GHG emissions in all sectors: electricity, heating & cooling, and transport, down to a level enabling carbon sinks to absorb more carbon than there would remain emitted (which should be quite limited).

To pave their way towards this final goal, Europe's largest economies – with the exception of Italy – have each accordingly set themselves GHG emissions reductions intermediate objectives to be met by 2030. In terms of GHG percentage decrease – compared to 1990, Germany and the UK with -55% and -57%, respectively, are the most ambitious countries. France follows with -40%, and Spain brings up the rear with -23% (Table 4).

Table 4: Europe's Largest Economies Medium & Long-term Decarbonization Goals

Country	2030	2050
France	-40% GHG emissions (compared to 1990)	Carbon neutrality
Germany	-55% GHG emissions (compared to 1990)	Carbon neutrality
Italy	X	Carbon neutrality
Spain	-23% GHG emissions (compared to 1990)	Carbon neutrality
UK	-57% GHG emissions (compared to 1990)	Carbon neutrality

Sources: For France (in French), Germany, Italy, and Spain from European Commission, National Energy and Climate Plans (NECPs), and for the UK from House of Commons Library, UK Carbon Budgets (July 2019).

It may be noted that in addition to these overall GHG emissions reduction goals the EU Member States, are also subject to specific GHG emissions reduction objectives for economic activities not covered by the EU ETS, like transport (excluding aviation) and housing: France 37%, Germany 38%, Italy 33%, and Spain 26% (all by 2030 compared to 2005).

To better understand the challenge of reaching future decarbonization goals, looking back at past achievements until very recently as well as providing some historical background is quite helpful.

Between 1990 and 2018, the GHG emissions of Germany and the UK decreased most – both in terms of percentage (reductions of about 30-40%) and volume of GHG emissions (decreases of more than 300 million tons of carbon dioxide (Mt CO2) each). Of this group of five countries, Germany and the UK are, however, still the two largest GHG emitters, but they have managed to close the gap with France, Italy, and Spain (Chart 9 on next page).

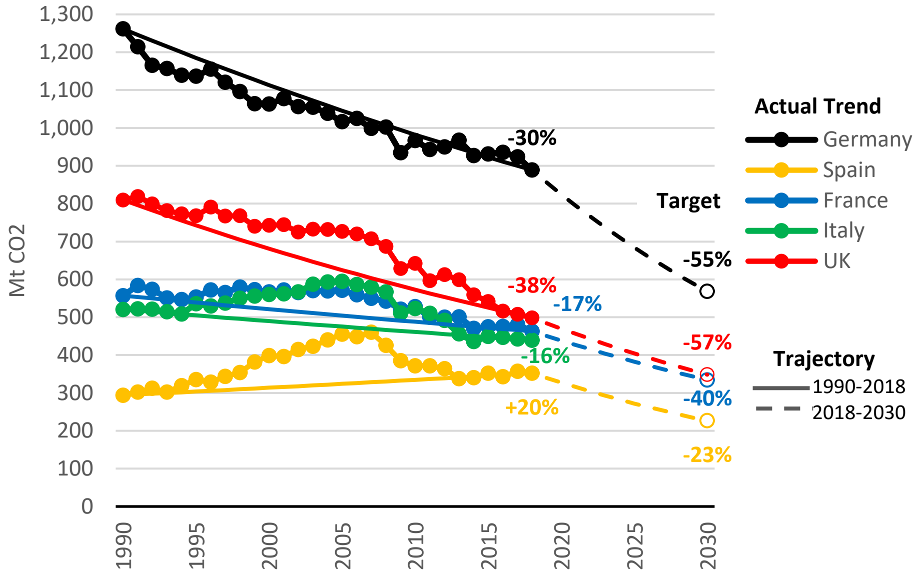


Chart 9: Europe's Largest Economies GHG Emissions Reductions 1990-2018 and 2030 Targets

Sources: GHG emissions reductions 1990-2018 from Eurostat, Greenhouse Gas Emissions by Source Sector – updated June 9, 2020 (accessed August 26, 2020), and 2030 targets for France (in French), Germany, Italy, and Spain from European Commission, National Energy and Climate Plans (NECPs), and for the UK from House of Commons Library, UK Carbon Budgets (July 2019).

From the first industrial revolution of the 18-19th centuries until relatively late in the 20th century Germany and the UK used to be strongholds of coal in Europe. In these two countries, coal consumption has significantly decreased in the past thirty years, a change originally initiated in the 1990s by the decisions to scale down the subsidized coal industry in Germany because of pressures on the country's public finances and the incompatibility of subsidies with policies within the European Union, and the electricity system reform in the UK which delivered a more favorable framework for gas resulting in the "dash for gas," to the detriment of coal. Today, RE has largely compensated for the reduction in coal in Germany, and RE and gas in the UK.[22]

Since 1990, France and Italy saw their GHG emissions be reduced by 16-17%, primarily thanks to a significant decrease in oil consumption in all sectors except transport. In the case of France, decarbonization has so far been based on a combination of nuclear – following the continuation until the end of the 1990s of a vast program launched in the 1970s in reaction to the oil shock – and RE. In the case of Italy, on a combination of RE and gas.

Finally, only in Spain, the smallest of Europe's five largest economies, GHG emissions rose – an increase of 20% between 1990 and 2018. In the period considered Spain's economy grew spectacularly (+76%, the most of Europe's five largest economies), a growth supported by increased energy consumption, primarily gas, especially until the international financial crisis of 2007-2008. An increase in RE consumption and a decrease in total energy consumption enabled a 23% decrease of GHG emissions in the period 2007-2018.

When comparing remarkable past achievements and future requirements the formidable challenge of meeting the intermediate objectives towards the bigger goal of carbon neutrality appears: a strong acceleration of decarbonization efforts will be necessary in the coming decade. More specifically, every year from 2018 onwards to 2030, these countries will have to decrease their GHG emissions by about 3-4%, which is much more than what any of these countries has realized over the period 1990-

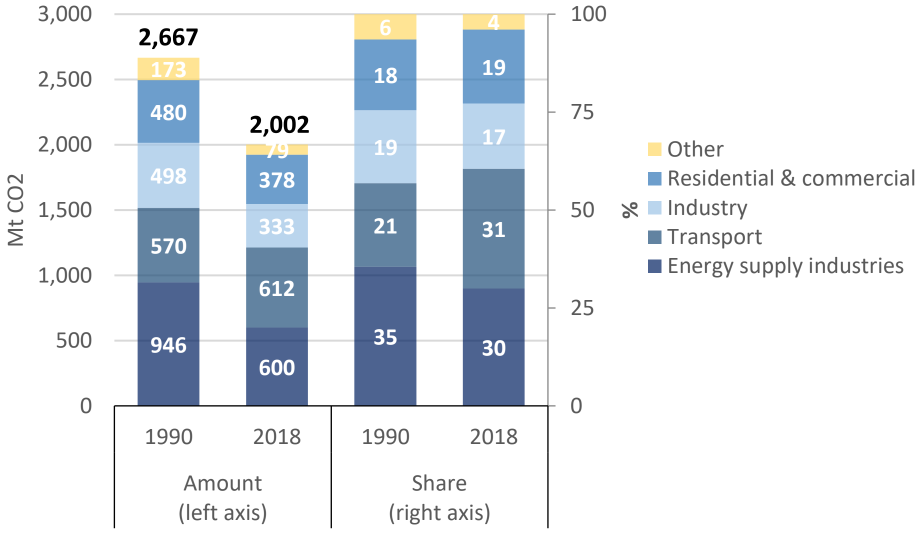
2018 (the UK, the best performer, got close to 2%). Reasons for optimism, however, are that decarbonization options keep becoming more affordable and available.

- Greenhouse gas emissions reductions by sector

Moving forward, accelerating Europe's five largest economies' decarbonization effort will largely mean decarbonizing the energy sector (mainly energy supply industries and fuel combustion in transport, industry, and commercial & residential) faster. Indeed, although in the past thirty years GHG emissions reductions from the energy sector have accounted for 83% of all GHG emissions reductions, this sector remains by far the largest source of GHG emissions; over three-quarters of the total GHG emissions of Europe's largest economies – a predominance that is common across all of them.[23]

Since 1990, within the energy sector, more than half (52%) of the sector's GHG emissions reductions have come from the energy supply industries alone, and within this sub-sector reductions have very largely come from public electricity and heat production (emissions all decreased in petroleum refining and manufacture of solid fuels and other energy industries, but less). In addition, it must be noted that among all the sub-sectors of the energy sector, GHG emissions only rose in the transport sub-sector (a 7% increase), essentially because of road transportation, making this sub-sector the first emitter of the energy sector in 2018, just ahead of the energy supply industries. These opposite trends highlight well the challenges and opportunities to decarbonize the energy sector, and more generally economies (Chart 10 below and Table 5 on next page).

Chart 10: Europe's Five Largest Economies GHG Emissions from the Energy Sector Breakdown 1990 and 2018 (Aggregated)



Note: "Other" includes fugitive emissions and unspecified.
Source: Eurostat, Greenhouse Gas Emissions by Source Sector – updated June 9, 2020 (accessed August 28, 2020).

Table 5: Europe’s Five Largest Economies GHG Emissions Energy Sector Breakdown 2018 – Additional Information –

Sub-sector of the energy sector	Main emitter(s) (share in total GHG emissions of the energy sector)
Energy supply Industries	Public electricity and heat production (25%)
Transport	Road transportation (29%)
Industry	Iron and steel (4%), chemicals (2%), and non-metallic mineral products (2%) manufacturing
Residential & commercial	Households’ fuel combustion (13%) and commercial & institutional sector’s fuel combustion (6%)

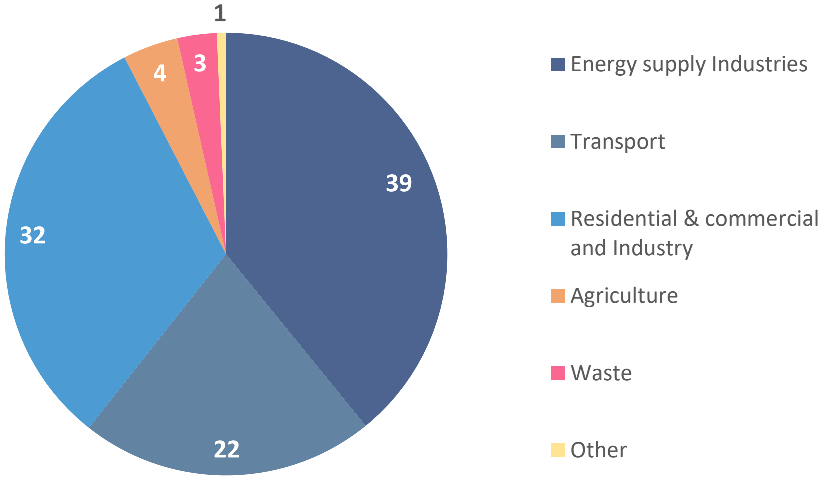
Notes: Shares are based on data aggregated for the five countries in question. No data available for the emissions from fuel combustion in manufacture of chemicals in Germany.

Source: Eurostat, Greenhouse Gas Emissions by Source Sector – updated June 9, 2020 (accessed August 26, 2020).

Recognizing the need for a deep and quick decarbonization of the energy sector as a top priority, Europe’s largest economies plan that about 90% of total GHG emissions reductions will come from this sector in the next decade.

Among the energy sector’s sub-sectors two priorities have been identified: energy supply industries and transport. These two sub-sectors are the two most GHG emitting of the energy sector (combined – more than 60% of the sector’s total GHG emissions in 2018), and those from which most GHG emissions reductions are programmed to be cut by 2030 (also combined – more than 60% of total GHG emissions reductions) (Chart 11).

Chart 11: GHG Emissions Reductions by Source Planned by Europe’s Five Largest Economies for the Period 2020-2030 (Aggregated) (%)



Notes: No breakdown available for the “Residential & commercial” and “Industry” sub-sectors for which relatively similar contributions in terms of GHG emissions reductions are expected. “Industry” here includes GHG emissions from industrial processes & product use which are not considered as emissions from the energy sector. “Other” includes fugitive emissions and unspecified.

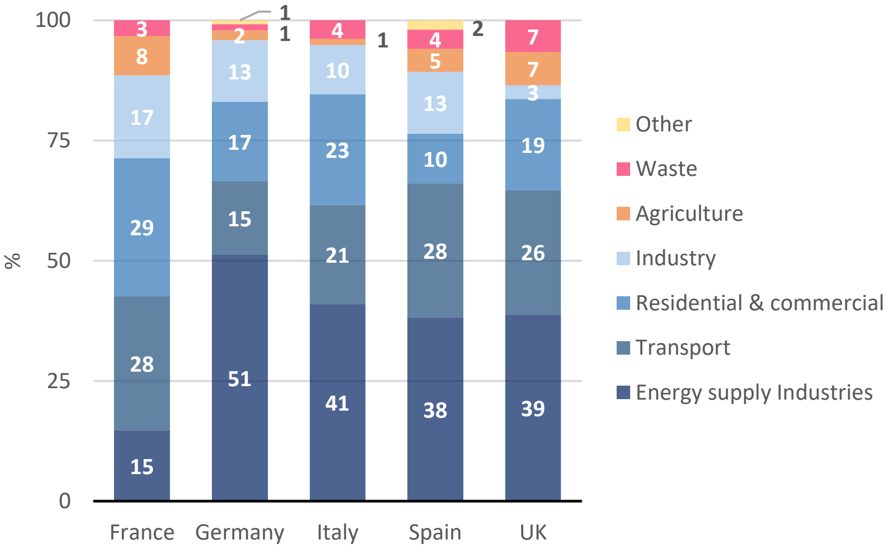
Sources: For France (in French), Germany, Italy, and Spain from European Commission, National Energy and Climate Plans (NECPs), and for the UK from the United Kingdom Government, Updated Energy and Emissions Projections: 2018 – updated May 16, 2019 (accessed August 26, 2020).

There is a common recognition that decarbonizing the energy supply industries will be done faster than transport because cost competitive RE alternatives to fossil fuels are already existing, in the power sector in particular.

In greater details, in Europe's five largest economies almost 40% of total GHG emissions reductions are planned to come from the energy supply industries, especially public electricity and heat production. In Germany, more than half of the country's total 55% GHG emissions reductions goal is to be delivered by the energy supply industries. This will be accomplished by further reducing the use of coal for electricity generation, which has already significantly declined, but is still relatively important (30% of electricity generation in 2019). It may be noted here that this coal decrease is a reality despite the country's nuclear phaseout (to be completed by 2022) thanks to the expansion of RE. In this framework, to go further Germany's recent decision to phaseout coal power by 2038 will be decisive. In France, where the electricity mix is largely decarbonized thanks to nuclear and RE, the contribution of the energy supply industries to GHG emissions reductions will be much smaller, only 15%. In Italy, Spain, and the UK the energy supply industries' targeted contributions to total GHG emissions reductions are around 40%.

Then, more than 20% of the five countries' total GHG emissions expected reductions between 2020 and 2030 is to come from transport. Overall, and with the exception of Germany, transport has become the first GHG emitting sub-sector in Europe's largest economies and it is therefore an unavoidable source of GHG to decrease (Chart 12).

Chart 12: GHG Emissions Reductions by Source Planned by Europe's Five Largest Economies for the Period 2020-2030 (by Country)



Notes: In the case of the UK only, parts of the GHG emissions from the industry sector is included in "Residential & commercial" because no breakdown was available. This probably makes the contribution of the industry sector to GHG emissions reductions look smaller than actually planned, and that of the residential & commercial sector bigger. "Industry" here includes GHG emissions from industrial processes & product use which are not considered as emissions from the energy sector. "Other" includes fugitive emissions and unspecified.

Sources: For France (in French), Germany, Italy, and Spain from European Commission, National Energy and Climate Plans (NECPs), and for the UK from the United Kingdom Government, Updated Energy and Emissions Projections: 2018 – updated May 16, 2019 (accessed August 26, 2020).

In addition, the combined contributions of the residential & commercial and industry sub-sectors – which are not possible to breakdown because of a data availability issue – are forecasted to account for nearly one-third of the forecasted GHG emissions reductions (with relatively similar contributions expected from each). The remaining GHG emissions reductions, roughly 5-10%, will come from the agriculture, waste, and other sectors.

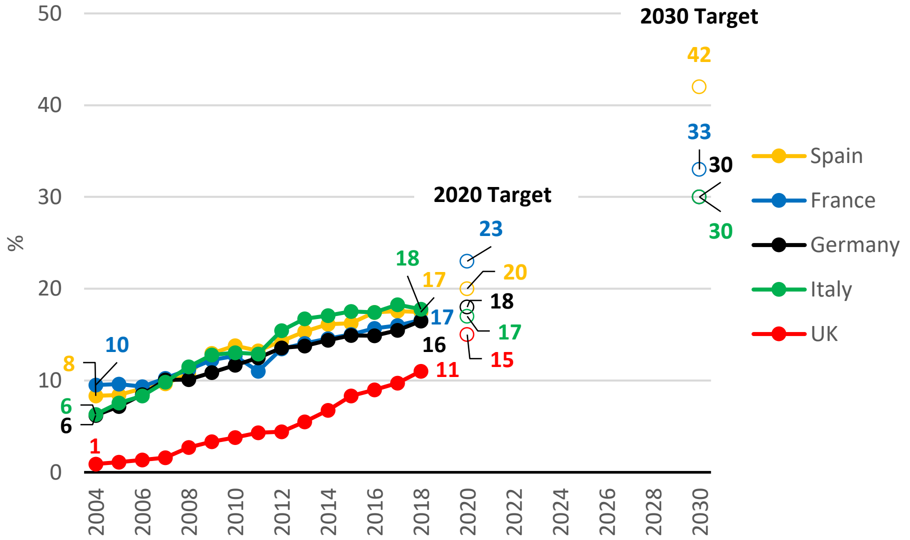
Central to the successful realization of these decarbonization plans will be RE expansion and energy efficiency improvements.

- Renewable energy expansion

When it comes to RE, Europe's largest economies have, with the exception of the UK[b], recently adopted new 2030 targets for RE share in total energy consumption (electricity, heating & cooling, and transport).

These new targets typically range between about 30% and 40%, roughly a 10 to 15 percentage points increase from the previous 2020 targets. Spain stands out in two ways, (1) it is the country with the highest 2030 target for RE; 42%, (2) which to be realized requires more than a doubling of its 2020 target. No other country comes close to this high level of ambitions (Chart 13).

Chart 13: Europe's Five Largest Economies RE Expansion (including all sectors)
2004-2018 and 2020 & 2030 Targets



Sources: RE expansion 2004-2018 from Eurostat, Share of Energy from Renewable Sources – updated August 27, 2020 (accessed September 2, 2020), 2020 targets from European Commission, National Renewable Energy Action Plans 2020, and 2030 targets for European Commission, National Energy and Climate Plans (NECPs) (both accessed August 26, 2020).

Regarding past developments, Europe's five largest economies have substantially increased the share of RE in their energy consumption since 2004. For instance, Italy tripled it from 6% to 18%, Germany multiplied it by 2.7 from 6% to 16%, Spain doubled it from 8% to 17%, France increased it from 10% to 17%, and the UK which started at only 1% managed to reach 11%. Just for comparison purpose, the share or RE in Japan's energy consumption was 9% in 2018 – lower than in all of Europe's largest economies.[24]

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[b] Scotland, however, targets a 50% RE share by 2030.

As of 2018, with the exception of Italy, no country had already met its 2020 target. France, the country with the highest ambition in this group (23%) was also the country the less likely to meet its target because of insufficient overall political efforts to promote RE.

As of the time of writing, the summer/autumn of the year 2020, it is difficult to make predictions on whether these targets would be met or not. However, it is certainly possible to observe that in the year 2020 the very latest positive developments for RE electricity and the negative impact of COVID-19 on energy consumption are definitely filling the gaps in.

Future targeted contributions and past achievements for RE in the electricity, heating & cooling, and transport sectors in each country are described in details in section 2 of this chapter.

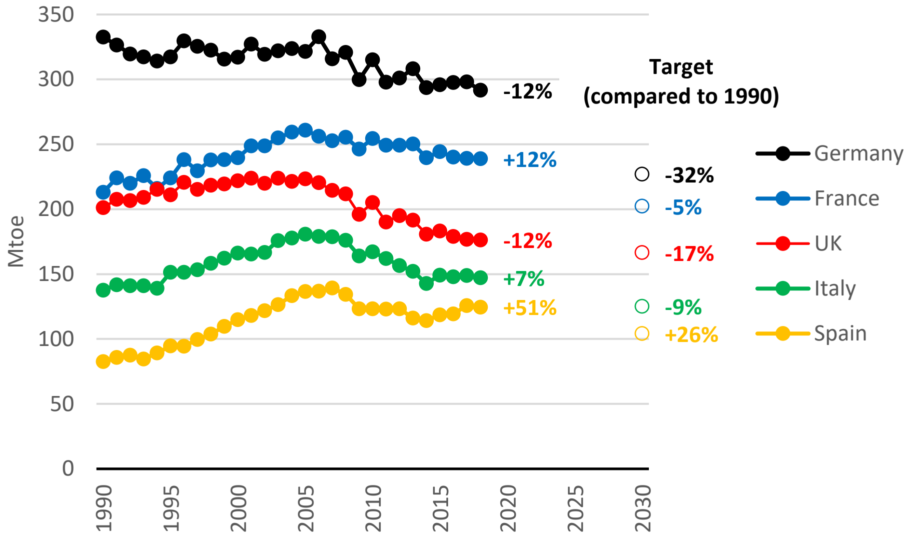
What may additionally be highlighted here is that as RE electricity leads and will keep leading decarbonization progresses the importance of sector coupling to take advantage of synergies among the different uses of RE will only grow. In this framework, electrification of transport and production of electricity-based fuels (including hydrogen) will be key to successfully integrate RE electricity and advance decarbonization in all sectors. Sector coupling will involve important system changes as for examples expanding charging infrastructures for electric vehicles (EVs) or efficient heating networks.

- Energy efficiency improvements

To meet their decarbonization goals Europe's largest economies all recognize the necessity not only to use more RE energy, but also to significantly reduce their energy consumption compared to their level today. Typically, by about 15 to 20% between 2018 and 2030, with the exception of the UK which only projects a mere 5% reduction of its energy consumption in this period. It must, however, be noted that among Europe's largest economies, the UK has – on a percentage basis – experienced the largest decrease in energy consumption since 1990; 12% (by a short head in front of Germany). As a matter of fact, only Germany and the UK have managed to reduce their energy consumption in the past thirty years.

If France and Italy are to meet their 2030 energy efficiency targets, they will also have to decrease their energy consumption below their 1990 level. Spain, which strong economic and energy consumption growths occurred later than in the other countries, targets to limit its energy consumption increase by 26% in 2030 compared to 1990, meaning halving the increase until 2018 (Chart 14 on next page).

Chart 14: Europe's Five Largest Economies Energy Consumption Improvements 1990-2018 and 2030 Targets



Sources: Energy efficiency improvements 1990-2018 from Eurostat, Energy Efficiency – updated February 24, 2020 (accessed August 27, 2020), and 2030 targets for France (in French), Germany, Italy, and Spain from European Commission, National Energy and Climate Plans (NECPs), and for the UK from the United Kingdom Government, Updated Energy and Emissions Projections: 2018 – updated May 16, 2019 (accessed August 26, 2020).

To reduce their energy consumption, Europe's largest economies are mainly targeting energy efficiency improvements in three sectors: buildings, transport, and industry.

In the building sector, energy efficiency improvements are essentially sought in residential, commercial, and public buildings. Improvements are considered in both existing and new buildings. Regarding existing buildings – which will still account for the majority of the building stock in the coming decades, significant renovation efforts will be pursued as for example in Spain where energy efficiency improvements for 1.2 million homes are targeted in the period 2020-2030. As for new buildings, near zero-energy buildings will be promoted (this objective should also apply in the long-term to existing buildings). In buildings, priority will be given to the thermal envelope; better insulation of walls, roofs, and windows or other façade elements. More efficient equipment (e.g. systems for heating & cooling, lighting, cooking, hot water heater, and other electronic devices…) are also to be disseminated.

In the transport sector, multiple strategies are advanced to cover the many ways people and goods move. These include: promoting modal shift which instead of road transport favors pedestrian/cyclist mobility in the case of people, and rail or inland waterway in the case of freight, increasing collective mobility either by sharing mobility (carpooling and carsharing) or developing rapid mass transport, and spurring more efficient vehicles adoption (e.g. battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), or fuel cell electric vehicles (FCEVs)).

In the industry sector, it is recognized that energy demand can be reduced by improving the energy efficiency of industrial products and processes, in particular with the development of techniques and plant solutions for boosting efficiency of industrial processes at high and low temperature. In addition, when it comes to the industrial building stock, not only the use of resource-efficient building materials (e.g. eco-cement, wood, clay…) should be pursued, but also the selective dismantling of buildings and the recycling of building materials.

In Europe's largest economies, measures implemented to achieve these energy efficiency improvements are as diverse as gains searched for. For instance, in the building sector, norms such as thermal regulations have been established (e.g. France and Spain) and economic incentives have been provided as for examples low-interest or interest free-loans (e.g. Germany and the UK) and tax deductions (e.g. Italy). In the transport sector, infrastructural changes are key, as well as regulations and economic incentives favoring low carbon emissions vehicles. For examples, facilitating the establishment of cycle zones and extending the ban on parking in front of junctions and junction areas (e.g. Germany), setting emission standards (decided at the EU level; e.g. 95 grams of CO2 per kilometer (gCO2/km) for new passenger cars in 2020), creating low-emission zones in cities (e.g. Spain and the UK), and offering conversion bonuses to accelerate the transition to cleaner vehicles (e.g. France). Finally, energy efficiency improvements in the industry sector are also stimulated by various regulatory and economic policies depending on the type of industry.

In addition to these measures, Europe largest economies anticipate technological progress and especially the development of digitalization technologies; instrumentation and control technology, sensor technology and energy management software and energy-related optimization of equipment and processes, as enablers of energy efficiency insofar these tools provide opportunities to make smarter use of energy.

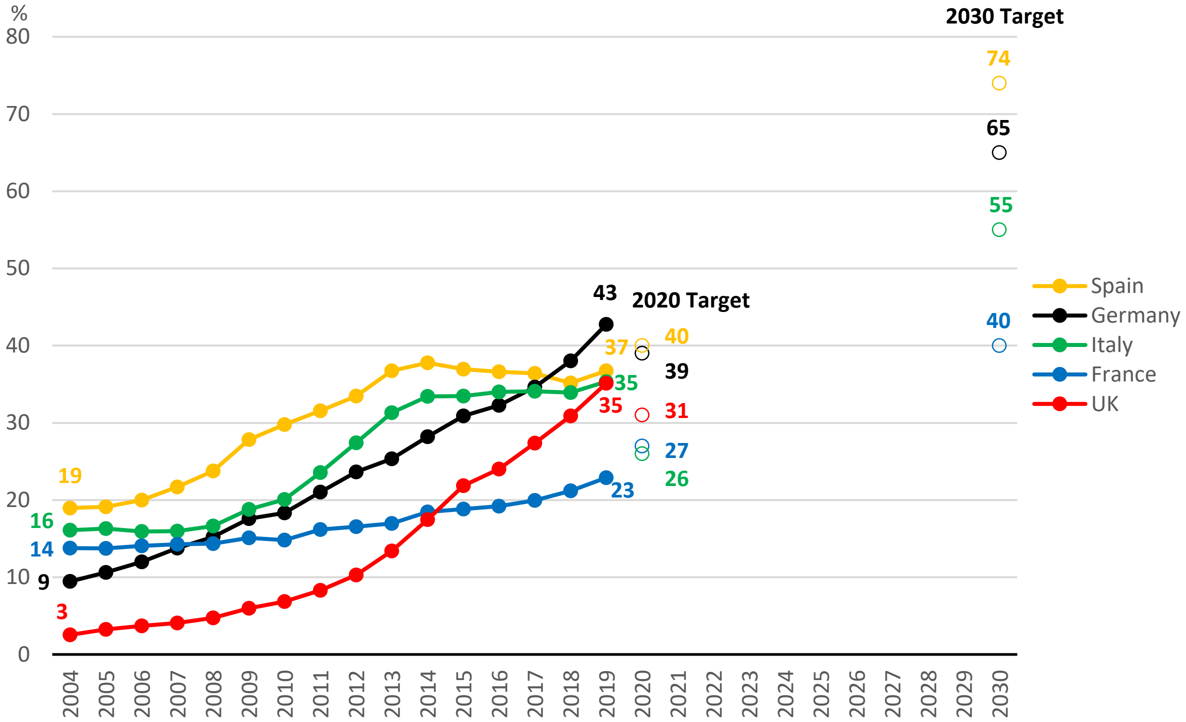
II Renewable Energy Contributions by Sector

- Electricity

High shares of RE are the backbones of Europe's largest economies' decarbonization strategies. In Germany, Italy, and Spain the shares of RE in electricity in electricity consumption (i.e. generation + imports - exports) are targeted to be about 55-75% in 2030, against 35-45% in 2019. In the UK, which targets one-third of its electricity to come from offshore-wind alone (no target for total RE), the large majority of the country's electricity should also come from RE in 2030, compared to 35% in 2019 including nearly 10% of offshore wind. Only in France, the share of RE in electricity is expected to remain below 50%; 40% exactly – which if realized would still be a doubling from 2019. In comparison to these economies, Japan's target of 22-24% RE electricity by 2030, against to 19% in 2019, is terribly unambitious.

In addition, it may be noted that assessing Europe's largest economies' 2030 RE electricity targets in the light of past achievements, by confronting latest actual progress with 2020 RE electricity targets – generally successfully met or to be met, strengthens the credibility of the newly announced ambitions (Chart 15 on next page).

Chart 15: Europe's Five Largest Economies RE Electricity Expansion 2004-2019 and 2020 & 2030 Targets



Sources: RE electricity expansion 2004-2018 from Eurostat, [Share of Energy from Renewable Sources – updated August 27, 2020] (accessed September 2, 2020), 2019 expansion from International Energy Agency, [Data and Statistics] (accessed September 16, 2020), 2020 targets from European Commission, [National Renewable Energy Action Plans 2020], and 2030 targets for European Commission, [National Energy and Climate Plans (NECPs)] (the latter two both accessed August 26, 2020).

The reason why France is less ambitious than its peers when it comes to RE electricity is because the country's power sector is already largely decarbonized with a significant contribution of nuclear power; 70% in 2019. The domination of nuclear on the French electricity mix is, however, to significantly diminish with a targeted reduction of the technology to 50% of the country's electricity by 2035. A decision mainly based on four criteria: economic, environmental, social, and technical. The economic criterion refers to the deteriorating relative cost competitiveness of nuclear (both of existing and new reactors) with new RE. The environmental criterion to the fragility of nuclear power to global warming with the cooling of reactors being sometimes problematic during heat waves, leading to temporary closures. The social criterion to the acceptance of the nuclear technology itself, which image suffers from major accidents (including that of Fukushima Daiichi). And the technical criterion to the difficulty of building new reactors (e.g. Flamanville-3) and realizing reactor decommissioning, and spent fuel & waste disposal projects.

Replacing nuclear by RE is actually a quite common approach in Europe's largest economies, with the majority of this small group of countries having either already phased out nuclear power (Italy, achieved in 1990), or announced plans to do so (Germany by 2022 and Spain by 2035). For the time being, only the UK has not announced it is moving forward in the direction of a nuclear power decrease because it considers the technology as source of low carbon electricity that is reliable despite its expensiveness as demonstrated by the Hinkley Point C project under construction at a cost of around $140 per megawatt-hour (/MWh), and Hitachi's decision to withdraw from the Wylfa project in September 2020 because of economic rationality issues.[25]

If the future of nuclear power in Europe's largest economies looks dark, that of coal power cannot be any gloomier; in all countries coal power will be phased out. Within the next five years, in France, Italy, and the UK. By 2030, in Spain. And finally, by 2038 in Germany (Table 6).

Table 6: Europe's Five Largest Economies Exiting Coal and Nuclear Power

Country	Phaseout/Reduction	
	Coal	Nuclear
France	Phaseout – by 2022	Reduction – 50% of generation by 2035
Germany	Phaseout – by 2038	Phaseout – by 2022
Italy	Phaseout – by 2025	Phaseout – achieved 1990
Spain	Phaseout – by 2030	Phaseout – by 2035
UK	Phaseout – by 2024/25	No plan

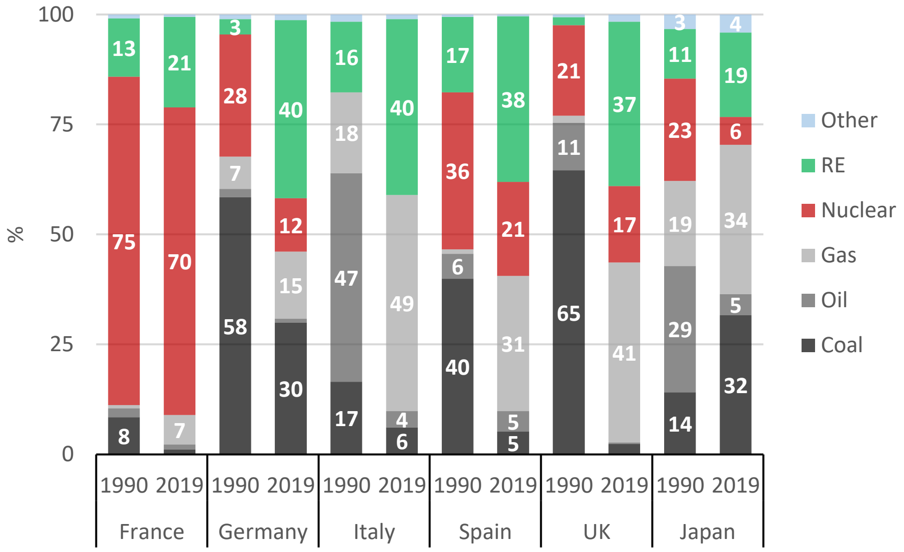
Sources: For France (in French), Germany, Italy, and Spain from European Commission, National Energy and Climate Plans (NECPs), and for the UK from the United Kingdom Government, End of Coal Power to Be Brought Forward in Drive Towards Net Zero – February 4, 2020 (accessed September 2, 2020).

Reducing or phasing out nuclear power, and phasing out coal power at the same time is an ambitious challenge, particularly when these domestic industries are admittedly declining, but still relatively powerful as for examples nuclear in France or coal in Germany with employments at stakes. It can, however, be done as demonstrated by the significant progresses in the ongoing phaseouts of nuclear power in Germany, which share in electricity generation has been decreased from 28% in 1990 to 12% in 2019, and of coal in the UK, which share has collapsed from 65% to 2% in the same period. In Germany, RE was the main source of replacement, and in the UK, RE and gas.

To support the energy transition in the most impacted regions such as coal-mining regions in Germany, the Just Transition Mechanism has been advanced at the EU level. It will focus on the social and economic costs of the transition and finance projects ranging from creation of new workplaces through support to companies, job search and re-skilling assistance for jobseekers who lost employment due to the transition.

In all countries in the past thirty years already, the shares of RE in electricity generation increased while those of fossils (coal, oil, and gas) – enabling decarbonization – and nuclear decreased. In comparison, in Japan since 1990, whereas the share of nuclear decreased (mainly as a result of Fukushima Daiichi nuclear accident in 2011) that of fossils slightly increased despite RE expansion (Chart 16 on next page).

Chart 16: Europe's Five Largest Economies and Japan Gross Electricity Generation Mixes 1990 and 2019



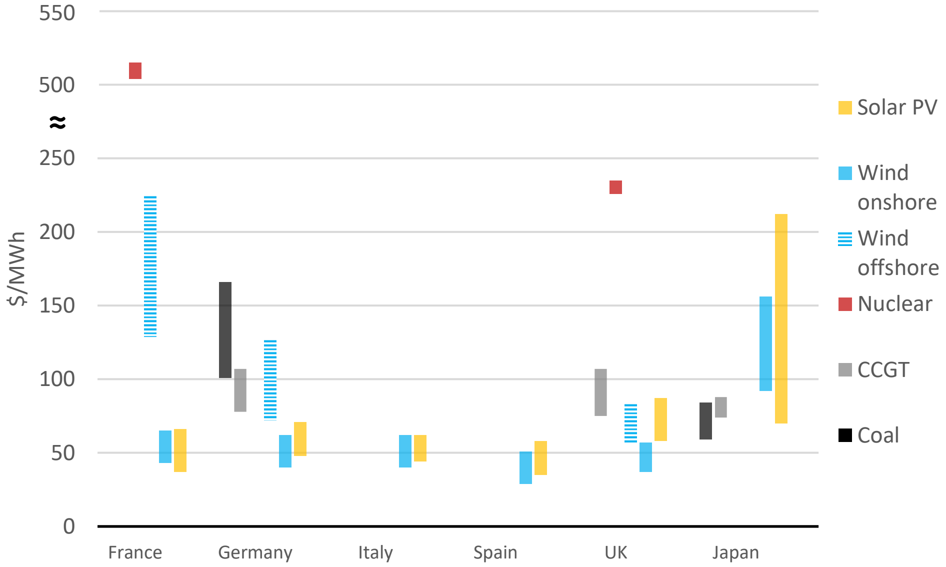
Notes: "RE" includes hydro (exceptionally pumped storage as well), wind, solar photovoltaic & thermal, bioenergy & renewable waste, geothermal, and tide. "Other" includes non-renewable waste and unspecified sources.
Source: International Energy Agency, Data and Statistics (accessed September 16, 2020).

The replacement of nuclear and coal (and other fossils) by RE has been made possible thanks to a combination of factors. Among which; electricity system reforms (providing a level playing field), support policies (internalizing positive externalities of generating electricity with close to zero GHG emissions) such as feed-in tariffs or auctions, and dramatic costs reductions in RE technologies, especially wind (on- & off-shore) and solar photovoltaic (PV), as a result of industrial progresses and economies of scale. Therefore, RE promotion in Europe's largest economies is today not only an environmental matter, but an economic one as well.

For instance, in Germany despite prolonged and significant investments in wind and solar PV, resulting in a combined additional 33 gigawatts (GW) between 2014 and 2019, retail electricity prices for households have remained stable; a small increase of only less than $0.02 per kilowatt-hour (/kWh) in this period. Even better, prices for bulk industrial buyers decreased by more than $0.02/kWh in the same period.[26] This demonstrates the affordability to replace nuclear and coal with RE under fair conditions.

That is because new onshore wind and solar PV are now by far the cheapest technologies for new electricity generation. In Europe's largest economies, based on LCOE, onshore wind costs around $40-50/MWh, and can be as low as less than $30/MWh. And solar PV is usually between $45/MWh and $70/MWh, with the most competitive projects at $35/MWh (Chart 17 on next page). These levels of costs are competitive with market prices (reflecting economic performances of existing generating capacity) observed in Europe's largest economies in 2019; $45-60/MWh.[27]

Chart 17: Europe's Five Largest Economies and Japan Electricity Generating Technologies LCOE 2020-H1



Notes: For "Nuclear," Germany, Italy, and Spain neither have had reactors under construction for a long time nor have plans to construct new reactors therefore no data is available. In the case of Japan, no recent official data is available except a 2015 estimate from the Ministry of Economy, Trade and Industry which is based on the construction costs of nuclear reactors having now been first grid connected about 10-15 years ago with conservative designs making this estimate irrelevant today. *Source: BloombergNEF, Levelized Cost of Electricity 1H 2020 (April 2020 – subscription required).*

In the past few years, offshore wind has also made great strides. Though offshore wind is still generally more expensive (with important disparities in terms of LCOE among countries) than onshore wind or solar PV, most competitive bids of recent large auctions in France, Germany, and the UK delivered results such as market prices (no subsidies) or prices in the range of $50-60/MWh. These suggest that the gap with the other leading RE technologies may not be so wide. Since the economics of offshore wind is very promising and the large potential of this technology remains quite untapped, it is no surprise Europe's largest economies are pushing for its vast scale-up for a cost-efficient decarbonization. Offshore wind is described further in CHAPTER 3 which focuses on key technological enablers.

To reach their 2030 RE electricity targets Europe's largest economies will thus massively invest in wind and solar PV. Between 2019 and 2030, in particular, France is aiming at almost quadrupling its solar PV installed capacity (from about 10 GW to 40 GW), doubling its onshore wind capacity (from 16 to 34 GW), and starting to install its first offshore wind farms totaling about 5-6 GW. Germany targets to double its solar PV installed capacity (from approximately 50 GW to 100 GW), and almost triple its offshore wind capacity (from 8 GW to 20 GW). Italy will especially move forward with solar PV, more than doubling its installed capacity (from about 20 GW to 50 GW). Spain projects to quadruple its solar PV installed capacity in a similar way as France (from about 10 GW to 40 GW) and double its wind capacity (from around 25 GW to 50 GW). Finally, the UK is by far the most ambitious country for offshore wind, for which it is already the world's leader, with a substantial planned quadrupling from 10 GW to 40 GW.

On the one hand, with already 62 GW of solar PV installed capacity in 2019, Japan compares relatively well with Europe's largest economies, which should stimulate the country to set itself higher ambitions to maintain its leadership which will fade away if it sticks to its current 2030 target of 64 GW. On the other hand, when it comes to wind, Japan is completely lagging behind with only 4 GW of installed capacity. This situation will worsen if the country does not raise its very unambitious goal of only 10 GW (including less than 1 GW of offshore wind) by 2030 – a level already reached before 2020 in all of Europe's largest economies (Table 7).

Table 7: Europe's Five Largest Economies Solar PV and Wind Installed Capacity 2019 and 2030 Targets (GW)

Country	Solar PV		Wind			
			Onshore		Offshore	
	2019	2030	2019	2030	2019	2030
France	11	35-44	16	33-35	0	5-6
Germany	49	98	53	67-71	8	20
Italy	21	51	11	18	0	1
Spain	9	39	26	50	0	N/A
UK	14	N/A	14	N/A	10	40
Japan	62	64	4	9	0	1

Notes: In the case of France only, the targets are not by 2030, but 2028. In the case of Spain only, the onshore wind target includes both onshore and offshore.

Sources: Installed capacity 2019 from International Renewable Energy Agency, Renewable Energy Statistics 2020 (July 2020), and 2030 targets for France (in French), Germany, Italy, and Spain from European Commission, National Energy and Climate Plans (NECPs), for the UK from Queen Elizabeth II, The Queen's Speech 2019 – December 19, 2019 (accessed September 3, 2020), and for Japan from the Japanese Ministry of Economy, Trade and Industry, Long-term Energy Supply and Demand Outlook (July 2015) (in Japanese).

Developing together solar PV and on- & off-shore wind provides some complementarity in terms of RE outputs. However, this is not sufficient to guarantee a stable power supply. Recognizing this challenge, Europe's largest economies are advancing a set of solutions to increase power systems' flexibility to manage the variability from these three technologies which are set to become the pillars of electricity generation in a near future.

In this framework, four strategical axes have been identified: international interconnections, storage, demand response, and flexible operations of conventional power plants.

International interconnections are absolutely key to RE integration in Europe. At the EU level, interconnection targets exist; 10% interconnectivity by 2020 and 15% by 2030. These targets mean that each country should have in place electricity cables that allow at least the aforementioned targeted percentages of the electricity produced by its power plants to be transported across its borders to neighboring countries at the indicated dates.[28] For instance, Germany projects reaching 30-35 GW of cross-border interconnections in 2030 by increasing its existing interconnection capacity by around 15 GW until this date. Though the UK is not an EU State Member anymore, it currently has more than 4 GW of interconnection capacity under construction, linking it with Norway, France, and Belgium, due for completion by 2021, and more developments are expected in the coming decade.[29]

As for storage, three main options are considered batteries, pumped-storage hydro (PSH), and hydrogen. Italy, which peak demand reached in 58 GW 2018, estimates that its power system will require 10 GW of new storage capacity by 2030, including 4 GW of distributed storage facilities (e.g. batteries), and 6 GW of PSH and centralized electrochemical production (e.g. hydrogen). Spain, peak demand of 40 GW in 2018, plans to develop an additional 6 GW of storage capacity by 2030, broken down between 2.5 GW of batteries and 3.5 GW of PSH. And France, peak demand of 97 GW in 2018, plans to add 1.5 GW of PSH by 2030-2035.[30]

As for PSH specifically, because of environmental concerns, in the majority of the EU Member States both building and environmental permits are required, which are usually delivered based on a comprehensive environmental impact assessment study. In addition, the Water Framework Directive, the EU main environmental legislation affecting existing and new hydropower facilities, including PSH, aims to prevent further deterioration, protect, and enhance river basins and ecosystems located in the EU by requiring the development of river basin management plans and accompanying appropriate measures.[31]

Regarding demand response, for example, France has for a long time adopted time of use tariffs incentivizing electricity consumption when it is low or disincentivizing it during peak periods. What is new, however, is that thanks to digital technologies, such as smart meters, it is now possible to automize and fine tune electricity consumption adjustments. France targets to double its demand response capacity from less than 3 GW in 2019 to almost 7 GW in 2028.

Flexible operations of conventional power plants are not new either, but still France considers further improving the flexibility of its nuclear power stations, with reactors capable of ramping their output up and down by hundreds of megawatts within an hour, and Germany still highlights the importance of gas power plants.

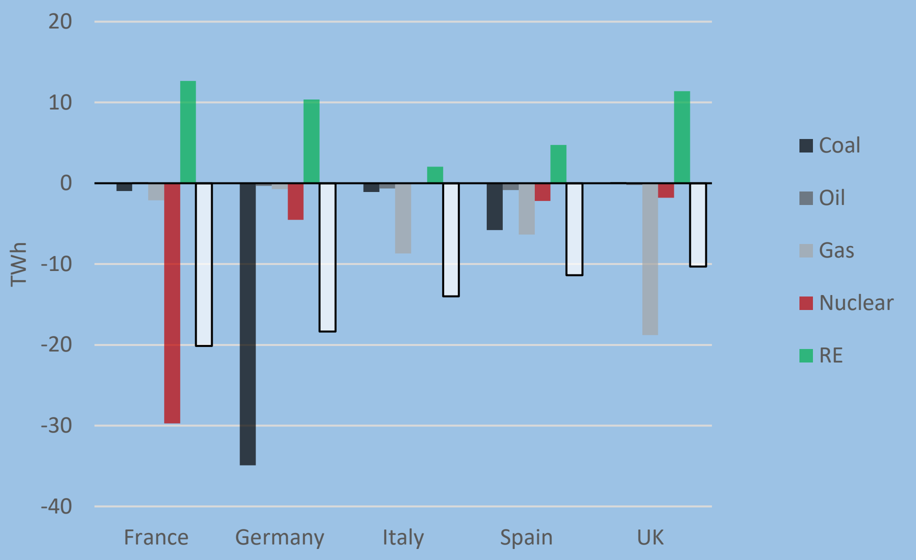
Box 1: Impacts of the COVID-19 Pandemic on the Power Sector of Europe’s Five Largest Economies

In 2020, the world has been struck by the COVID-19 pandemic. In response to this pandemic, sanitary measures such as lockdowns to reduce risks exposure to the virus have been implemented. These have impacted human activities at large, economic activity has been slow down notably. Energy supports economic activity and movement of human activities by transportation. In the case of electricity, one the most important impacts of COVID-19 on the power sector of Europe’s largest economies has been decreasing consumption.

Between January and June 2020, the electricity consumptions of Italy and Spain have been reduced the most; by 9% compared to the same period in 2019. The observed declines in France, Germany, and the UK all range between 6% and 8%.

The second impact of COVID-19 has been to penalize generating technologies which are the typical marginal sources of power with the highest marginal costs in their respective markets ("merit order dispatch”), for examples; nuclear in France, coal in Germany, and gas in the UK. In the first half of 2020, decreasing consumption has been combined with increasing generation from close to zero marginal costs RE. This combination has not only put downward pressure on electricity generation from nuclear and fossils, but also on electricity prices. Average spot prices in the first six months of this year have been quite low; below $30/MWh in France and Germany (compared to $45-50/MWh in the same period last year), and around $35-40/MWh in Italy, Spain and the UK (against $60-65/MWh a year ago). Selling less quantity at lower prices is a severe blow to nuclear and fossil power.

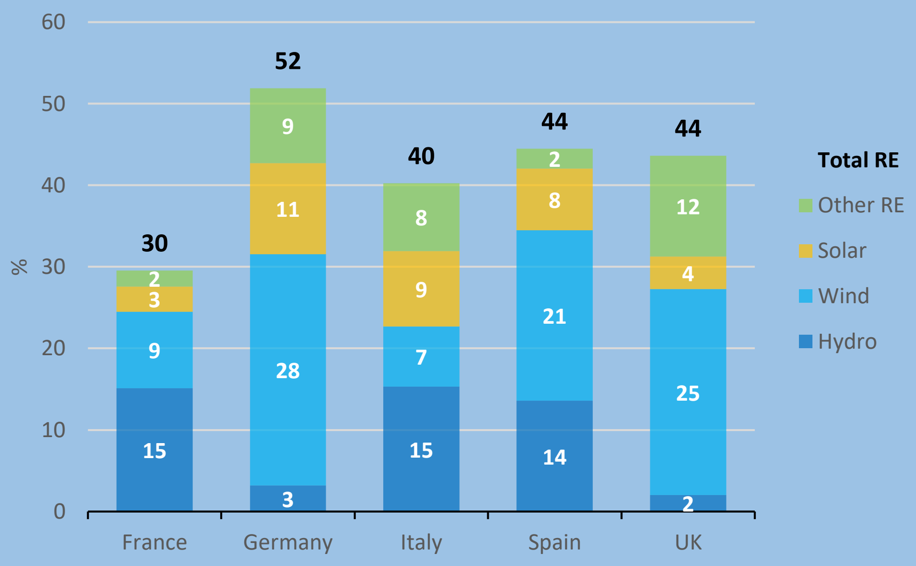
Europe’s Five Largest Economies Changes in Net Electricity Generation and Consumption 2020-2019 January-June



Notes: “RE” includes hydro, wind, solar photovoltaic & thermal, bioenergy & renewable waste, geothermal, and tide. Changes in “Other” including pumped storage, non-renewable waste, and unspecified sources are not represented because they are negligible (less than + or – 1 TWh in all countries).
Source: International Energy Agency, Monthly Electricity Statistics – Data up to June 2020 (September 2020).

The third impact of COVID-19 has been to demonstrate that it is already possible to integrate significant shares of RE. Indeed, in the first six months of this year, more than half of Germany’s electricity consumption has come from RE. Approximately, 40% to 45% in Italy, Spain, and the UK. And 30% in France.

Europe’s Five Largest Economies RE Shares in Electricity Consumption 2020 January-June



Note: “Solar” includes photovoltaic & thermal. “Other RE” includes bioenergy & renewable waste, geothermal, and tide.
Source: International Energy Agency, Monthly Electricity Statistics – Data up to June 2020 (September 2020).

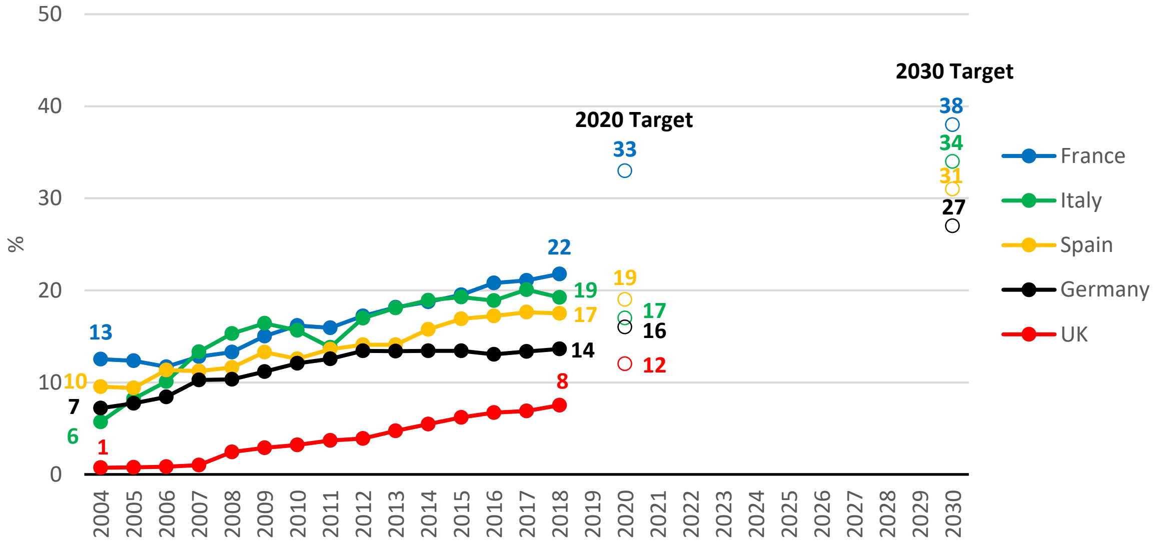
- Heading & cooling

Heating & cooling consumption may sometimes be electrified (e.g. heat pumps for residential uses), which with high RE electricity shares leads to decarbonization. It is, however, not possible to electrify all heating & cooling consumption (e.g. high temperature dispatchable heat in the industry). For all these cases, Europe's five largest economies are advancing RE targets. These targets if achieved would represent significant progresses from the current situation.

More specifically, France, Germany, Italy, and Spain would typically target to nearly double the share of RE in their heating & cooling consumption between 2018 and 2030. France, the leader among these countries, is projecting to increase the share of RE in its heating & cooling consumption from 22% to 38% in this period. Italy, which follows, aims at reaching 34% in 2030 from 19% in 2018. Spain and Germany forecast 31% and 27% in 2030 from 17% and 14% in 2018, respectively. Unfortunately, it is not possible to compare Japan with these countries because of a lack of accurate and reliable data.

Past experiences, progresses towards 2020 targets as of 2018, suggest reaching the 2030 targets will be no easy task. Indeed, with the exception of Italy, no other country has already reached its 2020 target for RE heating & cooling. Germany and Spain are not so far from meeting their 2020 targets. For France and the UK these targets seem out of reach (Chart 18).

Chart 18: Europe's Five Largest Economies RE Heating & Cooling Expansion 2004-2018 and 2020 & 2030 Targets



Sources: RE heating & cooling expansion 2004-2018 from Eurostat, Share of Energy from Renewable Sources – updated August 27, 2020 (accessed September 2, 2020), 2020 targets from European Commission, National Renewable Energy Action Plans 2020, and 2030 targets for European Commission, National Energy and Climate Plans (NECPs) (both accessed August 26, 2020).

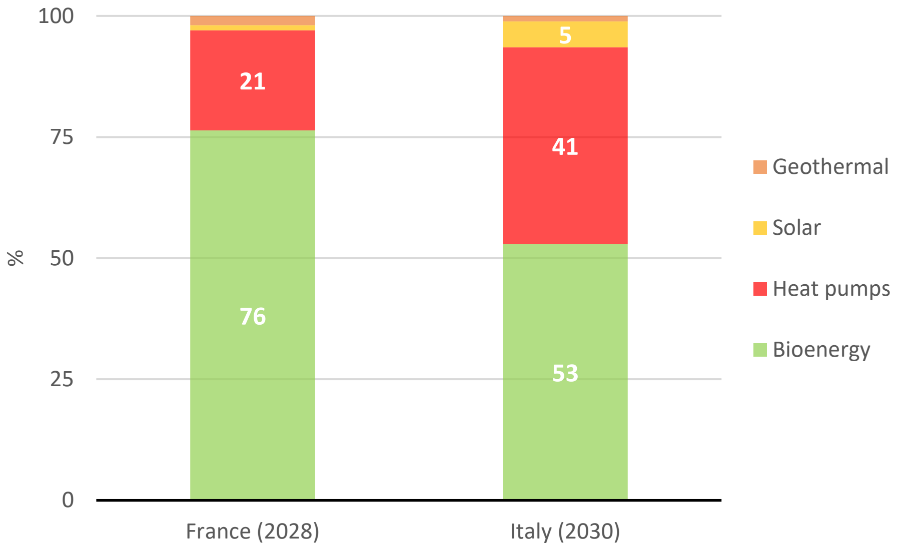
Though there may be technical difficulties in expanding RE heating & cooling, the lack of existing cost competitive RE alternatives – except bioenergy – to fossil fuels, especially gas, has been the biggest challenge until now. Indeed, in Europe's largest economies as of 2018, RE heating & cooling is very largely bioenergy, particularly solid biofuels (e.g. fuelwood, wood residues, wood pellets, animal waste, vegetal material…) – because of resource availability and access to it – and to a lesser extent RE municipal waste and biogases.[32]

Bioenergy for heat production is a mature industry and no significant costs reductions are expected neither in terms of technology or combustibles. Increasing bioenergy for heat production thus require support policies (as for examples grant funds), which is not the only direction taken by Europe's largest economies.

Indeed, these countries, are also promoting heat pumps to increase RE energy in their heating & cooling consumption, with the additional important benefit of improving indoor air quality through air filtration reducing allergens in the air. Today, equipment costs of heat pumps are higher than those of fossil heating technologies, for example in Germany air heat pumps (the most cost competitive heat pump technology in the country) costs per kilowatt are estimated to be about €940 (systems in large buildings) and €1,370 (small buildings) – roughly double the costs of gas and oil boilers. Like all new technologies, however, an increased uptake will trigger a faster industrialization and standardization of manufacturing, and consequently it will lower the costs.[33] For instance, for air heat pumps, Germany projects costs reductions of 3% by 2030. Policies to promote the expansion of heat pumps include; bonus in France, investment grants or low-interest loans in Germany, and tax deductions in Italy.

If these actions deliver the planned results, by 2030, heat pumps will become an important technology for RE heating & cooling behind bioenergy, in France and Italy notably (Chart 19).

Chart 19: France and Italy RE Heating & Cooling Consumption Mixes 2030 Targets



Notes: "Heat pumps" are included in RE because these technologies are using free energy from ambient temperature differences. For France, average values from two scenarios.
Sources: France (in French) and Italy from European Commission, National Energy and Climate Plans (NECPs).

Solar thermal (e.g. solar water heating collectors) and geothermal (e.g. deep geothermal for district heating) contributions to RE heating & cooling will be smaller.

In a more distant future, beyond 2030, green hydrogen will also play a role – an increasing role – as a substitute to fossil fuels, for industrial heat in oil refineries for example, thus contributing to RE expansion in heating & cooling and decarbonization (see CHAPTER 3 for more information).

- Transport

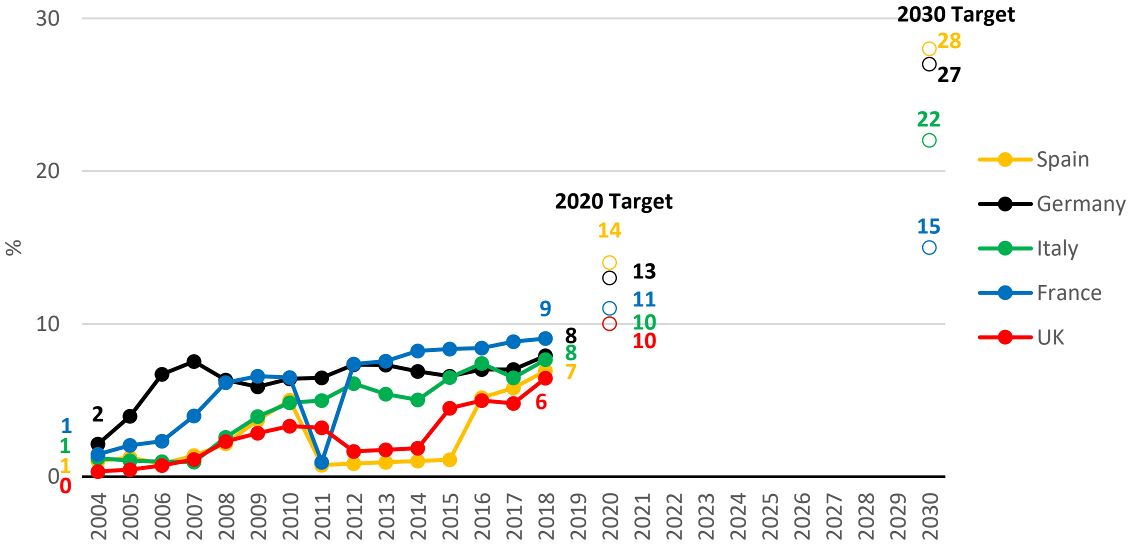
With the energy supply industries, transport is the other key sub-sector of the energy sector to decarbonize. Because of a lack of cost competitive alternatives to oil for mobility purposes so far (for example on the basis of the total cost of ownership, including fuel expenses as well as purchase costs, EVs are only gradually becoming competitive in some countries because of their sill higher upfront investment for consumers), RE penetration in transport has been much lower than in electricity and heating & cooling. Europe's largest economies' plans for RE in the transport sector is, however, spectacular increases – starting in the next ten years.

Indeed, Germany, Italy, and Spain project to triple or quadruple the share of RE in transport between 2018 and 2030, to reach 27%, 22%, and 28%, respectively, from 7-8%. Behind, France is less ambitious; 15% by 2030, despite being the most advanced country with 9% in 2018. Unfortunately, it is again not possible to compare Japan with these countries because of a lack of accurate and reliable data.

It may be noted that the statistical methodology to account for the contribution of RE in the transport sector is complex. Different multipliers are applied to the energy consumptions of different technologies to reflect their environmental and sustainable performances. For examples, the multiplication factor for advanced biofuels is 2, while that of electricity for road transport is 4, and that of electricity for rail transport is 1.5.

Reaching the 2030 targets will require substantial efforts as these countries will probably miss their not really ambitious 2020 RE transport targets (between 10% and 14% across all of Europe's five largest economies) (Chart 20).

Chart 20: Europe's Five Largest Economies RE Transport Expansion 2004-2018 and 2020 & 2030 Targets



Sources: RE transport expansion 2004-2018 from Eurostat, [Share of Energy from Renewable Sources – updated August 27, 2020]() (accessed September 2, 2020), 2020 targets from European Commission, [National Renewable Energy Action Plans 2020](), and 2030 targets for European Commission, [National Energy and Climate Plans (NECPs)]() (both accessed August 26, 2020).

Three options are mainly advanced to increase the proportion of RE in transport: bioenergy (increasingly based on advanced biofuels obtained in a sustainable manner from renewable raw materials such as biomethane originating from agricultural waste and the organic fraction of municipal solid waste) commonly and effectively supported by biofuel obligations, electrification, and green hydrogen. The latter two should be based on RE and their contributions decisive over the next thirty years. In this scope, Europe's largest economies are advancing policies in favor of electrification, especially of road transportation, and hydrogen for mobility purposes which for examples range from various types of subsidies to facilitate the acquisition of vehicles to the development of dedicated necessary infrastructures (e.g. charging stations) (see CHAPTER 3 for more information).

This new approach marks a shift of strategy as until now, the large majority of RE used in transport has come from conventional bioenergy (including biofuels produced from food and feed crops). For examples, the ratios bioenergy (including waste)/electricity (including both RE and non-RE electricity) in transport in France, Germany, Spain, and the UK in 2018 were between about 70/30 and 80/20.

The uses of bioenergy, RE electricity and green hydrogen will depend on transportation means and evolve over the coming decades as industrial progresses take place. More specifically, biofuels except advanced biofuels are relatively well-established, electric vehicles have started to take off, and hydrogen is expected to come next.

Into more details, regarding road transportation, which is by far the first source of GHG emissions in the transport sector of Europe's largest economies, electrification is expected to play an important role especially for passenger light-duty vehicles (BEVs and PHEVs) from the coming decade. Heavier transportation means such as trucks and buses may rather rely on hydrogen because of constraints related to batteries weight and volume, and limitations related to long charging times and availability of charging points.

As for rail, train electrification is further advanced where possible. Hydrogen may be a valid alternative when there is no electrified infrastructure to replace diesel locomotives.

Promotion of RE in maritime and air transportations is seen as more challenging for several reasons primarily cost and infrastructure, but also sustainability, changes in ship and aircraft designs or storage. Hydrogen or bioenergy could be used on ships, and bioenergy in airplanes for examples.

If these progresses take place as envisioned, and RE electricity also keeps expanding as planned, the share of RE electricity in total RE used for transport should increase. In the case of Germany – which appears to be the most ambitious country among Europe's largest economies, based on the data made available so far – the share of RE electricity in the total RE transport objective could increase from about 20-25% in 2020 to almost 50% in 2030.

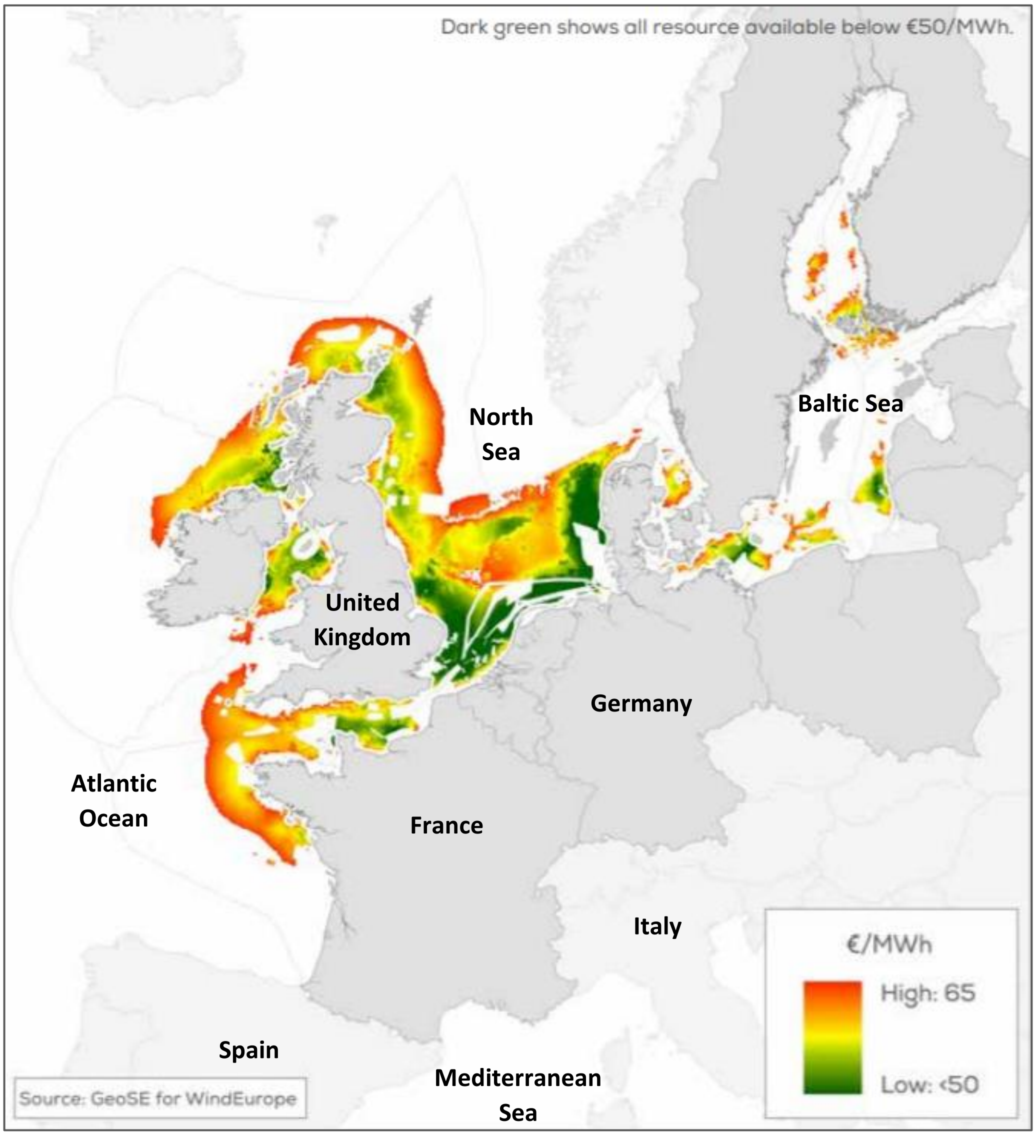
CHAPTER 3: KEY TECHNOLOGICAL ENABLERS

I Offshore Wind

- Economic potential

After onshore wind and solar PV, offshore wind has now become the third key new RE electricity generating technology Europe's largest economies are now massively investing in, especially the UK and Germany, but also France. The main reason behind this new trend is an enormous economically attractive resource potential; offshore wind with an LCOE of about $75/MWh or below (competitive with new gas and much cheaper than new nuclear) could cover between 80% and 180% of the EU total electricity consumption, forecasted at more than 3,200 terawatt-hours (TWh) in 2030. These excellent resources are largely located in the North Sea, and then in the Atlantic Ocean (Map 2).

Map 2: Europe Economically Attractive Offshore Wind Resource Potential at End of 2030



Notes: Based on the "upside scenario." The names of Europe's five largest economies and bodies of water have been added by Renewable Energy Institute.

Source: WindEurope, Unleashing Europe's Offshore Wind Potential: A New Resource Assessment (June 2017).

In Europe, thanks its access to the North Sea where there are good wind speeds, relatively shallow water, and distances to shore are not so long, the UK has by far the best offshore wind economically attractive resources, sufficient to at least cover the triple of its electricity consumption. Among Europe's largest economies, France has a more significant potential than Germany, but it will be more challenging to fully exploit it because in the Atlantic Ocean (west of France) there are high wind speeds, but also deeper waters, more extreme sea states, and some long distances to establish ports compared to in the North Sea.

The growth of offshore wind power in less favorable environments (as for examples the Atlantic Ocean as mentioned above, or the Mediterranean Sea to which France, Italy, and Spain have a direct access) will require the development of turbines mounted on floating foundations.

In comparison, most of Japan's significant offshore wind technical potential; more than 9,000 TWh per year – about 9 times the country's entire electricity consumption, is located in deep waters and thus requires floating platform technology.[34] To develop this rich resource, Japan may be inspired by the examples of the UK and France. The former because it is aggressively pursuing the expansion of its excellent potential, and the latter because it faces similarities in terms of challenging conditions (i.e. deep waters) to access good resources. Regarding floating offshore wind, France is planning to promote the technology by organizing dedicated auctions for hundreds of megawatts in the coming years. Prices are targeted to range between around $130/MWh and $140/MWh.[35]

Ideol's floating wind turbine in France

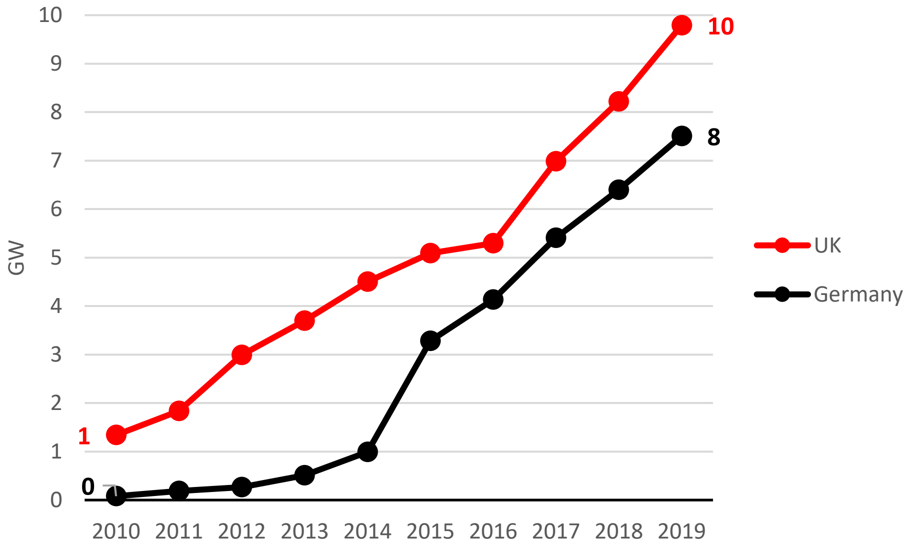
- Ambitions and progresses

Among Europe's largest economies, offshore wind power ambitions differ considerably, which is partly due to the availability of resources to exploit and the technological deployment achievements until now.

For instance, the UK not only benefits from the best resources, but it is also the world's leader in installed capacity. Taking advantage of a favorable situation and building upon its industrial success the UK has advanced very ambitious objectives for the medium-term; by 2030, it targets offshore wind to account for one-third of its electricity (compared to close to 10% in 2019) by multiplying by four its installed capacity to reach a whopping 40 GW (including 1 GW of floating offshore wind). This production would be more than enough to power every home in the country, based on current electricity usage.[36] The UK's installed capacity target is double that of Germany (20 GW) – another global offshore wind leader despite less good resources, and 7-8 times bigger than that of France (5-6 GW), which progresses have been relatively slow so far because of regulation complexities and consultations about sea uses. Less is to be expected from Italy and Spain. By 2030, the former plans only 1 GW and the latter has not made it clear yet what will be the contribution of offshore wind in its 50 GW overall wind power goal. Less favorable natural conditions (i.e. deep seabeds) and relative cost competitiveness in favor of onshore wind and solar PV are the key reasons currently holding back the expansion of offshore wind in these two countries.

Delivering the most ambitious 2030 offshore wind targets will be no easy task as it will require a significant industrial scale up. However, confidence may be found in the impressive capabilities to increase in size the industry has demonstrated both in the UK and Germany over the past decade. Indeed, back in 2010, the UK had only about 1 GW of offshore wind installed capacity and Germany nearly 0 GW. At the end of 2019, these numbers rose to 10 GW and 8 GW, respectively (Chart 21).

Chart 21: UK and Germany Offshore Wind Installed Capacity 2010-2019



Source: International Renewable Energy Agency, Renewable Energy Statistics 2020 (July 2020).

Progresses in offshore wind deployment in Europe have not been limited to the UK and Germany. For examples, Belgium and Denmark both had approximately 1.6-1.7 GW of offshore wind capacity installed at the end of 2019, and the Netherlands close to 1 GW.

As of 2020, in comparison to the UK and Germany, offshore wind developments in Japan have been quite limited; less than 0.1 GW. This fact should, however, not serve as an excuse to stick to the current very unambitious target of around 1 GW only by 2030. Japan's electricity market is roughly double the size that of Germany and triple that of the UK, and these latter two, which are thus both much smaller electricity markets, have each managed to add almost 10 GW of offshore wind power capacity in the past 10 years. In addition to its significant potential, market size and remarkable technological progress should definitely drive Japanese policy makers to seriously reconsider the future contribution of offshore wind in Japan's electricity mix. An ambitious target being the cornerstone to establish a powerful Japanese offshore wind industry.

- Support policies

Beyond targets, the main key policy instrument for concrete implementation of offshore wind power projects is the frequent organization of large-scale auctions.

Among Europe's largest economies, France, Germany, and the UK have already been implementing this strategy, smaller economies such as Denmark and the Netherlands as well, and based on past successes obtained will continue it. For instance, in the coming years, France, Germany, and the UK have announced their detailed plans to either hold multiple auction rounds with large-scale volumes at stake (i.e. hundreds of megawatts) as in the cases of France and Germany, or at least one round (subsequent auctions to be organized around two years thereafter) with an enormous pipeline of projects – between 7 GW and 8.5 GW (!) – as in the case of the UK (Table 8).

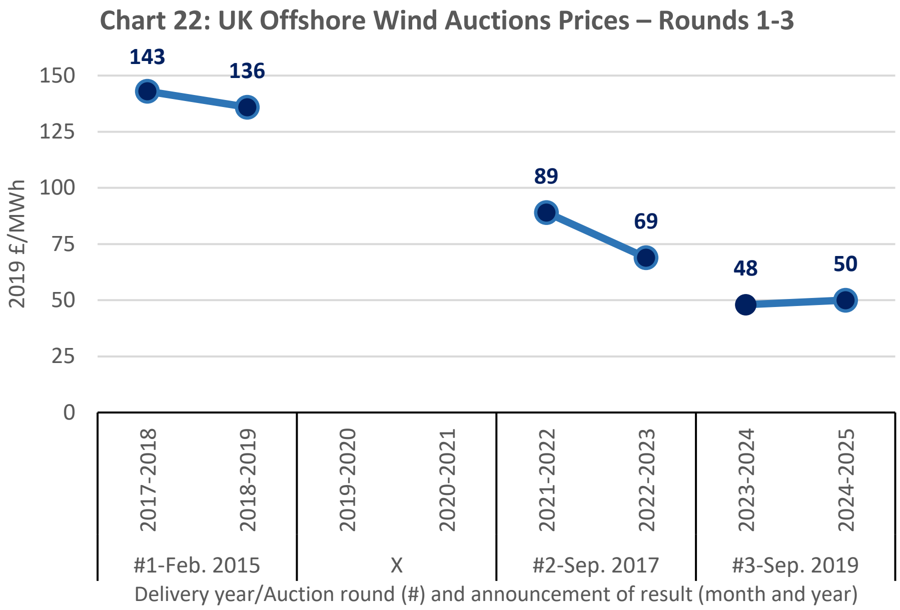
Table 8: France, Germany, and the UK Offshore Wind Planned Auctions

Country	Calendar and volume
France	2020; 1,000 MW (fixed), 2021; 250 MW (floating), 2022; 500 MW (floating), 2021-2022; 500-1,000 MW (fixed), 2023; 1,000 MW (fixed), and from 2024; 1,000 MW per year (fixed or floating)
Germany	From 2021; 700-900 MW per year
UK	2021; 7,000-8,500 MW

Sources: French Ministry of Ecological and Solidarity Transition, French Strategy for Energy and Climate: Multi-year Energy Programming 2019-2023 2024-2028 (April 2020) (in French), German Bundesnetzagentur, Wind Turbines at Sea (accessed September 23, 2020) (in German), and UK Oil & Gas Authority, UKCS Energy Integration Final Report: Annex 1. Offshore Electrification (August 2020).

Among important advantages of such planning initiatives are to give visibility and certainty to the investors in the sector. In addition, auctioning sizeable volumes enables economies of scale. These advantages combined with competition, which definitely is a central feature of auctions, and technological progresses, as for examples developments of larger turbines, simplification of offshore installations, innovations in floating foundations, and advances in electrical transmission infrastructures, especially high-voltage direct-current, have delivered substantial costs reductions and hence low or affordable prices in the past decade.

In the UK for example, between the first round of offshore wind auctions, which results have been announced in early 2015, and the third round of auctions, results announced in the second half of 2019 – just a little more than four years, offshore wind auctions prices have significantly decreased from £136-143/MWh to only £48-50/MWh (all constant 2019 prices – inflation indexed), a reduction of about 65% (Chart 22 on next page).



Source: United Kingdom Government, Department for Business, Energy & Industrial Strategy, Contracts for Difference Allocation Round Results 1 (February 2015), 2 (September 2017), and 3 (October 2019).

The most recent prices observed in the UK are equivalent to about $60/MWh prices. These compare to the result of France's third and latest auction in 2019 which reached a minimum price of €44/MWh or about $50/MWh. Even more impressive, in Germany in the two rounds of auctions held until now, in 2017 and 2018, some bids at market prices (without subsidies) were awarded projects.

These quite positive results should inspire Japanese policy makers to opt for these auction designs – frequent and large (at least several hundreds of megawatts) – as key mechanisms to support the takeoff of offshore wind in the country.

In addition, in the UK, the organization of auctions for offshore wind power has recently become part of a more ambitious and broader innovative plan with the launch in 2019 of the Offshore Wind Sector Deal deepening the partnership between the Government and the industry. The aim of this strategy is to build a Britain fit for the future based on the concept of clean growth. To realize this ambition the focus is on building the capability of a stronger local supply chain which will support productivity and enhance companies' competitiveness domestically and internationally. Among the key support policies are; (1) the commitment from the Government to run regular auctions, using up to more than $700 million for future contracts for difference (the key support mechanism in the UK which pays generators the difference between a fixed strike price and a market reference price), and (2) an industry investment into the Offshore Wind Growth Partnership of up to almost $320 million focusing on direct support to supply chain companies (e.g. array cables, blade manufacturing, civil engineering, logistics, offshore operations, vessels…) through a combination of strategic capability assessments, advisory services and grant funding.[37]

- Europe's five largest economies main power companies' interests

The energy transition in the power sector is deeply affecting the business of incumbent power companies by deteriorating the economics of their existing fossil and nuclear power plants. As a result, these companies are increasing their RE power plant portfolios by massively investing in solar PV and wind on- & off-shore. Offshore wind which offers bigger project sizes than solar PV and onshore wind has particularly raised the attention of some major power companies in Europe's largest economies.

For examples; EDF, in France, takes part in four large-scale offshore wind projects totaling 2 GW, including 480 megawatts (MW) under construction. Still in Europe, in the UK notably, the French Group also participates in the Neart Na Gaoithe 450 MW project under construction in the North Sea off the east coast of Scotland.[38] The UK offshore wind market has also been entered by another big French power company, ENGIE, which is active in the construction of the Moray East 1 GW project, also in the North Sea off the east coast of Scotland. ENGIE's main other under construction offshore wind project is in Belgium; the Seamade Seastar 1 project, 0.5 GW in the North Sea.[39] German RWE is now a well-established participant in the offshore wind market with installed capacity of around 2 GW mainly in the UK, but also in Germany.[40] Spanish Iberdrola despite limited domestic offshore wind developments has found growth opportunities in offshore wind – mainly in the UK again.[41] In comparison, only Italian Enel, now a global leader in solar PV, seems to be set back, at least for now, because of the Group's recognition that the technology is more expensive than onshore wind, and riskier, given the lack of a long-term track record for operation and maintenance.

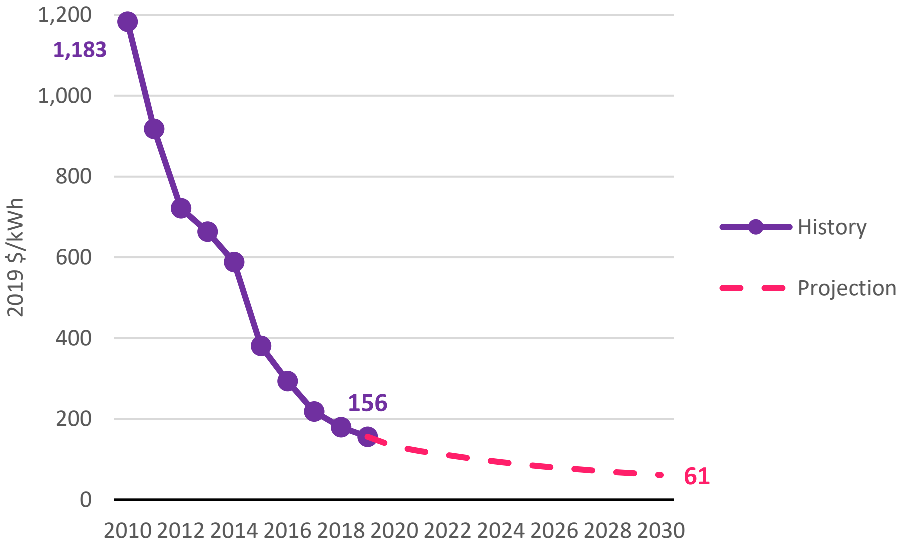
The participation of large power companies in offshore wind developments may be seen as good news as these companies have the investment strengths required to inject substantial sums into big projects. In this regard, the interests of power companies such as Tokyo Electric Power Company or Chubu Electric Power Company in the Japanese nascent offshore wind industry are promising.[42]

II Road Electrification

- Objectives

Road transportation – and predominantly cars – is by far the first source of GHG emissions in the transport sector of Europe's five largest economies making it one of the main environmental issues. However, thanks to technological innovation and industrial progresses resulting in lower battery prices (Chart 23), the necessary decarbonization of road transportation through electrification has become possible.

Chart 23: Worldwide Lithium-ion Battery Prices Reductions 2010-2019 and Projections to 2030



Source: BloombergNEF, Long-term Electric Vehicle Outlook 2020 (May 2020 – subscription required).

This analysis is commonly shared in Europe's largest economies (the exceptional case of Norway is separately and shortly presented in Box 2 "Electric Vehicles in Norway, a Glimpse of the Future" on page 53). That is the reason why in recent years these countries have advanced new ambitious goals for road electrification, and particularly for different electric cars (Table 9) which will therefore be focused on in this chapter.

Table 9: Different Types of EVs Acronyms and Definitions

Type	Acronym	Definition
Battery electric vehicle	BEV	Exclusively uses chemical energy stored in rechargeable battery packs (unlike a PHEV, a BEV does not have an internal combustion engine)
Fuel cell electric vehicle	FCEV	Combines hydrogen with oxygen in a fuel cell to generate the electricity needed to power an electric motor
Plug-in hybrid vehicle	PHEV	Has both an electric motor and internal combustion engine, and can be plugged in (it does not include hybrid electric vehicles that cannot be plugged-in)
Zero-emission vehicle	ZEV	Includes BEV, FCEV, and PHEV with zero emission

Source: Created by Renewable Energy Institute

For instance, both France and the UK have announced plans to fully phaseout the sales of new internal combustion engines (ICE) by 2040 and 2030, respectively, fully opening the door to alternative technologies and especially EVs. In different ways, Germany and Spain, aim for a similar goal by having committed to 100% zero-emission vehicles (ZEVs), including (BEVs, FCEVs, and PHEVs), by 2050 and 2040, respectively. Italy has not gone so far yet, but still the country pursues a 2030 target of 6 million EVs out of which 4 million should be BEVs, the rest being PHEVs (Table 10).

Table 10: Europe's Five Largest Economies National Electric Car Deployment 2030-2050 Targets

Country	2030	2040	2050
France	3 million BEVs, 1.8 million PHEVs (2028)	No sales of new cars and vans using fossil fuels	X
Germany	7-10 million BEVs, FCEVs	X	All passenger vehicle sales to be ZEVs
Italy	4 million BEVs, 2 million PHEVs	X	X
Spain	5 million EVs	100% ZEV sales	X
UK	No sales of new ICE (2030)	X	X

🟦 Relative to vehicle stock

🟨 Full ICE phase out or 100% EV target

Sources: for France, Germany, Italy, and Spain from International Energy Agency, Global EV Outlook 2020 (June 2020), and for the UK from United Kingdom Government, Department for Business, Energy & Industrial Strategy, The Ten Point Plan for a Green Industrial Revolution – updated November 18, 2020 (accessed November 25, 2020).

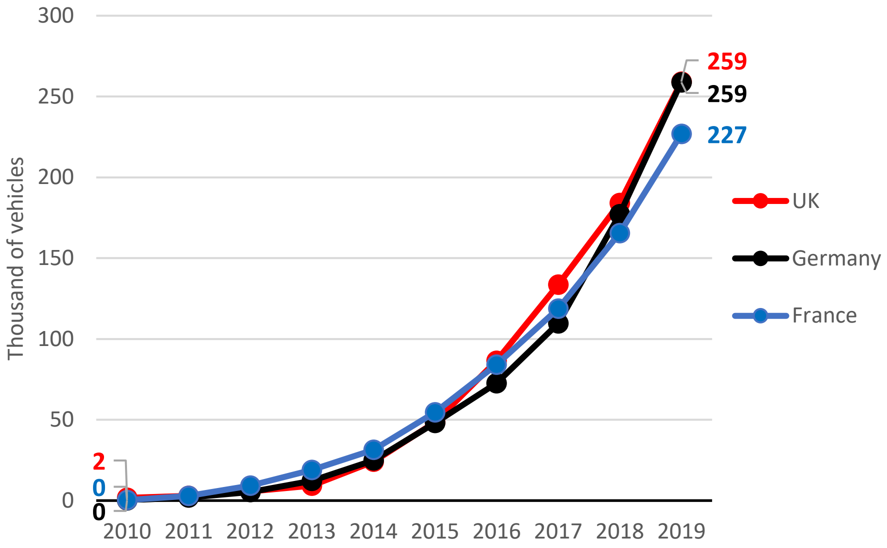
The exact amounts of GHG emissions reductions targeted from these specific measures for electrification are not provided. They are included in the total GHG emissions reductions in the transport sector.

In addition to vehicle-oriented target types, France and Germany, for examples, have also adopted charging infrastructures targets. More specifically, France aims for 100 thousand of public charging points by 2023 – more than a tripling from 2019, and Germany 1 million by 2030 – from less than 40 thousand last year.

- Progresses

In 2019, after a decade of explosive growth supported by more favorable economics and support policies, in France, Germany, and the UK the total electric car stock (only including BEVs and PHEVs, not FCEVs which number is quite small) reached about 230-260 thousand of vehicles in each country (Chart 24). Into greater details, France had the lowest total electric car stock, but the highest number of BEVs 167 thousand, clearly ahead of Germany 146 thousand. The UK's had by far the highest number of PHEVs 160 thousand, and lowest number of BEVs just below 100 thousand. In comparison, with 294 thousand of vehicles the total electric car stock of Japan was a little higher than in these three countries – principally owing to a larger automobile market size.

Chart 24: France, Germany, and the UK Electric Car Stock 2010-2019



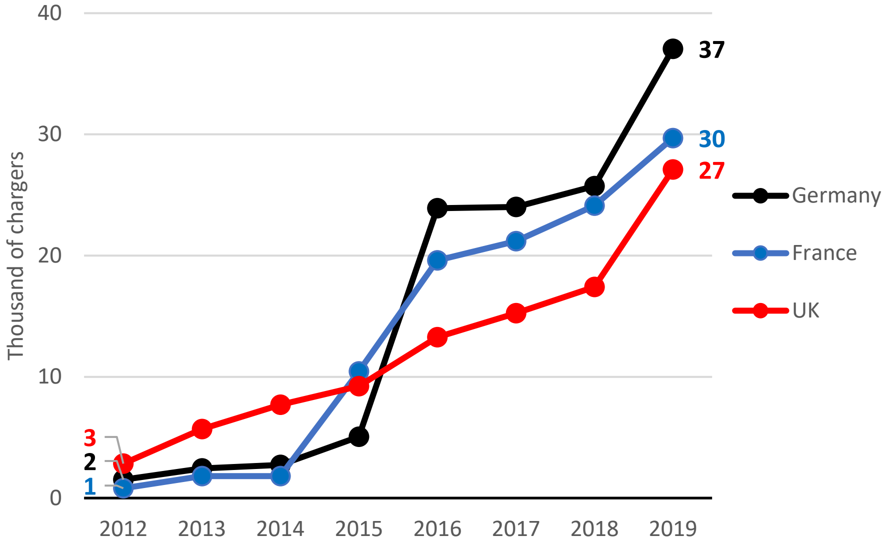
Note: Including BEVs and PHEVs, excluding FCEVs (quite small in these three countries).
Source: International Energy Agency, Global EV Outlook 2020 (June 2020).

At around 3% in France, Germany and the UK, the market shares of electric cars in new vehicle registrations remain small, but are increasing.

Regarding publicly accessible chargers (including both slow and fast chargers), infrastructure developments are also well underway. In 2019, among Europe's largest economies, Germany was leading with 37 thousand of public chargers installed. France and the UK followed with approximately 27-30 thousand of public chargers (Chart 25 on next page). In these three countries, chargers were primarily slow chargers (up to 22 kilowatts).

To provide some additional contextual information, at the end of 2019, France had some 11 thousand gas stations, Germany 14 thousand, and the UK 8 thousand.[43]

Chart 25: France, Germany, and the UK Publicly Accessible Chargers 2012-2019



Source: International Energy Agency, [Global EV Outlook 2020](#) (June 2020).

In comparison, there were about 30 thousand publicly accessible chargers in Japan in 2019. This number is similar with those of France and the UK, two smaller automobile markets, suggesting more can be done in Japan to extend the EV charging network.

- Incentives

Because EVs are not perfectly cost competitive with conventional vehicles yet, particularly when it comes to the upfront investment for consumers, the electric car market still relies on governments' support schemes.

In all of Europe's five largest economies measures to support the adoption of EVs are implemented. These essentially fall under two categories; purchase subsidies and tax reductions.

Depending on vehicle types (BEV, PHEV, FCEV), GHG emissions or electric range thresholds, and if an old car (e.g. newly registered before 2011 in Italy) is scrapped (i.e. vehicles sold are not eligible), purchase subsidies worth thousands of United States dollars possibly combined with tax reductions (exemption of registration tax, temporary exemption from annual ownership tax) are applicable. Purchase subsidies are often capped to maximum retail price.

To illustrate, France, Germany, and Italy all offer maximum purchase subsidies of $6,800, but conditions required to be met to obtain this maximum sum differ. In the case of France, BEVs, FCEVs and highly efficient PHEVs with emissions below 20 gCO2/km (i.e. a level almost 5 times lower than the European emission standards for new passenger cars) are eligible to this maximum purchase subsidy if their retail prices do no exceed $50,800. In addition, in many subnational regions of the country new EVs are exempted from registration tax. In Germany, only BEVs which retail prices do not exceed $45,200 are eligible to this maximum subsidy. Finally, in Italy, when scrapping an old car at the same time as buying an EVs with emissions below 20 gCO2/km the maximum purchase subsidy may be received. And in the case of a BEV, the buyer of the vehicle is exempted from the annual ownership tax during the first five years after registration (Table 11 on next page).

Table 11: Europe's Five Largest Economies National Electric Car Purchase Incentives

Country	Purchase subsidy	Tax reduction	Comments
France	$6,800* / $3,400** (BEV, FCEV and PHEV < 20 gCO2/km)	No registration tax in many subnational regions	* Maximum retail price $50,800, ** $67,800 (not applying to FCEV). Subsidy can be increased if an old car is scrapped (depending on revenues)
Germany	$6,800* / $5,600** (BEV) $5,100* / $4,230** (PHEV)	X	* Maximum retail price $45,200 ** Retail price between $45,200 and $73,400
Italy	$6,800* / $4,500** (0-20 gCO2/km) $2,800* / $1,700** (21-70 gCO2/km)	BEV exempt from annual ownership tax during five years after registration	* When scrapping an old car at the same time as buying the EV ** Without scrapping an old car
Spain	$1,500 – 6,200* (PHEV and BEV)	X	* Depending on electric range: $6,200 > 72 km. Only applicable if retail price < $45,200
UK	Up to $3,800* (BEV and PHEV**)	X	* Capped at 35% of retail price. Only for cars < $63,600 ** If < 50 gCO2/km and electric range >112 km

Source: International Energy Agency, Global EV Outlook 2020 (June 2020).

In comparison, in Japan, purchase subsidies up to $3,700 for BEVs and up to $1,800 for PHEVs are available, which are lower than in most of Europe's largest economies. These, however, come with tax reductions such as no purchase tax for example. Also, it may be highlighted that Japan supports the adoption of FCEVs to a level unseen in all of Europe's largest economies with purchase subsidies up to $20,800. This clearly demonstrates a different strategical option choice.

- Europe's five largest economies car industry's response

The push in favor of EVs is deeply impacting the business of the car industry in Europe's five largest economies. And major manufacturers are showing that they are responding to the challenge by announcing new objectives for EVs for the years to come and up to 2030, in terms of sales, share in Group's sales, or new models for examples (Table 12 on next page).

For instance, by chronological order; between 2020 and 2022, German Group Volkswagen has announced a target of selling 300 thousand EVS by the summer 2020. Another German Group, Daimler, 100 thousand in 2020. And French PSA almost 1 million in 2022. In the middle of the decade, Volkswagen projects to increase its EV sales up to 3 million. And by the end of the decade it forecasts about 26 million cumulative sales.

In terms of EVs share in Group's sales, also by chronological order; in 2022, French Brand Renault aims for 20%. In 2025, German BMW 15-25%, and Daimler and Volkswagen 25% both. By 2030, Daimler pursues the goal that more than half of its sales will come from EVs.

Finally, in the period 2021-2023, BMW, Daimler, PSA, and Renault, will each advance between 10 and 14 new models. And by 2029, Volkswagen seeks to develop 75 new models.

Table 12: Europe's Five Largest Economies Main Car Manufacturers' Announcements for EVs

Country	Group	Announcement		
		Sales	Share in Group's sales	New models
France	PSA	900 thousand in 2022	X	14 by 2021
	Renault	X	20% in 2022	12 by 2022
Germany	BMW	X	15-25% in 2025	13 by 2023
	Daimler	100 thousand in 2020	25% in 2025 More than 50% by 2030	10 by 2022
	Volkswagen	300 thousand by summer 2000 Up to 3 million in 2025 About 26 million cumulative by 2029	25% in 2025	75 by 2029

Note: Renault is a Brand of the Renault-Nissan-Mitsubishi Alliance (Group) with its own objectives.
Source: International Energy Agency, Global EV Outlook 2020 (June 2020).

In comparison, announcements made by major Japanese car manufacturers are relatively less ambitious. For examples; the Toyota Group targets more than 1 million BEV and FCEV sales in 2030, and 10 new BEV models by the early 2020s. The Honda Group aims for 15% EV sales in 2030. And the Nissan Brand pursues eight new BEV models by 2022.

Renault Zoe electric vehicle

Box 2: Electric Vehicles in Norway, a Glimpse of the Future

At the end of 2019, with an electric car stock of 329 thousand of vehicles Norway was the world's third largest EV market, behind China and the United States, and Europe's largest. In the Nordic country in 2019, the market share of EVs in new vehicle registrations even reached a global historical record of 56% (!), largely thanks to the significant growth of BEV sales.

Norway has significant hydropower resources, sufficient to cover its entire electricity consumption (about 120-130 TWh since 2010) depending on years. Taking advantage of this favorable environmental situation, and of quite positive global economic and technological developments in the EV industry, the country has decided to move faster than any other to decarbonize its automobile sector by targeting all new cars sold in 2025 to be ZEVs.

Norway is successfully making this change happening fast not thanks to purchase subsidies, as available in all of Europe's largest economies, but mainly thanks to tax exemptions. The most notable of which is the value-added tax exemption on BEVs (this tax is usually 25% for cars in Norway).

The next key challenges for Norway will be to progressively reduce economic incentives, keep up with charging infrastructure installations – there were almost 10 thousand publicly accessible chargers (out of which more than 40% were fast chargers) in the country in 2019, and ensure proper grid integration of EVs.

III Green Hydrogen

- Brief Description

Green hydrogen is produced via the electrolysis of water, and the electricity that is used for the electrolysis is to be derived from RE sources. Irrespectively of the electrolysis technology, this production process is considered to be zero-carbon since all the electricity used comes from RE sources which are zero-carbon.

In comparison to green hydrogen, grey and brown hydrogens which are based on the use of fossil hydrocarbons, natural gas and coal, respectively, are mainstream today and entails considerable GHG emissions.

The development of green hydrogen and its widespread use may lead to deep transformations since it has the potential to be an effective solution for key decarbonization challenges.

For instances; in the power sector, the energy density of green hydrogen makes it a suitable energy vector for storing energy (particularly seasonal) and subsequently releasing it gradually. Since more and more electricity will be generated from solar and wind power with periods of excess and lack, green hydrogen is one of the promising flexibility complements. Moreover, in the chemical (e.g. ammonia), refining or steel industries, green hydrogen may be used as a substitute for fossil fuels. Already today, ArcelorMittal Europe is actively exploring steelmaking from green hydrogen by creating one of Europe's first industrial-scale direct reduced iron plants that uses hydrogen for the direct reduction of iron ore, instead of natural gas.[44] Finally, in transport, green hydrogen could be used rather in heavy road transport than passenger cars – a market largely and increasingly dominated by BEVs, trains, ships and airplanes. Regarding the latter, the European aerospace Group Airbus recently revealed three concepts for the world's first zero-emission commercial aircraft with traveling ranges of more than 1,000 or 2,000 nautical miles which could enter service by 2035 – all of these concepts rely on hydrogen as a primary power source.[45]

AirbusZEROe Blended Wing Body Concept

However, before these visions become reality, green hydrogen will first need to be cost competitive compared to fossil-based hydrogen, which does not appear insurmountable; estimated costs today for fossil-based hydrogen are around $1.5-2.0 per kilogram for the EU (depending on natural gas prices, and disregarding the cost of CO2), and for green hydrogen $3.0-6.5 per kilogram.[46] On the one hand, internalizing the negative externalities from fossil-based hydrogen by putting a price on these or recognizing the climate change mitigation benefits of green hydrogen leading to an increasing willingness to pay for it would help filling the gap in. On the other hand, cheap RE electricity and significant costs reductions in electrolyzers (60% in the last ten years) will also contribute to bridge the gap.

These developments, in addition to the facts that new investment plans are frequently announced in Europe and that the number of companies joining the Hydrogen Council based in Brussels, Belgium – a global initiative of leading energy, transport and industry companies (e.g. General Motors, Microsoft, Saudi Aramco, Sinopec, Toyota…) with a united vision and long-term ambition for hydrogen to foster the energy transition – has grown from 13 to 92 in the past three years, have led European countries and companies to conclude that green hydrogen is now close to a tipping point for its takeoff.[47]

As a result, the EU, countries like France and Germany, as well as businesses now have strategies in place to promote the development of green hydrogen. The remainder of this chapter introduces these actors' plans.

- The European Union's strategy[48]

During the summer 2020, the European Commission advanced its hydrogen strategy. This strategy highlights the facts that hydrogen can be used as feedstock, a fuel or an energy carrier and storage, and has many possible applications across industry, transport, power and buildings sectors. Also, it stresses that hydrogen does not emit CO2 and almost no air pollution when used and therefore offers a solution to decarbonize industrial processes and economic sectors where reducing carbon emissions is both urgent and hard to achieve. As a result, hydrogen is recognized as “essential” to support the EU commitment to reach carbon neutrality by 2050.

The EU, however, notes that hydrogen needs to be scaled up, its production fully decarbonized; from fossil fuels, notably natural gas and coal, to RE (i.e. “green hydrogen” using mainly solar and wind) – a priority clearly identified, and that it has to become cost competitive.

It may be added that the EU sees “blue hydrogen” (i.e. hydrogen produced using a CCS system) as transitional. It stresses the fact that CCS has not yet reached the commercialization stage, hampered by lack of demonstration of the technology and economic viability, and limited public acceptance. When it comes to electricity generation especially, CCS may rather be fitted to biopower plants than fossil power plants.

To realize its hydrogen strategy, the EU industry has developed an ambitious plan in three chronological phases:

First, between 2020 and 2024, deployment of at least 6 GW of renewable hydrogen electrolyzers to produce of up to 1 Mt of green hydrogen in the EU by 2024. The objective is to decarbonize existing hydrogen production (e.g. in the chemical sector) and facilitating take up of hydrogen consumption in new end-use applications such as other industrial processes (e.g. steel) and possibly in heavy-duty transport. In this period, manufacturing of electrolyzers, including large ones (up to 100 MW), needs to be scaled up. Electrolyzers could be installed next to existing demand centers in larger refineries, steel plants, and chemical complexes. Ideally, they would be powered directly from local RE. In addition, hydrogen refueling stations will be needed for the uptake of hydrogen fuel-cell buses for example.

Second, from 2025 to 2030, hydrogen becomes an intrinsic part of an integrated energy system, at least 40 GW of renewable hydrogen electrolyzers are deployed to produce of up to 10 Mt of green hydrogen in the EU by 2030. In addition, the EU will also pursue the installation of 40 GW of renewable hydrogen electrolyzers in Europe’s neighborhood with export to the EU. According to the EU, 2030 is the time horizon when in regions where RE electricity is cheap, electrolyzers are expected to be able to compete with fossil-based hydrogen. Gradually, new applications for trucks, rail, and some maritime transport are advanced. Green hydrogen also starts to provide balancing services in RE based power systems enhancing security of supply. In this phase, the need for an EU-wide logistical infrastructure will emerge, and steps will be taken to transport hydrogen from areas with large RE potential to demand centers. The back-bone of a pan-European grid will need to be planned and a network of hydrogen refueling stations to be established. The existing gas grid could be partially repurposed for the transport of green hydrogen over longer distances and the development of larger-scale hydrogen storage facilities would become necessary. International trade can also develop, in particular with the EU neighboring countries in Eastern Europe (e.g. Ukraine) and in the Southern and Eastern Mediterranean countries (e.g. Algeria, Egypt, Morocco…).

Third, between 2030 and 2050, green hydrogen technologies should reach maturity and be deployed at large scale to reach all hard to decarbonize sectors where other alternatives might not be feasible or have higher costs.

From a financial perspective, achieving the goals outlined above will require strong investments. From now to 2030, the EU estimates that investments in electrolyzers could range between €24 and €42 billion. In addition, investments of €65 billion will be needed for hydrogen transport, distribution and storage, and hydrogen refueling stations. To support these investments and the emergence of a whole hydrogen eco-system, the European Commission started the European Clean Hydrogen Alliance that brings together industry (e.g. Air Liquide, BASF, Bosch, BP Europa, Daimler Truck, EDF, Enel, ENGIE, Mitsubishi Hitachi Power Systems Europe, RWE, Shell, Siemens Energy, Total, Toyota Motor Europe…), national & local public authorities, civil society, and other stakeholders with activities for green or low carbon hydrogen (including non-renewable; fossil-based hydrogen with carbon capture, and electricity based hydrogen).[49] The priority is given to green hydrogen for the long-term, low carbon hydrogen being used during a transition period.[50] The key deliverable of this Alliance will be to identify and build up a clear pipeline of viable investment projects. Between 1.5 GW and 2.3 GW of new green hydrogen production projects are already currently under construction or announced, and an additional 22 GW of electrolyzer projects are envisaged and would require further elaboration and confirmation. If all of these projects were realized, about 60% of the EU 40 GW renewable hydrogen electrolyzers 2030 target would be achieved.

The launch of the European Clean Hydrogen Alliance is one of the key actions of the overall energy policy of the EU to promote hydrogen. It falls within the area of developing an investment agenda. There are four others areas identified by the EU in which key actions should be taken: boosting demand for and scaling up production, designing an enabling and supportive framework, promoting research and innovation, and the international dimension (Table 13).

Table 13: Areas and Key Actions Identified by the EU to Promote Hydrogen

Area	Example of key action(s)
Developing an investment agenda	Through the European Clean Hydrogen Alliance, stimulate the roll out of production and use of hydrogen and build a concrete pipeline of projects (by end of 2020)
Boosting demand for and scaling up production	Explore additional support measures, including demand-side policies in end-use sectors for green hydrogen (by June 2021)
Designing an enabling and supportive framework	Start the planning of hydrogen infrastructure and accelerate the deployment of different refueling infrastructure (2021)
Promoting research and innovation	Launch a 100 MW electrolyzer and a Green Airports and Ports call for proposals (Q3 2020)
The international dimension	Promote cooperation with Southern and Eastern Neighborhood partners and other countries, notably Ukraine on RE electricity and hydrogen

Source: European Commission, A Hydrogen Strategy for a Climate-neutral Europe (July 2020).

At this stage, it is certainly too early to assess the success of these nascent initiatives. Nonetheless, the facts that the EU has advanced such ambitious strategy and is making concrete first steps in this direction are clear indications that meaningful progress is set to take place.

- Main points of France and Germany's strategies[51]

Announced in the past few months the new national hydrogen strategies of France and Germany are among the world's most significant roadmaps to date.

In both countries, not only green hydrogen is part of the national hydrogen strategies, but in the case of France decarbonized hydrogen (i.e. based on electricity from RE or nuclear) is clearly advanced, and Germany considers only green hydrogen (electricity generation from offshore wind is highlighted notably) to be sustainable in the long-term. Blue hydrogen is not considered in France's hydrogen strategy, and barely mentioned in that of Germany. The objective is to decarbonize industrial activities such as steel or chemicals, as well as some segments of transport; trucks, buses, trains, ships, and aircrafts.

The French strategy allocates €7 billion to hydrogen funding by 2030. The German one €9 billion, including €7 billion for speeding up the market rollout of hydrogen strategy in Germany and another €2 billion for fostering international partnerships. Regarding the latter, an important difference between the two countries is that Germany emphasizes the importance of green hydrogen imports. For instance, Germany recognizes that the domestic generation of green hydrogen will not be sufficient to cover all new demand, which is why most of the hydrogen needed will have to be imported (e.g. from other EU Member States, particularly those bordering the North and Baltic Seas, but also with the countries of Southern Europe).

In terms of targets for electrolyzers, France aims for 6.5 GW installed by 2030, and Germany 5 GW by 2030, rising to 10 GW by 2035-2040. Assuming – as Germany does; 4,000 hours full-load hours of electrolyzer operation per year and an efficiency ratio of 70%, with 6.5 GW and 5 GW of installed capacity France and Germany could generate 18 TWh and 14 TWh or 0.5 Mt and 0.4 Mt, respectively, of decarbonized and green hydrogens in 2030. In comparison, France's current annual hydrogen consumption is 0.9 Mt, and that of Germany 1.7 Mt, in both countries most of these hydrogen consumptions are fossil-based.

In addition, France has various additional hydrogen-related goals to be met by 2028, such as; reaching an incorporation rate of decarbonized hydrogen into industrial hydrogen of 20-40%, increasing the number of heavy hydrogen vehicles to 800-2,000, or developing hydrogen charging stations from about 30 in 2019 to 400-1,000.

To spur the adoption of hydrogen, more support schemes than those already existing, essentially capital grants, are yet to be advanced.

Behind France and Germany, recently, Spain unveiled its roadmap for 4 GW of electrolyzers to produce green hydrogen by 2030, and the UK announced targeting 5 GW of electrolyzers for low carbon hydrogen (similar to France's decarbonized hydrogen, including CCS additionally) by 2030 – without presenting a comprehensive strategy yet (it should be the case in 2021).[52]

- Three major European projects

Green hydrogen projects with MW-scale electrolysers to be fed by cost competitive solar or wind power are taking shape across Europe. These projects involve various actors such as large oil & gas or power companies, notably.

This sub-section quickly presents three of the most significant ongoing projects in this field – all of which are probable and on schedule, and their capital expenditure unknown; Hyport Ostend in Belgium, HyGreen Provence in France, and NortH2 in the Netherlands (Table 14 on next page).

Table 14: Three Major European Green Hydrogen Projects

Country	Project name	Owners	Target use	Electrolyzer	RE	Completion
Belgium	Hyport Ostend	DEME, PMV, Port of Oostende	Transport, heating and industry	50 MW	Curtailed wind power	2025
France	HyGreen Provence	ENGIE, Air Liquide, Durance Luberon Verdon Agglomération	Industry	760 MW	900 MW of solar	2027
Netherlands	NorthH2	Shell, Gasunie, Groningen Seaports	Industry	750 MW	10 GW of offshore wind	2040

Source: Institute for Energy Economics and Financial Analysis, Great Expectations: Asia, Australia and Europe Leading Emerging Green Hydrogen Economy, but Project Delays Likely (August 2020).

Hyport Ostend, Belgium

This project is the smallest in size; the electrolyzer installed capacity is to be “only” 50 MW. Also, contrarily to the two other selected projects it is planned to use existing generating capacity by consuming curtailed wind power, and to use green hydrogen for various purposes; transport, heating and industry. Of the three projects presented here, it should be the first completed – by the middle of the current decade if progresses take place as scheduled (currently in the general feasibility phase).

Partners engaged in the projects are: PMV which has experience in financing the development, construction and operation of the infrastructure necessary for energy projects, DEME which is one of the pioneers in the development of offshore energy projects, and Port of Oostende which is the host of the project and aims at expanding it sustainable economic activities.

HyGreen Provence, France

This project is quite ambitious as it aims to develop not only a large electrolyser; 760 MW – the largest of the three selected projects, but also close to 1 GW of new solar power capacity for green hydrogen production to meet industrial needs. Completion is scheduled for 2027 (currently in the pre-development phase).

Participants involved in the projects are: ENGIE which is one of Europe’s largest power companies, Air Liquide which is a world leader in gases, and Durance Luberon Verdon Agglomération which is the host of the project.

NortH2, Netherlands

This project is gigantic, not by the scale of its electrolyzer – still quite large at 750 MW, but by the new planned offshore wind capacity to feed the electrolyzer; possibly 10 GW by 2040 (!), located in the North Sea. Hydrogen production for industrial uses could begin by 2027, initially powered by 3-4 GW of offshore turbines (currently in the feasibility study phase).

The decision regarding the location of the electrolyser (on- or off-shore) is not yet finalized. Placing it offshore would avoid the transmission of electricity back to the mainland, a process which requires costly underwater cables and incur transmission losses. The possibility of installing and operating an electrolyzer offshore is being tested at a separate oil & gas platform in the area.

Interestingly, also, this project solves the issue of the impending legislated closure of the Groningen gas field by 2022. The pipeline network of this gas field would be integrated into the NortH2 project.

Stakeholders taking part in this project are: Shell which is a major European oil & gas company, Gasunie which is a gas infrastructure and transportation company, and Groningen Seaports which is the host of the project.

Conclusion

Europe and its main economies are targeting carbon neutrality by 2050. To achieve this ambitious and necessary goal, intermediate targets have been set to pave the way, originally for 2020 and now for 2030. Renewable energy and energy efficiency are the two main solutions identified to deliver greenhouse gas emissions reductions in the coming decades. In this framework, to accelerate progress, the European Union and its Member States have recently adopted new key energy policies, most notably the European Green Deal unveiled in December 2019. In line with these efforts, European countries' response to the COVID-19 pandemic is a green recovery.

The vision of carbon neutrality developed by the European Union and Europe's main economies, largely relies on decreases in total energy consumption thanks to energy efficiency improvements in the buildings, transport, and industrial sectors, and substantial shares of cheap variable renewable energy (solar and wind) in electricity generation. Regarding the latter, coal power be phased out in all of Europe's five largest economies before 2040, and nuclear power contribution should be greatly reduced. Significant increases of renewable energy are also forecasted in the heating & cooling and transport sectors.

Three technological options are emerging as decarbonization enablers: offshore wind, road transport electrification, and green hydrogen. Willing to take advantage of overall good resources for offshore wind, European countries are advancing support policies based on targets, auctions, favorable industrial frameworks, and technological innovations. With dramatic cost reductions in batteries and support policies road electrification, essentially for cars, has taken off. Finally, thanks to low cost renewable energy and costs reductions in electrolyzers, as well as growing political momentum, green hydrogen for hard to decarbonize activities in the industrial and transport sectors is becoming a reality.

With these comprehensive and progressive plans Europe has taken on a commanding global leadership to solve the ongoing climate crisis, and to seize new economic, environmental, and social opportunities from it. The future is admittedly characterized by uncertainties, but Europe is setting on example which is definitely instructive for all countries, and especially for those – like Japan – which have now committed to climate neutrality, but still lack of robust energy and climate action plans and enabling policies.

List of Abbreviations

BEV: Battery electric vehicle

CCS: Carbon capture and storage

CO2: Carbon dioxide

ETS: Emissions Trading System

EU: European Union

EV: Electric vehicle

FCEV: Fuel cell electric vehicle

gCO2/km: Gram of CO2 per kilometer

gCO2/kWh: Gram of CO2 per kilowatt-hour

GDP: Gross domestic product

GHG: Greenhouse gas

GW: Gigawatt

ICE: Internal combustion engine

kWh: Kilowatt-hour

LCOE: Levelized cost of electricity

Mt CO2: Million tons of carbon dioxide

MW: megawatt

MWh: Megawatt-hour

NDC: Nationally determined contribution

NECP: National Energy and Climate Plan

NREAP: National Renewable Energy Action Plan

PHEV: Plug-in hybrid electric vehicle

PSH: Pumped-storage hydro

PV: Photovoltaic

RE: Renewable energy

TWh: Terawatt-hour

UK: United Kingdom

ZEV: Zero-emission vehicle

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