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The Development of Renewable Energy in the Electricity Market

Sebastian Busch, Ruben Kasdorp, Derck Koolen, Arnaud Mercier and Magdalena Spooner

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Abstract

Renewable energy sources (RES) play a crucial role in the decarbonisation of the electricity system. Their share in electricity production has grown significantly since 2005 and it is expected to grow further to reach over 70% of gross electricity generation in 2030. This development will change electricity market dynamics and increase the need for flexible power.

The introduction of RES has so far been policy driven. Technology development has progressed thanks to massive public support to deployment. Different modes of support have been used, with various impacts on the market. We need to continue to move towards more market-based instruments in order to reduce both overall support costs and the distortive impact on the market, and in particular towards self-standing instruments such as power purchase agreements (PPAs).

The key question is whether and when renewable technologies can become competitive in the electricity market. A complication is their cost structure, with close to zero marginal costs. Our analysis shows that their profitability depends on both the price level of energy commodities and the carbon price, and the flexibility of the electricity system to reduce the cannibalisation effect that renewables have on their own revenues.

As renewables move to open merchant markets, we need to ensure adequate investments by introducing different forms of long-term contracts. Such contracts would contribute to stabilise market revenues of these investments, thereby benefiting both consumers and producers while ensuring market-based solutions.

JEL Classification: Q40, Q42, Q47, Q48.

Keywords: renewable energy, electricity generation, solar, wind, Fit-for-55, public support, power purchase agreements, cost-competitiveness, cannibalisation effect, renewables in the electricity market.

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ABBREVIATIONS

COUNTRIES

AT	Austria
BE	Belgium
BG	Bulgaria
CY	Cyprus
CZ	Czechia
DE	Germany
DK	Denmark
EE	Estonia
EL	Greece
ES	Spain
FI	Finland
FR	France
HU	Hungary
IE	Ireland
IT	Italy
LT	Lithuania
LU	Luxembourg
LV	Latvia
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia
UK	United Kingdom

UNITS

GW	Gigawatt
GWe	Gigawatt of electric energy
GWh	Gigawatt hour
kWh	Kilowatt hour
Mtoe	Million tonnes of oil equivalent
MWh	Megawatt-hour
TWh	Terawatt-hour

OTHERS

bn	Billion
CEEAG	Guidelines on State Aid for Climate, Environmental Protection and Energy
CEER	Council of European Energy Regulators
CfD	Contract for difference
CO2	Carbon dioxide emissions
CSP	Concentrated solar power
ETS	Emissions trading scheme
EU	European Union
EUR	Euro
EV	Electric vehicle
FiP	Feed-in premium

FiT	Feed-in tariff
GDP	Gross Domestic product
GHG	Greenhouse gas
IRENA	International Renewable Energy Agency
JRC	joint Research Centre
LCOE	Levelised cost of electricity
MS	Member State
MV	Market value of the electricity
NECP	National Energy and Climate Plans
NRA	National regulatory authority
PHS	Pumped hydropower
PPA	Power Purchasing Agreement
PV	Photovoltaic
REDII	Renewable Energy Directive recast
RES	Renewable energy sources
RES-E	Renewable energy sources - Electricity
SME	Small and medium-sized enterprise
USD	US Dollar
VPPA	Virtual Power Purchasing Agreement
VRE	Variable Renewable Electricity

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EXECUTIVE SUMMARY

Renewables are playing a prominent role in achieving our climate goals as part of the Green Deal and the EU's ambition to reach net-zero greenhouse gas emissions by 2050. This paper discusses the role of renewables in the electricity market up until today and looks at projected future developments as reflected in our policy framework. It covers the policy instruments that have been developed to drive this integration of renewable energy and looks at the conditions needed in the market for reaching cost-competitiveness.

While electricity production has remained roughly stable over the past 15 years, the share of renewable energy sources[1] has grown at a fast pace in the EU reaching 38% of gross electricity consumption in 2021 (compared to 16% in 2005). This happened on the back of a diminishing use of solid fossil fuels – and to a lesser extent also nuclear – for electricity generation. The increase in renewables has taken place across the EU, though the development was more modest in some Member States. In particular, electricity production from wind power has sharply increased, in 2019 overtaking for the first time hydropower as the largest source of renewable electricity. The biggest relative increase in produced electricity can be attributed to offshore wind farms.

Looking ahead to 2030, the 'Fit for 55' policy package puts forward a series of legislative proposals to make the climate and energy policies fit for delivering the updated 2030 greenhouse gas emissions net reduction target of 55% below 1990 levels. To achieve this objective, lower total energy demand combined with a significant increase of renewables in gross inland consumption will be needed, with the energy mix of electricity generation already projected to be dominated by renewables in 2025. Responding to the sharp increase of energy prices and the global energy market disruption in 2022, the REPowerEU Plan builds on the 'Fit for 55' package and aims at frontloading decarbonisation efforts through energy efficiency and renewable energy actions in order to phase out the dependence on Russian fossil fuels. Therefore, the Commission proposed to increase EU's 2030 renewable target to 45% which implies a substantial acceleration in deployment of renewable sources2. In this context, it is projected that between 2020 and 2030 the share of wind and solar energy in installed power production capacities in the EU would increase from 33% to 67%3. The large share of variable renewable electricity generation will require enhanced flexibility solutions to the electricity grid such as balancing and storage services.

The deployment of renewable electricity to date has primarily been driven by support schemes in the EU. It reflects the fact that up until recently, renewable technologies have not been competitive with other technologies without subsidies. However, when such public interventions are not carefully designed, they risk distorting the efficient functioning of the electricity market and ultimately lead to higher costs for European households and businesses. The Council of European Energy Regulators (CEER) report[4] found that the volume of publicly supported renewable electricity increased from 297 TWh in 2014 to 422 TWh in 2019 in the EU, of which the majority is wind energy. Germany supported by far the largest production of renewable electricity in 2019 (170 TWh or 40% of the supported production in the EU). In terms of costs, the level of support received by renewable electricity producers in the EU reached EUR 35bn in 2018 and EUR 43bn in 2019 (of which EUR 19bn in Germany alone). The level of weighted average support received by solar and wind technologies varies significantly per country, from a minimum of 50 EUR/MWh to a maximum of 500 EUR/MWh for solar electricity in 2019.

The policy instruments applied to support the introduction of renewable energy have developed over time. The use of feed-in premiums (FIPs) is increasing in Member States, gradually replacing feed-in

[1] Hydro, geothermal, wind on shore and off shore, solar thermal and solar photovoltaic, tide, wave and ocean, solid and liquid biofuels, biogases and renewable waste.

[2] On 30 March 2023, the European Parliament and the Council reached a provisional agreement to raise the binding renewable energy target to at least 42.5% by 2030.

[3] European Commission (2022a).

[4] CEER (2021).

tariffs (FITs). As the premium depends on a reference tariff level, FIPs provide certainty on a minimum level of market revenues to renewable projects, but at the same time avoid overcompensation by governments when prices are high. With high energy prices, two-way Contracts for difference (two-way CfDs) go even one step further by preventing that investors receive excessive returns and, in fact, governments are paid back the difference between the reference tariff level set and the wholesale price. Recent auctions however reveal that renewable projects are becoming increasingly competitive, with potentially less public support needed in the future.

One specific type of financial instrument to promote renewables are power purchase agreements (PPAs). These complement the government-based support schemes, as PPAs are long-term energy supply agreements concluded directly between a power consumer and a power producer. PPAs can provide certainty for the producer about a certain income whilst the buyer can benefit from a stable electricity price. The market for PPAs has steadily increased over the past ten years and given the recent volatility in electricity prices, demand for PPAs is likely to increase even further as businesses and electricity retailers seek to hedge against volatile energy prices**.** The market of corporate renewable PPAs for wind and solar electricity in Europe reached a cumulative capacity of 18.5 GW in 2021 (or about 6.5% of total installed capacities). Spain currently has by far the highest contract capacity in Europe with 4.2 GW. The Commission is committed to work with Member States to facilitate a wider market for decarbonised power purchase agreements beyond large businesses, including SMEs[5].

Today, investments in renewables are still to a large extent covered by the different forms of support schemes. However, the need for support is determined by the cost-competitiveness of the renewable technologies, which has been improving substantially over time. The production costs of onshore wind and solar photovoltaic electricity have decreased dramatically in the last decade. The cost of producing solar photovoltaic electricity (utility scale) decreased at an annual rate of 17% from 2010 to 2020, while for onshore wind the annual reduction rate was around 8%. The continued reduction in the investment costs has been a key driver behind the overall decline in the costs of production. There is still potential for further reduction in investment costs in the future. However, bottlenecks in global supply chains and an increase in commodity prices may slow down or even reverse this investment costs' decline.

Overall solar photovoltaic and onshore wind electricity are expected to be cost-competitive by 2030, in particular explained by the increase in energy and carbon prices and the level of flexibility of the power system. Without a flexible system, there is the risk of the so-called 'cannibalisation effect of renewable energy'. Solar photovoltaic and wind generators have a very low variable production cost. This means that when they operate, they are dispatched first on the wholesale market before other energy sources. With the current market design and without mitigation measures such as an increased flexibility of the power system, this can result in a drop in wholesale prices. Flexible solutions such as cross-border interconnections, demand response, electricity demand for hydrogen generation or energy storage can, to some extent, counteract this, as it allows demand to be shifted in time and space depending on the price signal. At the same time, renewable technologies can be quite profitable if they generate at the time when expensive technologies are setting the price on the margin and they are not covered by a long-term arrangement that would induce a cap on their infra-marginal revenue.

The analysis therefore highlights the need to adjust the current market framework, as the share of renewables will continue to grow in view of achieving the EU's climate ambitions. In particular, reforms are needed to further promote the use of long-term contracts to stabilise revenues and de-risk renewable energy investments, while ensuring that consumers benefit from the low cost production of power systems with a high share of renewable energies. It also shows the need for reforms to promote a more flexible electricity system. These findings are consistent with the proposal for a reform of the electricity market design published by the European Commission on 14 March 2023[6].

[5] European Commission (2022b).

[6] European Commission (2023a)

1. INTRODUCTION

Renewables play a prominent role in achieving our climate goals as a key part of the Green Deal and the EU's ambition to reach net-zero emissions by 2050. Wide deployment of renewables is crucial to decrease the emission intensity of electricity production, along with energy efficiency. As electricity production is seen as potentially emission free thanks to renewables being the main source, electrification of many processes has started to take off (e.g., electric vehicles and heat pumps, or various industrial processes originally dependent on energy from fossil fuels), supported by increasing energy efficiency. Therefore, it is expected that electricity will cover an increasing part of energy needs of our society in a decarbonised economy.

The transition to fully decarbonised electricity production and its expansion to be successfully finalised requires substantial investment, mainly from the private sector but also by public sectors or with public support. The development and expansion of renewable generation has so far been incentivised through different forms of public support schemes. For the future development, it is important to increase the cost-efficiency of these instruments, which has been ensured in the 2022 revised state aid rules and the Renewable Energy Directive[7], while also moving towards a market design that allows renewable electricity projects to recoup their investment and operating costs on a market basis.

Increasing shares of intermittent renewable sources require to review the electricity market design to better enable their deployment and integration in the market. The current market design was developed on the basis of stable sources of electricity (fossil fuels and nuclear). While it could integrate a certain amount of renewable sources without major changes, an increasing share of renewables brings along pressure on the current system. Renewables come with very low production costs but with high needs for storage and flexible solutions to offset their variability due to the dependence on weather conditions.

The rising electricity prices since the second half of 2021 show certain drawbacks of the current EU electricity market design in terms of affordable prices for consumers. Electricity prices started to grow following the rebound effect of post-COVID recovery in 2021 in combination with the withholding of gas supply from Russia. The invasion of Ukraine by Russia in February 2022 has further aggravated energy prices as large amount of fossil fuels (gas, but also oil and coal) were imported from Russia. Following the marginal pricing system, wholesale electricity price is regularly linked to the gas price. Gas generation often clears the market and sets the price, even in a situation where renewables are growing in importance for the electricity production overall.

In this context, the Commission has recently proposed a reform of the EU's electricity market design[8]. The proposed reform aims, in particular, at introducing measures that incentivise longer term contracts with non-fossil power production, such as renewable energy, and at bringing more clean flexible solutions into the system to compete with natural gas, such as demand response and storage. The goal is to ensure that consumers and suppliers benefit from more price stability based on renewable and non-fossil energy technologies. The reform contains also a range of measures to further protect and empower consumers.

This paper is providing a closer look at renewable developments and their implications for the future. It is structured as follows. Section 2 describes the penetration of renewables in electricity markets since 2005 and provides an overview of the future scenarios as modelled to support the 'Fit for 55' package (including the REPowerEU package), especially with regards to future development of renewables, and in the light of increasing flexibility needs. Section 3 presents the different public support schemes and their development over time, including ways to ensure cost-competitiveness of

[7] European Commission (2022c) and European Commission (2018).

[8] European Commission (2023a)

renewables as well as how these schemes are financed. Section 4 presents purchasing power agreements (PPAs) as a new decentralised way to procure renewable electricity, while allowing producers a stable remuneration. Section 5 follows with the evolution of cost-competitiveness of the main renewable technologies, namely solar photovoltaic and wind, while section 6 concludes the paper.

2. RENEWABLES PENETRATION IN ELECTRICITY MARKETS

As the EU is pursuing its decarbonisation agenda by increasing its reliance on clean energy sources in combination with energy efficiency efforts, fossil-free electricity production is seen as the optimal solution. However, renewable sources of energy, in particular wind and solar energy, do not produce a stable amount of electricity, as they are dependent on the weather conditions[9]. At times, electricity generation needs to be covered by flexible and reliable energy sources, at least until sufficient options for storing excess renewable electricity and smart grid to allow for flexibility are developed. This is reflected in the current market conditions: electricity prices are growing since about a year and a half following the rising prices of natural gas (the energy source providing flexible power), putting strain on the budget of households and companies. Despite the fact that electricity generation has observed a huge surge in renewable sources with low operating costs, the current electricity market is still dependent on gas generation to cover the peak demand and to provide the balancing source of electricity.

In this context, this section looks at the development of fuel mix to date and the projection as embedded in the Fit for 55 package and further developed in the REPowerEU policy package. Special focus is on the electricity production, demand, the needs for flexibility solutions stemming from its decarbonisation and the diminishing reliance on gas and fossil fuels at large.

2.1. ELECTRICITY GENERATION

Electricity demand in the EU has remained stable over the past 15 years. Since 2005, gross production of electricity has lingered just under 3 million GWh annually (Graph 2.1). Lower production was recorded only in 2009 during the financial crisis and in 2020 due to lower energy demand during the COVID-19 crisis (electricity production decreased by 5.1% and 4.0% compared to previous year, respectively).

The stable electricity production stems from two opposing trends: decreasing energy consumption on one hand and increasing reliance on electricity on the other hand. Gross inland consumption of energy decreased by 11.5% over the period 2005-2021, following the EU's commitment to increase energy efficiency of our economy[10]. At the same time, decarbonisation of energy consumption accelerated as the decline in the use of total fossil fuels was even larger: -22.1% over 2005-2021. Solid fossil fuels (coal etc.)[11] dropped by 40.7% over the last 16 years and oil (including oil products) by 23.4%. From fossil fuels only natural gas managed to increase its relative importance in energy mix (in 2021 covering 24% of energy needs in the EU) while in nominal terms declining by 5.4%. Increasingly more of the EU's energy needs are covered by renewable sources (18.8% of energy mix in 2021, see Graph 2.2), and consequently electricity.

The penetration of renewables in electricity markets in the EU continues to grow at fast pace (see Graph 2.3). In 2021 the share of renewable electricity as percentage of gross electricity consumption has increased to 38% (compared to 16% in 2005) and since 2020 renewables have been EU's main power source while overtaking fossil fuels. Fossil fuels covered 35% (the lowest share in history yet) and nuclear 25% of electricity production in 2021 (down from 52% and 31% in 2005, respectively). The decrease in fossil fuels happened on the back of diminishing use of solid fossil fuels[12] for electricity generation, in line with the EU's efforts to decarbonise, though this trend has been partially offset in

[9] Hydropower can also be weather dependent, but even in that case its generation is less variable, and can, depending on its features, be used as balancing power (see also footnote 11).

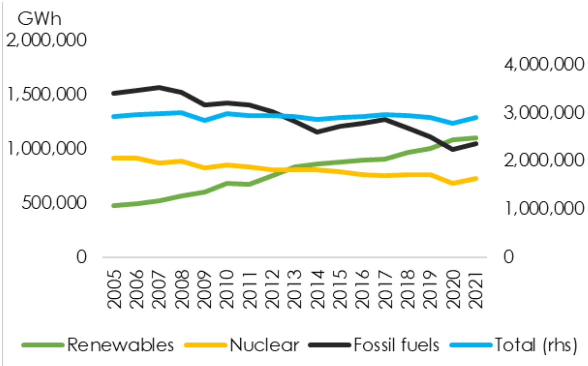
[10] EU 2020 target to increase energy efficiency by 20% compared to 1990 levels, see European Commission (2012) (Energy Efficiency Directive 2012/27/EU). This directive is currently being reviewed to set higher targets.

[11] Including peat and oil shale.

[12] Hard coal, Brown coal, Peat and peat products, Oil shale and oil sands.

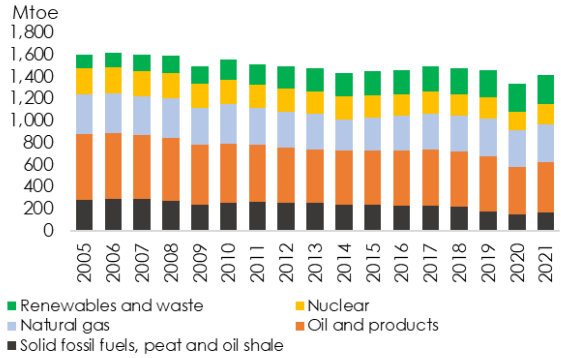
2021 as a response to rising gas prices. Natural gas, traditionally serving as a bridging[13] source of electricity but since the second half of 2021 used less due to its price surge, has provided around 500 TWh of electricity annually over the last 16 years (natural gas comprised 19% of electricity production in 2021 compared to 18% in 2005).

Graph 2.1 **Gross electricity production** (EU27)



Source: Eurostat.

Graph 2.2 **Energy mix – gross inland consumption of energy** (EU27)

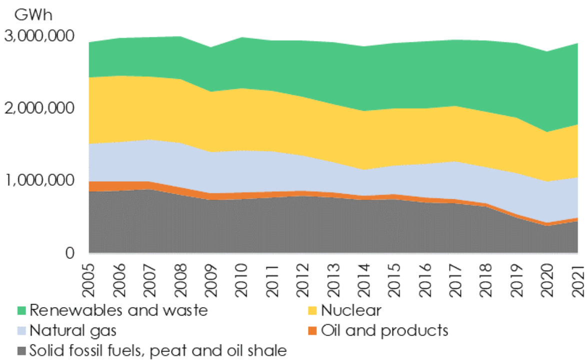


Source: Eurostat.

While the year 2020 was seriously affected by the COVID-19 pandemic, in 2021 electricity generation bounced back and renewables continued to increase their stake in electricity generation. Fossil fuels and nuclear were affected the most by lower electricity demand caused by the COVID-19 pandemic. In contrast, in 2020 electricity generated from renewables recorded the highest production level up until that point, seemingly undisturbed on its expansionary path. In 2021, on the other hand, electricity production from all sources increased but only in the case of renewable sources the electricity production in 2021 was higher than pre-pandemic.

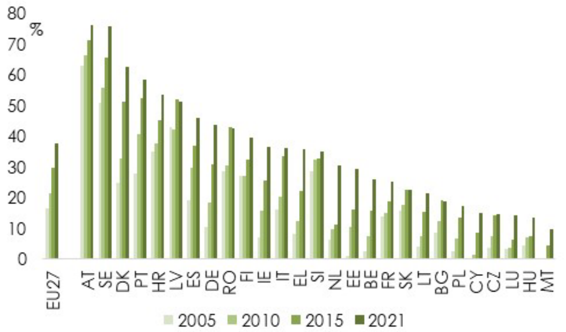
The substantial increase in renewable electricity was observed across EU Member States, with the development in some States being more modest. Fifteen Member States had a share above 30% in 2021 compared to four Member States in 2005, while in six Member States renewables cover more than 50% of electricity generation (Austria, Sweden, Denmark, Portugal, Croatia and Latvia, see Graph 2.4). On the other hand, five Member States are still relying predominantly on fossil fuels and nuclear, as renewable production cover less than 15% of total electricity needs (Malta, Hungary, Cyprus, Luxembourg and Czechia).

Graph 2.3 **Gross electricity production by energy source** (EU27)



Source: Eurostat.

Graph 2.4 **Share of energy from renewable sources in gross electricity consumption** (by Member State)



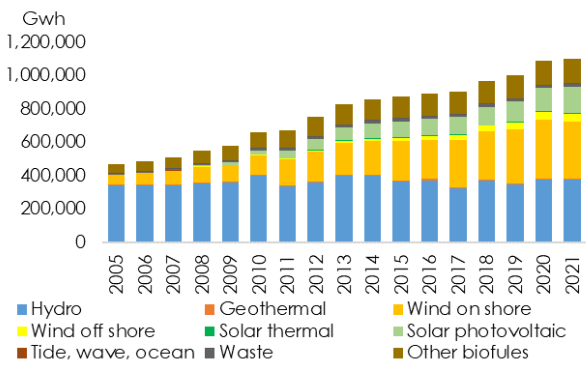
Source: Eurostat (SHARES 2021).

[13] Natural gas plays a role as bridging fuel to achieve greenhouse gas reductions by replacing coal-fired power, as natural gas-based power plants emit less CO2. While zero-emission technology is being developed and needs time to mature, the power sector needs a fuel which can provide flexibility missing from traditional RES based electricity production. Wind and solar are dependent on weather conditions and sufficient energy storage is not yet available.

Renewable electricity production continues to rise supported by a sharp increase in wind production (Graph 2.5)**.** Hydropower generation remained roughly stable over the last 20 years, and as such, its importance as source of renewable electricity is decreasing in relative terms. While in the beginning of the century hydropower plants produced more than 90% of electricity from renewable sources across the EU, in 2021 it accounted for 40% of the production. In 2019 for the first time hydropower was overtaken by wind power which currently covers 41% of electricity production from renewable sources. It should, however, be recalled that hydropower can often play an important role as a balancing power source.[14] While it is not yet economically viable to store excess electricity from solar or wind power plants, water can be stored in reservoirs. Hydropower plants can be started and adjusted as needed and stopped at a short notice[15] within the limits provided by the reservoirs (see also Section 2.3).

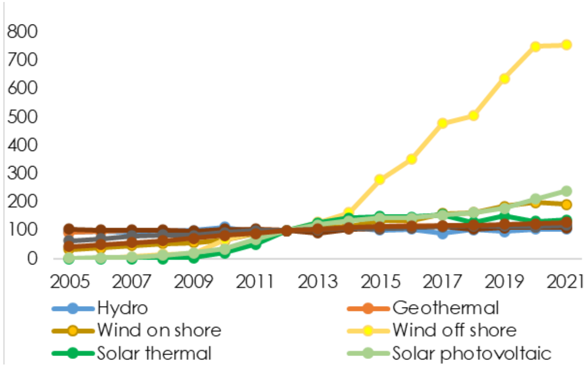
The biggest relative increase in produced electricity is attributed to offshore wind farms. Even though offshore wind still covers only 4% of renewable electricity production, its size increased more than 6-times since 2012 (Graph 2.6). Over the same period, solar photovoltaic doubled its production (covering 14% of renewable electricity production in 2021), while onshore wind electricity generation increased by 91% (reaching 31% of renewable electricity production in 2021). Combustible renewable energy sources (biofuels) covered 14% of renewable electricity production in 2021, increasing in level by 29% since 2012. Other sources (geothermal, solar thermal or tide, wave, ocean) also increased its production but they cover less than 1% of renewable electricity production each.

Graph 2.5 **Gross production of electricity from Renewables** (EU27)



Source: Eurostat.

Graph 2.6 **Gross production of electricity** (EU27, 2012=100)



Source: Eurostat.

2.2. 'FIT FOR 55' AND REPOWEREU: ASSUMPTIONS AND MODELLING RESULTS

The 'Fit for 55' policy package published on 14 July 2021 puts forward a series of legislative proposals to make the climate and energy policies fit for delivering the updated 2030 greenhouse gas emissions (GHG) net reduction target of 55% below 1990 levels, as set out in the 2030 Climate Target Plan[16]**.** The proposals cover a wide range of policy areas including climate, energy, transport and taxation, setting out the ways in which the Commission proposes that the EU will reach its updated

[14] There are four main types of hydropower projects with different storage/balancing ability: **Storage hydropower** (typically a large system that uses a dam to store water in a reservoir - electricity is produced by releasing water from the reservoir through a turbine, which activates a generator), **Pumped storage hydropower** (provides peak-load supply, harnessing water which is cycled between a lower and upper reservoir by pumps which use surplus energy from the system at times of low demand), **Run-of-river hydropower** (a facility that channels flowing water from a river through a canal or penstock to spin a turbine) and **Offshore hydropower** (using tide, waves or ocean power).

[15] Pumped storage hydropower plants are designed to lift water to a reservoir at higher elevation when the electricity demand is low or when prices are low, and turbine water to produce electricity when the demand is high and/or prices are high.

[16] European Commission (2020a).

2030 target. The proposals are based on a comprehensive impact assessment, which shows how all sectors of the economy and society will have to contribute to reduce the emissions, and sets out the policy actions required to achieve this goal.

The choice of the proposed mix of policies for the 'Fit for 55' package was based on the EU Reference Scenario 2020[17], which served as the baseline for the Impact assessment. The EU Reference Scenario is one of the European Commission's key analysis tools in the areas of energy, transport and climate action. It allows policy-makers to analyse the long-term economic, energy, climate and transport outlook based on the policy framework in place in 2020. The Reference Scenario builds on the current policies at EU and Member State level, whose implementation intensifies until 2030 and continues afterwards, assuming no additional measures apply between 2030 and 2050. The Reference Scenario reflects the current GHG target of 40% by 2030. The representation of renewables in the power sector in the policy scenario was updated compared to the previous Reference Scenario. It is assumed that the balancing of renewables occurs in a very cooperative and cost-efficient manner in the EU power system as whole, allowing to avoid excessive investments in peak generation technologies.[18]

The expected impact of the 'Fit for 55' package can be assessed by comparing projections from policy scenarios and the Reference scenario. The MIX scenario achieves around 55% GHG reductions, expanding carbon pricing and increasing the ambition of policies. It features in the impact assessment accompanying the 2030 Climate Target Plan along with several others policy scenarios[19], and served as a guidance for the respective legislative proposals.

However, since the publication of the 'Fit for 55' package and responding to the Russian aggression against Ukraine, the sharp increase of energy prices and global energy market disruption, the REPowerEU Plan[20] was published. Among other things, this Plan aims at frontloading decarbonisation efforts in order to phase out the dependence on Russian energy. Therefore, it proposes to increase EU's 2030 renewable target to 45%. This leads to an increase in all sectors relevant to supply and demand of renewable power – and has a sizable impact on future electricity generation. According to the REPowerEU Plan, by 2030 the renewable energy share in the electricity ('RES-E') sector would reach 69% (compared to 65% under the 'Fit for 55' modelling and 37% as recorded in 2020). This implies a substantial acceleration in deployment of renewable sources. It is

[17] European Commission (2021a). (PRIMES and PRIMES-TREMOVE are the main models used for the EU Reference Scenario 2020) – see Annex 1.

[18] The modelling includes a shift towards flow-based allocation of interconnection capacities, assuming a market model purely relating trade to market forces throughout the EU internal energy market with perfectly operating market coupling across all participating countries. The target market model is assumed to be successfully implemented as of 2025.

[19] **REG**: a regulatory-based measures scenario that achieves around 55% GHG reductions. It assumes high increase of the ambition of energy efficiency, renewables and transport policies, while keeping the EU ETS scope unchanged. This scenario thus does not expand carbon pricing and relies mostly on other policies;

CPRICE: a carbon-pricing based scenario that achieves around 55% GHG reductions. It assumes strengthening and further expanding of carbon pricing, be it via EU ETS or other carbon pricing instruments, to the transport and buildings sectors, combined with low intensification of transport policies while not intensifying energy efficiency, renewables policies;

MIX: includes both carbon price signal extension to road transport and buildings and strong intensification of energy and transport policies. With its uniform carbon price, it reflects either an extended and fully integrated EU ETS or an existing EU ETS and a new ETS established for road transport and buildings with emission caps set in line with cost-effective contributions of the respective sectors. Maritime transport sector is assumed to be included in the existing EU ETS in MIX.

MIX-50: an increased ambition scenario achieving at least 50% GHG reductions, similar to MIX in that it combines both expanding carbon pricing and increasing the ambition of energy and transport policies but to a more limited extent than in MIX;

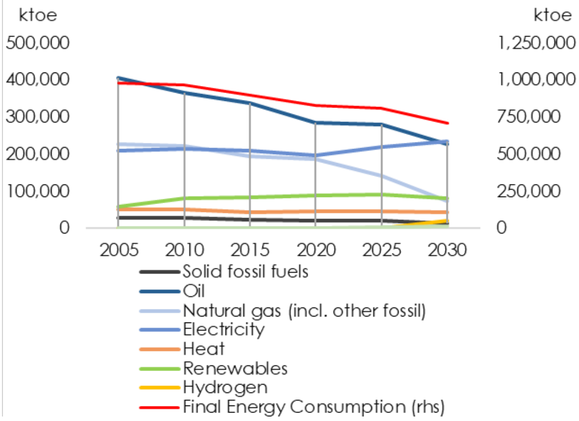
ALLBNK: the most ambitious scenario in GHG emissions reduction, based on MIX and further intensifying fuel mandates for aviation and maritime sectors in a response to the extended scope of GHG reductions covering all aviation and navigation.

[20] European Commission (2022d).

projected that between 2020 and 2030 the share of wind and solar energy in installed power production capacities would increase from 33% to 67%.

According to the modelling underpinning REPowerEU, achieving 55% GHG reductions in 2030 while substantially decreasing EU's reliance on Russian fossil fuels requires also further lowering of energy demand (see Graph 2.7). In terms of final energy, EU needs to decrease its consumption by around 21% between 2015 and 2030 (compared to the expected development under the Reference Scenario of -8%). This is a substantial increase in ambition as the 'Fit for 55' modelling suggested 17% decrease. However, the uptake of energy intensive new fuels including hydrogen, e-gas and e-liquids is front-loaded in the REPowerEU scenario, with their development assumed to accelerate after 2030, leading to slower energy demand reductions after 2030.

Graph 2.7 **Final energy consumption by fuel** (REPowerEU scenario)

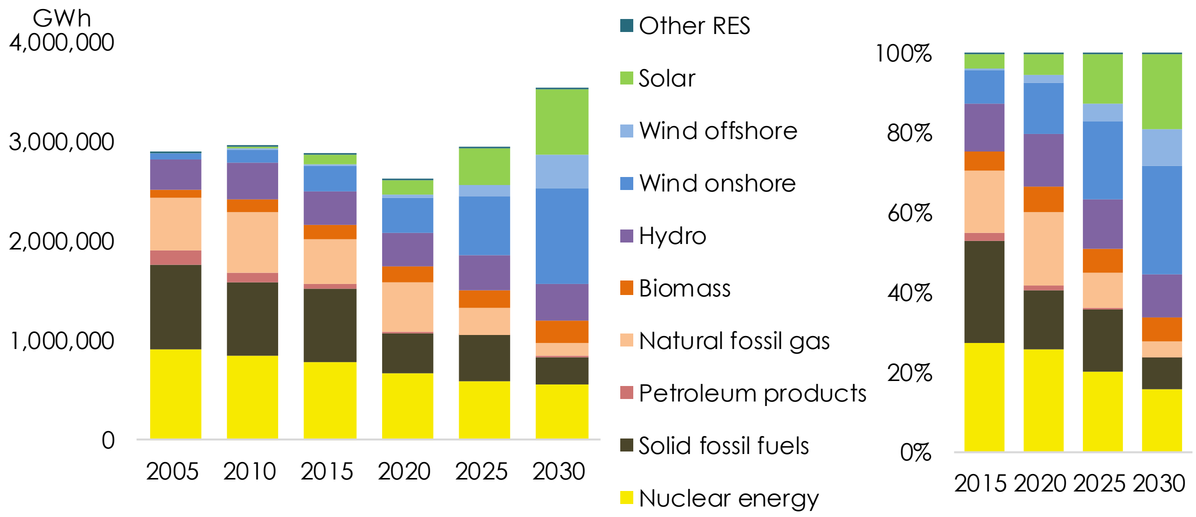


Source: REPowerEU modelling.

The demand for electricity increases between 2020 and 2030, and grows further by 2050, in the context of a fuel switch away from fossil fuels, and with an increasing role of technologies like heat pumps or electric vehicles. According to the REPowerEU modelling, relative to the level in 2020, electricity demand increases by almost 40 Mtoe by 2030 (i.e. about 20% increase). Furthermore, the 'Fit for 55' modelling suggests that the electricity demand should continue growing towards the 2050 goal when electricity would cover almost 50% of our energy needs. Electrification will be driven by demand growth in the transport, industry and residential sectors while there is some decrease in services and agriculture. REPowerEU will frontload some of this electrification but in the long term the 'Fit for 55' projections are still valid.

In a REPowerEU pathway, the energy mix of electricity generation would be dominated by renewables already in 2025 (Graph 2.8). Renewables would cover 55% of gross electricity generation in 2025 (up from 30% in 2015 and 40% in 2020) and 72% in 2030, while the importance of fossil fuels would be sharply declining (falling to 12% in 2030, compared to 43% in 2015). The acceleration of penetration of renewables would be faster than in the baseline scenario as well as in the Fit for 55 modelling, reflecting the higher GHG reduction ambition (Fit for 55 increases the GHG reduction to 55% by 2030, from 40% in the reference scenario) and the need to drastically reduce dependency on Russian fossil fuels (REPowerEU suggests increased renewables target: 45% of energy demand in 2030, up from 40% included in the Fit for 55 package).

Graph 2.8 **Gross electricity generation EU** (REPowerEU scenario)



Source: REPowerEU modelling.

Wind and solar are the most important sources of renewable energy, also going forward. In 2030 these two fluctuating sources of energy are projected to cover together 63% of electricity produced from renewables, up from 43% in 2015. Wind will become the sole most important source of electricity, providing 37% of total gross electricity generation in 2030 (the bulk coming from onshore sites). Similar effect can be observed in the baseline scenario, but the up-take of RES is slower.

Nuclear power will remain important as a stable electricity source, though declining. By 2030, the combined installed capacity of the EU's nuclear power plants is projected to decline as result of planned phase-outs in several Member States. Nuclear power will cover about 16% of electricity generation in 2030 (compared to 27% in 2015).

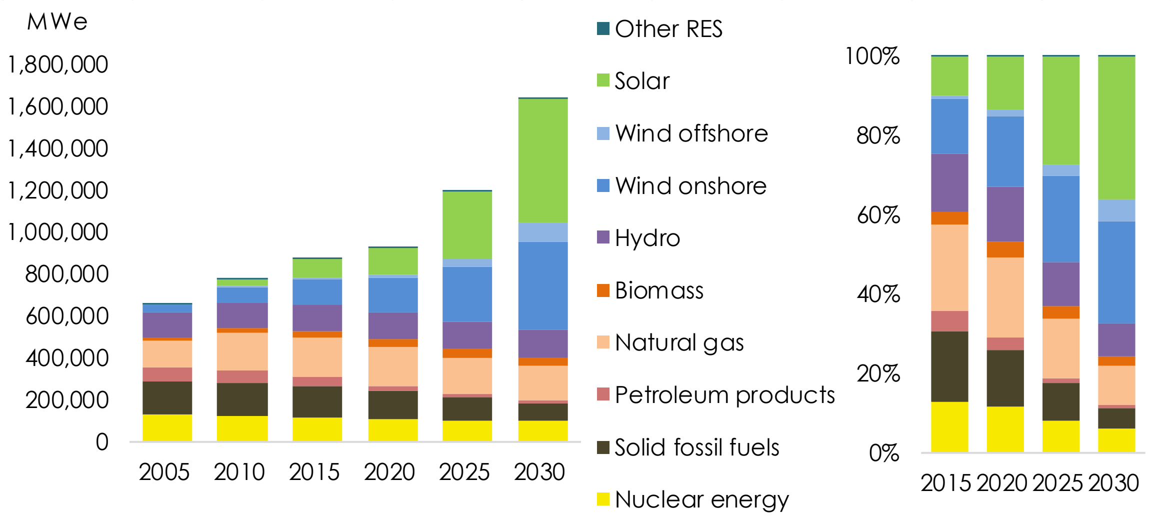
The total installed electricity generation capacity will have to see a much faster increase than the electricity produced, to counter-balance the meteorologically determined low load factors of wind and solar electricity generation[21] (Graph 2.9). The installed capacity increases from 870 GWe in 2015 to over 1,600 GWe in 2030 in the REPowerEU modelling (compared to 1,180 GWe under the baseline scenario and 1,400 GWe in the main scenario underpinning the Fit for 55 package). By 2030, solar energy will have the highest installed capacity, profiting also from the support under the EU Solar Strategy[22]. Solar is followed by wind energy with most of the installed capacity being located onshore. At the same time, offshore wind will be the fastest growing technology, growing by 20% annually. Given the weather-dependency of many renewable energy sources, the load factor[23] of the renewable power plants will remain rather low compared to traditional non-intermittent electricity producers, especially in the case of solar installations.

[21] As energy coming from intermittent renewable energy sources can be harvested only under favourable weather conditions (wind or sunshine), the wind and solar parks have to be ready in sufficient capacity when these conditions occur; but lay idle at other times.

[22] European Commission (2022e).

[23] Load factor is defined as an installation's average load divided by its peak load. For intermittent renewables, like PV and wind, which cannot always be dispatched according to the installed capacity, the load factor shows how much electricity is on average produced for a given installed peak capacity. Load factor accuracy is important when assessing the feasibility of intermittent renewables.

Graph 2.9 **Net Installed Power Capacity per plant type** (REPowerEU scenario)



Source: REPowerEU modelling.

2.3. FLEXIBILITY: STORAGE AND BALANCING

The increasing penetration of variable renewable energy sources implies significant needs for flexibility services in the power system. Gas plants, hydropower, cross-border flows and storage are the main current flexibility and balancing solutions. Storage facilities undergo an increase by 2030, which accelerates even afterwards: pumped storage, which develops further but has potential limitations; batteries that also develop considerably and benefit from decreasing costs over time; and power-to-X, which emerges in the longer-term.

Daily dedicated storage needs are currently met by pumped hydropower (PHS) and increasingly by batteries. According to the 'Fit for 55' modelling, both will grow under the baseline as well as in the policy scenarios. Increased needs for electricity storage will also trigger the deployment of electrolysers for the production of hydrogen[24]. The REPowerEU communication of 8 March 2022 included the Hydrogen Accelerator with the ambition of using 20 million tonnes of renewable hydrogen in 2030 in the EU. This development will support the decarbonisation of the gas system and over time replace gas, and is likely to necessitate partial repurposing of gas infrastructure.

In the REPowerEU Plan scenario, natural gas is plummeting in importance in electricity generation, while solid fossil fuels are decreasing at a slower pace. This is a change as compared to the Fit for 55 proposal where gas was the fuel assumed to offering flexibility services. The originally planned fast coal phase out combined with the rising ETS prices and expected coal-to-gas switch in power generation has been reversed driven by the sky-rocketing gas prices. According to the REPowerEU modelling, by 2030, natural gas is expected to cover only 4% of produced electricity, while solid fossil fuels account for 8% (compared to 11% and 5% expected in the Fit for 55 modelling, respectively). By 2050, it is expected that the demand for renewable and low-carbon gases will become even higher; even before REPowerEU it was foreseen that hydrogen and e-gases would account for over 70% of all renewable and low-carbon gases in 2050[25].

The proposal for the REDII recast[26] from July 2021 puts forward several ways how to ensure enough flexibility in the electricity market to facilitate and enable the large RES penetration. For

[24] See also the European Commission (2020b).

[25] See Fit for 55 modelling.

[26] European Commission (2021b).

instance, information on battery properties must be readily available[27] and access to storage and balancing market should be non-discriminatory[28].

The EU Solar Strategy[29] accompanying the REPowerEU communication suggests various ways how to seamlessly integrate the solar energy in the energy system at large. The rapid growth of solar energy proposed by the Strategy requires new technological, digital and operational advances. The system will fully benefit from the new flexibility assets, such as batteries, only if they can be properly integrated and able to participate in all electricity markets, including balancing and congestion management markets. At EU level, the ongoing work on the EU network code[30] on demand side flexibility aims at addressing remaining regulatory barriers and unlocking the potential of such distributed assets as flexibility sources.

It is expected that electric vehicles (EVs), if well integrated into the electricity system, can also serve as energy storage devices. In addition, they can potentially reduce investment needs in other flexibility assets such as batteries[31]. Electric vehicles can contribute to solar electricity self-consumption, if parked within the premises of the owner or user. However, it should be possible to create a system where recharging EVs away from home could be linked to one's own electricity production, for instance through the same electricity supplier. Hence, allowing for using the same contract and data-sharing agreement for the recharging needs both as an owner at home and as a re-charger user away from home. Off-grid recharging stations equipped with PV panels and energy storage offer the possibility to increase access to EV recharging infrastructure in rural areas and, in general, in those locations with limited grid connection.

The increase in the demand-side-related flexibility potential brings a re-optimisation of the electricity generation capacity mix, as demand-response makes the system less reliant on expensive peak generation technologies (e.g., gas turbines), with investments reduction of the order of 13-23% to those technologies. The introduction of information on share of renewables also shows the tendency to further optimise the investment and use of conventional sources, while giving more priority to less polluting ones. Shifting power demand for heating and cooling (via controlling the operation of heat pumps and thermal storage systems) and EV charging into hours with high RES-E share would thus favour the use of renewable electricity and incentivise the absorption of RES generation in real-time.

2.4. CONCLUDING REMARKS

The take-over of electricity generation by renewable energy sources is set to continue. Renewables are already producing 38% of electricity in the EU and it is foreseen that this share will increase to more than 50% by 2025. This trend answers the call for a climate neutral EU and the decarbonisation of its energy system, and is further pressed by the ongoing Russian military aggression in Ukraine. The latter

[27] Battery manufacturers must enable access to information on battery capacity, state of health, state of charge and power set point, to battery owners as well as third parties acting on their behalf.

[28] Regulatory provisions concerning the use of storage and balancing assets do not discriminate against participation of small and/or mobile storage systems in the flexibility, balancing and storage services market.

[29] European Commission (2022e).

[30] Network codes or guidelines are legally binding European Commission implementing Regulations. They govern all cross-border electricity market transactions and system operations alongside the Regulation on conditions for accessing the network for cross-border electricity exchanges.

[31] Especially as intelligent charging and bidirectional flow between charger and vehicle (V2G) become widely accessible technologies, EVs will act not only as a valuable flexibility and storage service to the grid, but potentially also as an additional remuneration stream for EV users, thus further incentivising the penetration of electric vehicles in the market and their contribution to the energy system.

has brought forward substantial risks for EU’s energy security which are mitigated also by cutting the EU’s dependence on Russian fossil fuels.

Large deployment of renewables in the electricity system comes with its challenges stemming mainly from their weather-dependent nature. Traditionally hydro power used to be the largest renewable energy source. Hydro power is relatively stable and acts also as electricity storage. However, the fast-increasing share of wind and solar energy needs to be accompanied by development of proper flexibility solutions providing balancing and storage. Apart from well interconnected electricity grid the development of efficient batteries and modern integration of other demand-response technologies (e.g., electric vehicles) are needed to support the system with less gas available to fulfil the flexibility function.

3. PUBLIC SUPPORT SCHEMES FOR RENEWABLE ELECTRICITY IN THE EU

The introduction of renewable energy sources on the electricity markets has been supported by different forms of public support schemes. The electricity markets alone would not have been able to deliver the 2020 EU renewables target due to uncertainty for investment in renewable energy**.** In fact, the deployment of renewable electricity in the EU to date has primarily been driven by support schemes. In 2019, this support covered 89% of the total electricity produced from wind and 83% by solar PV[32]. If such public interventions are not carefully designed, they can risk distorting the functioning of the electricity market and lead to higher costs for European households and businesses. This section will discuss the various types of public support schemes that are currently used in the EU, their associated costs and the manner through which governments finance those schemes.

3.1. THE USE AND DIFFERENT TYPES OF SUPPORT SCHEMES

The Council of European Energy Regulators (CEER) report[33] found that the volume of supported renewable electricity increased from 297 TWh in 2014 to 422 TWh in 2019 in the EU[34]. Of this, 295 TWh of on- and offshore wind energy and 94 TWh of solar photovoltaic (PV) electricity received support in 24 Member States in 2019[35]. Especially support to wind energy has increased markedly from 170 TWh since 2014. This is equal to around 80% of the total solar and wind energy production receiving support[36]. Other renewable electricity received only limited support, being hydropower (29 TWh) and concentrated solar power (CSP)[37] (5 TWh, almost exclusively in Spain). Therefore, the focus of this section is on electricity produced from wind and solar PV.

Germany supported by far the largest production of renewable electricity in 2019 (170 TWh or 40% of EU), as shown in Graph A2.2.1 in Annex 2. Second is Spain (55 TWh), followed by France (50 TWh), and Italy (46 TWh). Since 2014, support to renewable electricity increased significantly in Germany from 95 TWh, but also France saw an almost doubling from 27 TWh. The support to renewable electricity in Spain and Italy remained more or less stable over the period.

Based on the volume of renewable electricity that received support, support schemes play an important role in the EU for the development and deployment of these technologies. However, the other remaining renewable electricity has not necessarily been produced without support (e.g. via Power Purchase Agreements (PPAs), see Section 4). This difference can correspond to data discrepancies in the reporting processes in the CEER report. It is also possible that part of this production is generated from installations that do not receive support any longer. It should be noted that the data from the CEER report is based on a snapshot. For fluctuating renewables, the output also depends on varying meteorological and hydrological conditions.

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[32] As reported by Eurostat in 2019.

[33] CEER (2021).

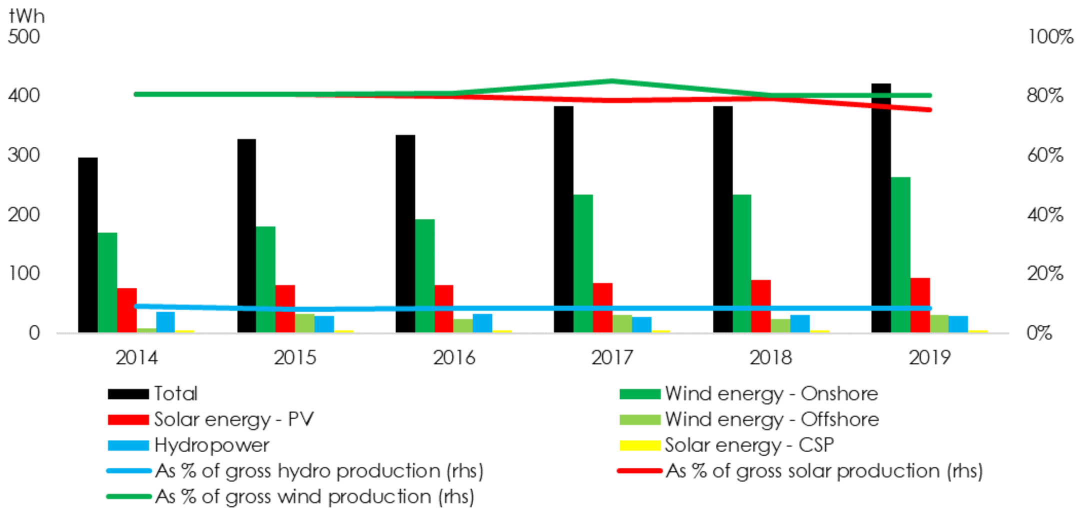
[34] We only cover electricity from solar, wind and hydropower. When comparing aggregate numbers over time, only 21 MS are counted. BE, FI, NL, PL, SK do not have complete yearly data coverage and are therefore excluded to retain comparability over time, while there is no data on BG. As these are smaller MS, the overall Graphs do not change much (e.g. if all MS were included, the volume of renewable electricity supported would have increased to 316 TWh in 2014 and to 423 TWh in 2019).

[35] There is no data available for BE, BG, FI, NL, and PL in 2019.

[36] Solar PV and CSP are added together, as well as onshore and offshore wind energy.

[37] CSP systems generate solar power by using mirrors or lenses to concentrate a large area of sunlight into a receiver. Electricity is generated when the concentrated light is converted to heat.

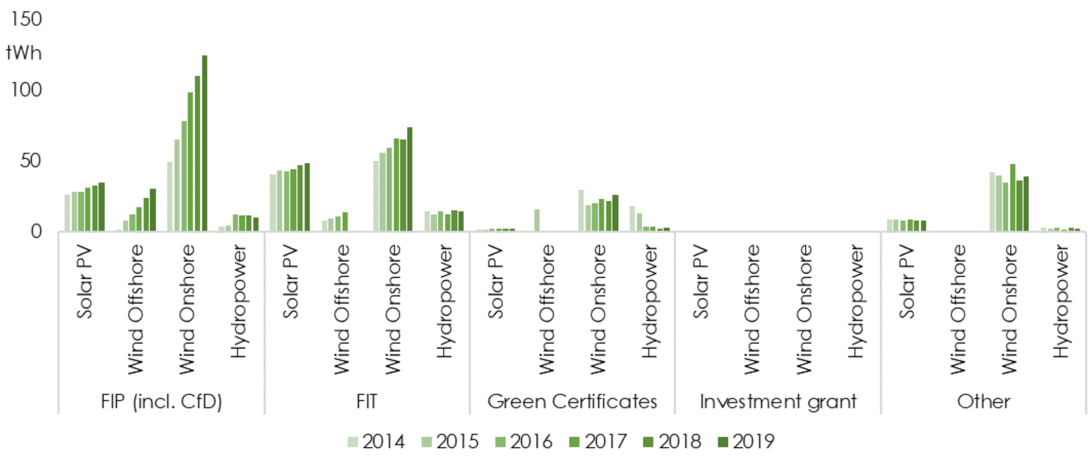
Graph 3.1 **Volume of renewable electricity receiving support in the EU**



Source: CEER 2021 Status Review of Renewable Support Schemes reports.

In terms of types of renewable energy support schemes, feed-in premiums are increasingly used in Member States in line with the implementation of the Guidelines on State aid for environmental protection and energy 2014-2020 (see Box 1 for description on the various types of existing support schemes). The 2014-2020 guidelines required a gradual replacement of feed-in tariffs (FITs) by feed-in premiums (FIPs). It introduced the obligation to go through competitive bidding processes e.g. auctions for allocating public support in order to increase cost effectiveness and limit distortions on the electricity market. The most recent 2022 EU Guidelines on State Aid for Climate, Environmental Protection and Energy (CEEAG)[38] also promote Contracts for difference (CfD) as a good model to support the further expansion of renewables.[39]

Graph 3.2 **Renewable electricity receiving support per type of support scheme in the EU**



Source: CEER 2021 Status Review of Renewable Support Schemes reports.

The CEER report confirmed the increase of FIPs across Member States. Only five Member States had at least one FIP scheme in place by 2014-2015, which increased to fourteen by 2018-2019, while over the same period, Member States with at least one FIT scheme in place decreased from nineteen to

[38] European Commission (2022i).

[39] Note that paragraph 90 of the CEEAG includes a clawback mechanism linked to possible positive scenarios that may be required to ensure proportionality in the support.

seventeen (CY, EE, IE moved away from FIT schemes, while PL introduced one). In total, FIPs supported 200 TWh of renewable energy compared to 136 TWh by FITs in 2019. The volume of renewable electricity supported through FIPs increased by 2.5 times over the period 2014-2019, overtaking FITs in 2016. The growth is particularly noteworthy in onshore wind electricity, followed by offshore wind electricity, which by 2019 was exclusively financed through FIPs. Green certificates and investment grants are used in a more limited way, and Spain is the only country that is relying solely on investment grants, according to the CEER report.

Box 1 **Types of renewable energy support schemes**

There are various types of support schemes to promote the deployment of renewable energy in the EU (the Member State indication is based on the CEER report), namely:

- **Feed-in tariffs (AT, CZ, DE, DK, EL, FR, HR, HU, IT, LT, LU, LV, MT, PL, PT, SI, SK):** Feed-in tariffs (FITs) usually involve long-term agreements on fixed volumes and prices tied to the cost of production of the energy in question. This protects producers from risks inherent in renewable energy production both in relation to the volume and price, and encourages investment and development that otherwise might not take place. FITs are usually differentiated by technology and size to reflect the different generation costs between the various renewable energy technologies. They are currently primarily used for small scale systems, such as solar PVs. However, the support level of FITs is determined through administrative procedure, which can lead to overcompensation due to the risk of a long reaction time to respond to changes in renewable energy production costs.

- **Feed-in premiums (CZ, DE, DK, EE, EL, FR, HR, HU, IT, LT, LU, MT, NL, PL):** Feed-in premiums (FIPs) have been introduced in several EU Member States over the past few years as an option and/or development of existing FIT schemes. FIPs allow producers to receive a premium on top of the market price for their electricity production, with electricity from renewable energy sources typically sold on the electricity spot market. However, if market prices are higher than the reference tariff level, no FIP is paid. Hereby, FIPs provide an incentive for RES operators to respond to price signals of the electricity market, resulting in a somewhat more responsive supply, with FIPs - compared to FITs - also being more cost-efficient support schemes for the government to increase renewable energy projects.

- **Contracts for Difference (no info on Member States):** In addition to the characteristics of a FIP, under contracts for difference (CfD) or a sliding premium (Art.4 of Renewable Energy Directive[40]), if the wholesale price rises above the guaranteed price, generators are required to pay back the difference between the guaranteed price and the wholesale price. Therefore, a CfD can be thought of as a symmetric hedge[41]. Hence, such contract provides certainty on market revenues to renewable projects, while avoiding excessive returns for investors and overcompensation by governments in periods when market prices are high, as the government would act as a counterparty to the contract. The contracts would be awarded and priced through tenders.

- **Green Certificates (BE, IE, PL, RO, SE**): A green certificate is a market-based instrument that proves that electricity has been generated from a renewable energy resource. Such systems are only in place in a limited number of Member States. Once the power provider has fed the energy into the grid, the green certificate received can be sold on the open market as a separate commodity. Renewable energy is impossible to separate from the conventionally generated energy once it is into the grid. Therefore, purchasing a green certificate from the power provider provides the guarantee to the certificate owner that they consumed the renewable portion of the energy that was fed into the grid. Green certificates are normally technology neutral, and will ensure that the cheapest renewable sources and locations are developed first. However, as the price of electricity is set on the margin, it can create infra marginal rents for some low-cost producers resulting in overall relatively higher support costs.

[40] European Commission (2018).

[41] Jörn C. Richstein et al (2022).

- **Investment grants (AT, CY, ES, FI, MT, SE):** Investment grants fund part of the investment costs of an renewable energy project to reduce its ultimate financial cost in order to increase its cost-competitiveness in relation to other alternative technologies, and ensure the investment. Financial support for wind and solar projects has also been provided at EU level in particular through the European Fund for Strategic Investments and cohesion policy funds.

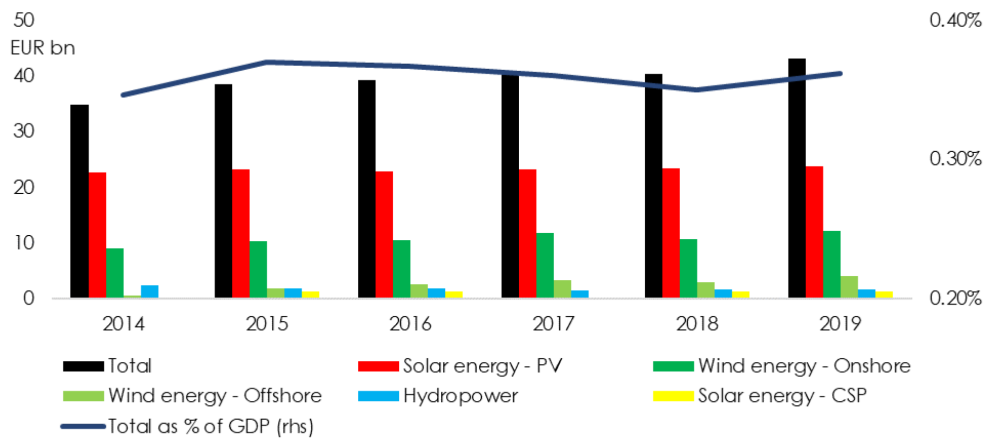
- **Other:** Renewable energy is sometimes supported indirectly, e.g. through full or partial exemptions from taxes or levies. Typically, this is support linked to self-consumption of renewable electricity (often residential installations of PV), where certain charges do not apply, such as a general energy tax or grid charges. Support can also be provided indirectly through public funding or support to the additional infrastructure needed to connect the new generation facilities, e.g. for off-shore wind power.

3.2. COSTS OF SUPPORT SCHEMES

The level of support received by renewable electricity producers reached EUR 35 bn in 2018 and EUR 43 bn in 2019 (corresponding to around 0.35% of GDP)[42]. EUR 24 bn, or 55% of total support, was devoted to solar PV in 2019, and EUR 16 bn supported wind electricity, of which EUR 4 bn to offshore wind[43]. This level of support is calculated as the additional revenue that a renewable producer receives through public subsidies on top of what the producer could earn from the market. For FITs, which do not directly market their production on the market, the support level is calculated ex-post by subtracting a reference market price (e.g. average wholesale electricity price or market value) from the tariff actually received.

With EUR 19bn, Germany has the highest amount of subsidies in 2019 in the EU, which is about equally split between solar PV and wind energy (see Graph A2.1). Italy ranks second with to EUR 8 bn, and Spain third with EUR 5 bn. Notably, both Italy and Spain dedicate more than 70% of the subsidies to solar electricity (also CSP in the case of Spain). On the other hand, the support to offshore wind electricity is concentrated to a few Member States with a coastline (e.g. Germany, Denmark, The Netherlands). In terms of subsidies as share of GDP, Czechia and Greece provided most support in the EU [44].

Graph 3.3 **Subsidies per renewable electricity technology in the EU**



Source: CEER 2021 Status Review of Renewable Support Schemes reports.

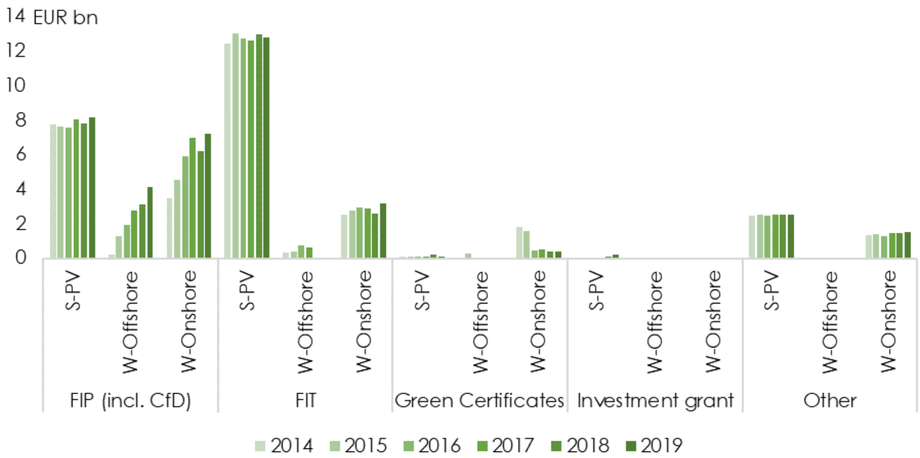
[42] European Commission (2022f). The study found overall higher levels of support in the EU; EUR 29 bn to solar energy and EUR 20 bn to wind energy in 2019. This could be explained by different data collection or reporting methods.

[43] Only limited support to offshore wind in 2019: DE EUR 3.7bn, DK EUR 362mln, and SE 4mln.

[44] CEER 2021 Status Review of Renewable Support Schemes reports & Eurostat [NAMA_10_GDP].

By 2019, FIPs subsidised renewable electricity for EUR 20bn compared to EUR 16bn through FITs. In 2014, FITs were still the largest type of support schemes in the EU, but since then, FIPs quickly caught up in terms of funding. Subsidies through FIPs are about equally split between solar PV and wind energy in 2019, with support to wind energy having increased significantly since 2014. FITs subsidise mostly solar PVs (EUR 12.9bn in 2019), with no noticeable increase in the support to wind energy (EUR 3.2bn in 2019). A comparison between Graphs 3.2 and 3.4 reveals that despite that even though more subsidies are being given through FITs, FIPs support overall a higher volume of renewable electricity (with less money). See Graphs A2.3 and A2.4 for the results at Member State level.

Graph 3.4 **Subsidies per type of support scheme**



Source: CEER 2021 Status Review of Renewable Support Schemes reports.

The level of effective support received by solar and wind technologies varies quite significantly per country (as can be seen in Graph A2.5 in Annex 2). Effective support is the support received after deduction of the average wholesale electricity price, representing the revenue that the project could obtain from selling its production on the electricity wholesale market. The reported support level was highest for solar electricity in 2019, ranging from a minimum of 50 EUR/MWh to a maximum of 500 EUR/MWh, with an arithmetic average of 202 EUR/MWh. The lowest level was in Hungary and highest in Sweden. For wind electricity, the support level ranged from 7 EUR/MWh to 166 EUR/MWh for the two wind technologies i.e. onshore and offshore, with an arithmetic average of 51 EUR/MWh. The lowest support level for onshore wind electricity was in Sweden and the highest in Cyprus. It should be noted that the level of support reported is at the fleet level. It reflects country specific framework conditions, in particular the electricity market set-up and technology mix, the maturity of the technology markets as well as the influence of the history of deployment of the technologies in the given country. In particular, under feed-in based support schemes, a larger installation rate in earlier year implies higher levels of support due to the steep technology learning experienced by solar and wind technologies.

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3.3. FINANCING OF RENEWABLE ENERGY SUPPORT SCHEMES

There are two main approaches to funding RES support schemes, and they have not changed much over time. According to the CEER report, in the period 2018-2019, most Member States either use general taxation (DK, LU, MT, RO)[45] or non-tax levies paid via the electricity bill by some or all customers (AT, HR, CY, CZ, EE, DE, EL, HU, IE, IT, LT, LV, LU, NL, PL, PT, SK, ES SE). In the latter case, either the government or the regulator determines the levy. It is also possible to finance the RES support directly through the state budget, such as in CZ and FR.

Sometimes there are exemptions (partial or full) to the financing contributions, e.g. for energy-intensive industries, for self-generated electricity from RES[46] or conventional power plants consumed on site, for low-income households, for industries that are obligated to obtain a permit for greenhouse gas emission, and for SMEs. These exemptions often increase the financial burden for non-exempted consumers.

RES policies, including support for renewables, can affect consumers in a number of ways, notably through overall impacts on the electrical system (e.g. grid development, market integration, etc.). In most cases, the costs for achieving the agreed renewable energy objectives will ultimately be borne by end-users, for example, if the RES support is directly added to electricity bills, or by the taxpayers. It is therefore also in the interest of all consumers to achieve RES deployment in the most cost-effective manner.

More intermittent and decentralised energy sources means that network operators will face extra costs in providing their service of constant interventions to match supply and demand to keep the grid stable (see section 2.3 for a discussion on the need for storage and balancing capacity) **.** Each national regulatory authority (NRA) has the duty of fixing or approving network tariffs or their methodologies, according to the Electricity Directive (EU) 2019/944. The network tariffs should ideally be set to reflect the fixed costs of transmission and distribution system operators, while at the same time provide appropriate incentives to them to increase efficiencies, fostering market integration and security of supply, supporting efficient investments and related research activities. Also, facilitating innovation in the interest of consumers in areas such as digitalisation, flexibility services and interconnection is to be encouraged.

3.4. RECENT DEVELOPMENTS

Recent auctions reveal that zero-bid subsidies and subsidy-free projects are now emerging in Europe both for solar photovoltaic and wind electricity. Auction schemes do not represent a distinct support category, but they are used to allocate the financial support (i.e. through FIP or CfD) to different renewables technologies and to determine the support levels through a competitive bidding procedure. The emergence of these projects indicates that the renewable electricity sector is moving towards market competitiveness with less public support. A number of (wind) projects is now auctioned without subsidies[47]. This gives an impetus to the renewable sector to move towards the development of new business models and the use of price-hedging tools such as private power purchase agreements (see section 4).

The competitiveness of renewables has only further increased in the current situation with energy prices at extremely high levels. In particular, RES operators supported through FIPs will not have received as large, if at all any, subsidies, resulting in a lower cost of renewable energy support schemes. Instead, some Member States (e.g. BG, ES, HU, IT, RO, SK[48]) started to tax the windfall profits made

[45] Meanwhile, DE also introduced financing through the use of general taxation.

[46] Note that if the financing system is based on consumed electricity taken from the public grid, then self-consumption of self-generated electricity is not covered by the financing system and thus in practice exempt.

[47] CarbonBrief (2020).

[48] Sgaravatti, G., S. Tagliapietra, G. Zachmann (2021).

by, in particular renewable and nuclear, energy producers due to the high electricity prices[49]. In addition, the Commission proposed in September 2022 a temporary remuneration cap for infra-marginal technologies, namely technologies with lower costs, such as renewables, nuclear and lignite, which are providing electricity to the grid at a cost below the price level set by the more expensive 'marginal' producers. The Commission proposed to set the inframarginal revenue cap at €180 EUR/MWh. This will allow producers to cover their levelised cost of electricity (LCOE) (this includes all costs - investment, operation, fuel, ETS allowances - per unit of electricity produced), without impairing investment in new capacities in line with our 2030 and 2050 energy and climate goals.

3.5. CONCLUDING REMARKS

Public support schemes played a crucial role in the initial rollout of renewables. However, the schemes were often designed in an inefficient manner with high support costs. Moving forward, it will be crucial to continue to guarantee renewable energy producers with a stable remuneration when prices are low and thereby provide them with enough incentives to invest in renewables, but on the other hand also avoid overcompensation by governments and excessive returns for producers when prices are high. To this end, the increased use of feed-in premiums between 2014 - 2019 is a step in the right direction eliminating any overcompensation by governments. Even better, two-way Contracts for difference awarded through competitive bidding would additionally also avoid excessive profits by producers when market prices are high and thereby is the preferred form of support.

[49] For this, the Commission has provided guidance (See European Commission (2022g) Annex 2) to the Member States for tax measures on windfall profits in case they decide to capture a part of these returns for redistribution to consumers. Such measures need to fulfil certain criteria to ensure that they are proportionate, limited in time and that they avoid undue market distortions.

4. POWER PURCHASE AGREEMENTS

Power purchase agreement (PPA) is another form of contracts on the market for renewable energy producers that cover the risks associated with financing large energy projects, but that does not involve the government as one of the contracting parties. It provides an alternative to the government-driven support schemes discussed in Section 3. In terms of design, it has a similar logic as contracts for difference.

4.1. PPA: DEFINITION AND SCOPE OF THE MARKET

A PPA is a long-term energy supply agreement concluded directly between a power consumer and a power producer. As government subsidies are removed (see section 3), a PPA can instead be used to secure long-term revenues to RES projects, whilst the buyer can benefit from a stable electricity price[50]. It plays a central role in investment decisions for the producer, as it mitigates risks related to fluctuations in energy prices. As such, a PPA provides a market-based alternative as it is based on contracts between different market operators, rather than with the government.

Buyers are typically electricity supplier on the retail market or final energy consumers such as corporations and energy communities[51]. The offered prices are normally below analyst forecasts of future electricity price, corresponding to the risk premium related to the price volatility, locking in potential cost savings. The market for PPAs has steadily increased over the past ten years and given the recent energy price surge, demand for PPAs is likely to increase even further as businesses and electricity retailers seek to hedge against volatile energy prices**.** They therefore will play a crucial role to support future investments in renewables.

There are two main PPA variants: physical (on-site or off-site) PPAs and financial PPAs[52] (which are off-site)[53]. In a physical PPA, the electricity produced is delivered to the buyers physically. In an off-site PPA, an intermediary utility company handles the transfer of money and energy to and from the power producer on behalf of the buyer (sleeved PPAs). On the other hand, a financial PPA includes an agreement between the power producer and buyer. The electricity generated is sold to the wholesale market. The contracting parties are required to make differential payments depending on the electricity price development on the wholesale market as well as on the agreed fixed price.

4.2. PPA MARKET DEVELOPMENTS

The market of PPAs for wind and solar electricity in Europe[54] reached a cumulative capacity of 18.5 GW in 2021. This represents about 6.4% out of the 289 GW installed wind and solar capacity in the EU in 2020[55]. The market began to emerge in the EU around 2013, mainly in Scandinavia, the United Kingdom and The Netherlands. It reached more than 1 GW of installed capacity in 2016 and has further continued to grow. As shown in Graph 4.1, 2021 saw a remarkable uptake of 6.7 GW in PPAs, which is more than the total PPAs signed in both 2019 and 2020 together. Most of the installed

[50] Note that state aid guarantees could be used to support the development of the PPA market.

[51] German Energy Agency (dena, 2019).

[52] also called synthetic or virtual PPAs (VPPAs).

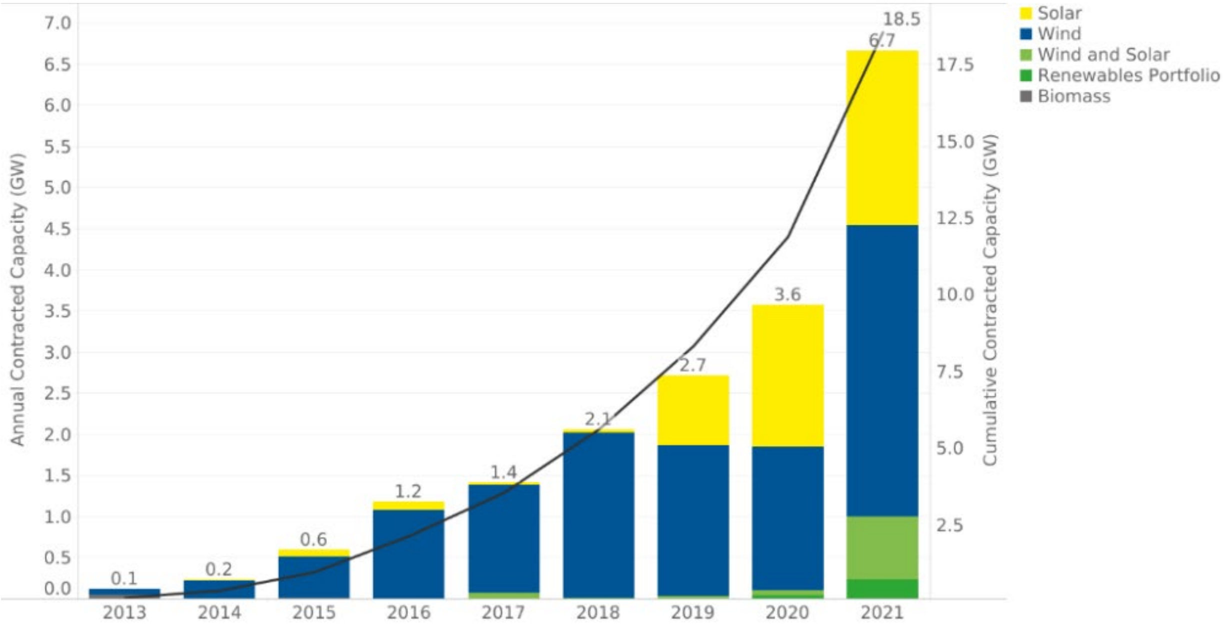
[53] Energy Brainpool (2019).

[54] Including Norway, UK and Switzerland.

[55] Eurostat (2022). NRG_INF_EPC. Latest available data is from 2020.

capacity covered by PPAs are for wind electricity, but PPAs for solar energy have rapidly grown since 2019. By 2021, PPAs covered about 12.3 GW of installed on- and offshore wind capacity (or equal to 6.8% of total capacity in 2020) and 4.9 GW of installed solar PV capacity (or equal to 4.5% of total capacity in 2020)[56]. Since 2021, there is also a significant share (about 1 GW) of one PPA covering combined wind and solar.

Graph 4.1 **Evolution of corporate renewable PPAs in Europe by year and renewable technology**

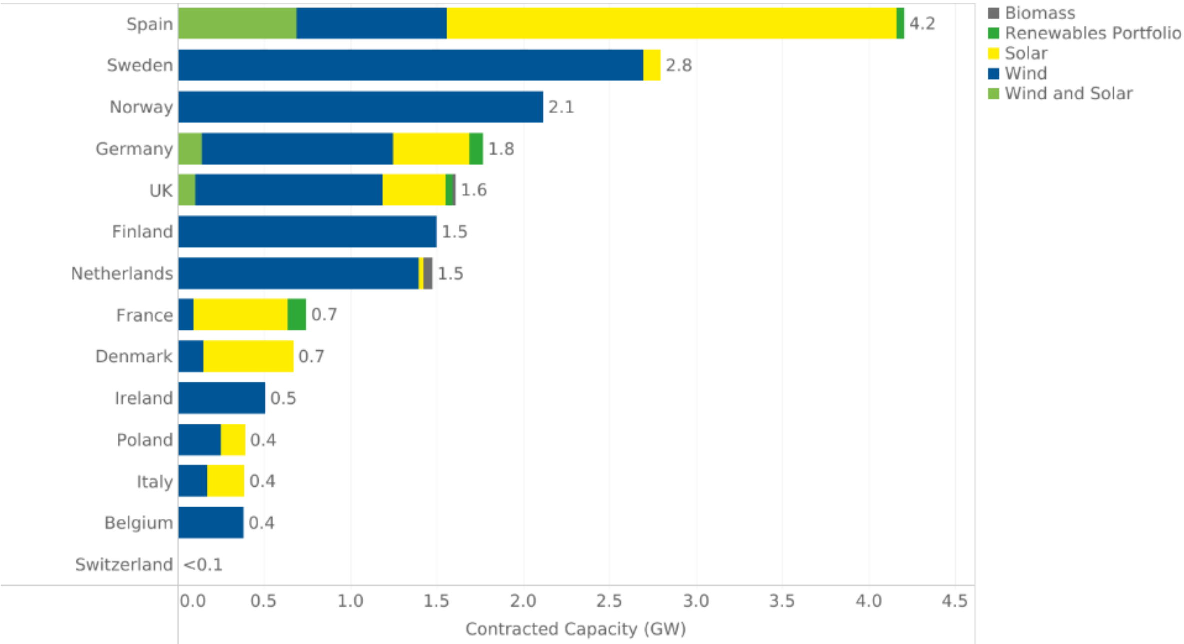


Source: RE-Source Platform (2022) – Renewable Energy Buyers Toolkit.

In terms of uptake across different countries, Spain has impressively caught up since its first PPA in 2018 and currently has by far the highest contract capacity in Europe with 4.2 GW (see Graph 4.2). This is mostly in terms of solar energy, where Spain holds more than 50% of all European PPAs. Sweden (2.8GW), Norway (2.1GW) and Germany (1.8GW) follow at a respectable distance and mostly use PPAs for wind energy. Also the number of European countries where PPAs are used has increased from four (The Netherlands, UK, Sweden and Finland) in 2015 to fourteen countries (of which eleven EU Member States) in 2021, though this development is still mostly limited to Western European countries, with Poland being the exception.

[56] Idem.

Graph 4.2 **Country breakdown of the contracted installed capacity under PPAs per technology type - 2021**



Source: RE-Source Platform (2022) – Renewable Energy Buyers Toolkit.

In the Commission communication 'Tackling rising energy prices: a toolbox for action and support'[57], the Commission committed to work with Member States to facilitate a wider market for decarbonised power purchase agreements beyond large businesses, including SMEs. For instance, through aggregating end-user demand, addressing relevant administrative barriers or providing standard contract clauses. In the short term, flanking measures through InvestEU financial products can support the deployment of such agreements. Lastly, the Commission has put a guidance to facilitate power purchase agreements together with guidance on speeding up permit-granting procedures for renewable energy projects as part of the REPowerEU plan published on 18 May 2022[58].

[57] European Commission (2021c).

[58] European Commission (2022b).

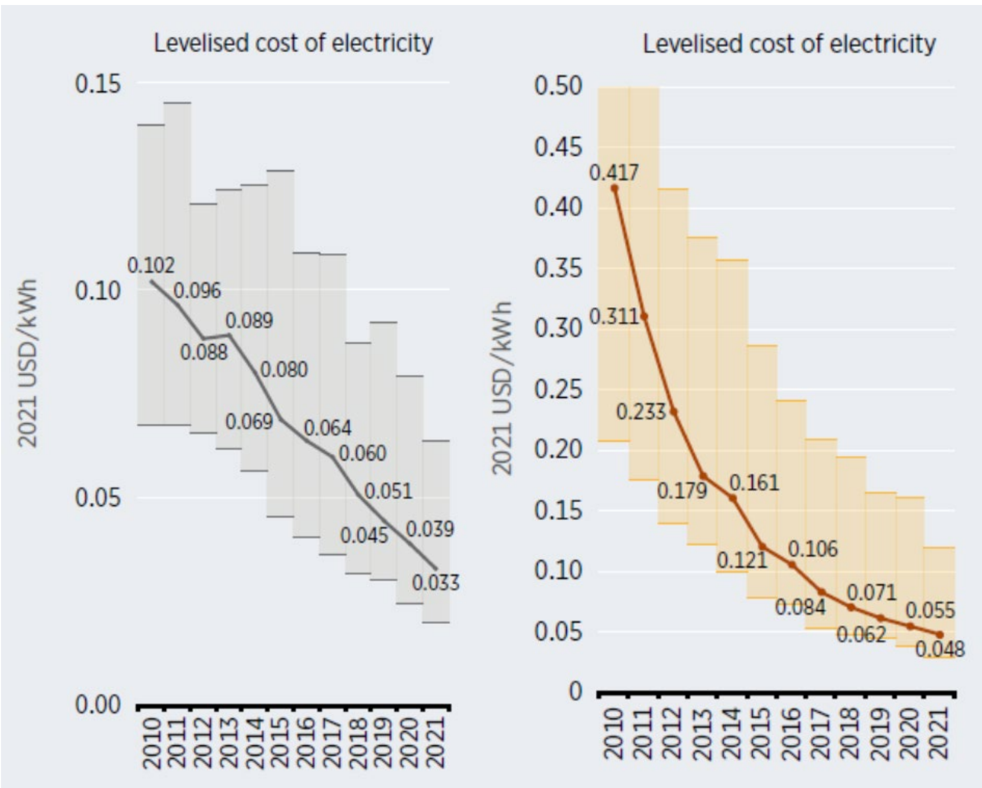
5. EVOLUTION OF THE COST-COMPETITIVENESS

The objective of this section is to analyse the evolution of the cost-competitiveness of solar photovoltaic and on-shore wind electricity by 2030. The cost of production of renewable electricity has continued to fall over the last decades. However, this does not necessarily lead to an absolute improvement in the cost competitiveness of these technologies. A technology is competitive if its production costs are lower than its market income based on electricity prices. Electricity market prices in power systems with a high share of renewable energies are strongly influenced by the cost structure of these renewable technologies and the climate dependence of its production. This section uses a model-based analysis with the METIS energy system model[59] to identify the key mechanisms driving market revenue dynamics and chart prospects for renewable electricity competitiveness to 2030.

5.1. EVOLUTION OF THE PRODUCTION COSTS

Graph 5.1 **Evolution of the levelised cost of electricity for onshore wind and solar photovoltaic electricity from 2010 to 2021 at global level.**

On-shore wind *Solar photovoltaics*



Source: reproduced from IRENA - Renewable Power Generation Costs in 2021.

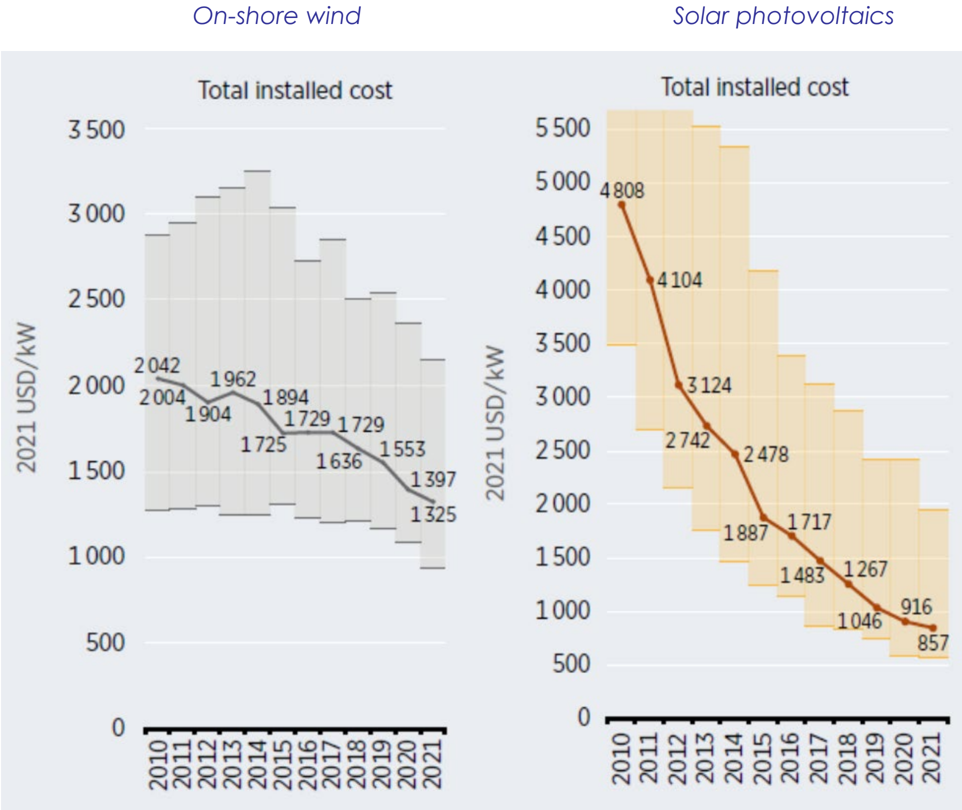
The production costs of onshore wind and solar photovoltaic electricity have decreased significantly in the last decade. As shown in Graph 5.1, the cost of producing solar photovoltaic electricity (utility scale) decreased at an annual rate of 18% from 2010 to 2021, a reduction of about a factor of 8 on average from 2010 to 2021. For onshore wind, the cost reduction achieved from 2010 to 2021 was more moderate, with an annual reduction rate of around 9% on average or a decrease of

[59] https://energy.ec.europa.eu/data-and-analysis/energy-modelling/metis_en,

Kanellopoulos, K., De Felice, M., Busch, S. and Koolen, D. (2022).

around a factor of 3 on average. The difference between solar and wind technologies may be explained by the characteristics of wind projects, which reflect, to a large extent, site-specific construction conditions. The modularity of the solar panels makes it possible to reach a higher degree of standardisation of the installation techniques[60].

Graph 5.2 **Global weighted average total installation costs**



Source: reproduced from IRENA - Renewable Power Generation Costs in 2021.

The continued reduction in the investment cost of the technologies has been a key driver behind the overall decline in the cost of production. As shown in Graph 5.2, the total installation cost of solar photovoltaic projects has decreased since 2010 with average cost savings of 80% from 2010 to 2021 for utility scale projects. This is due, in particular, to large-scale investments in manufacturing capacity in China. The cost decrease for onshore wind farms from 2010 to 2021 was less pronounced with a 35% cost reduction over this period. However, it should be taken into account in the lower cost reduction compared to solar photovoltaic electricity that the design and technical characteristics of wind turbines has evolved significantly over time. They are larger, which brings in more complexity that would tend to increase the cost per unit capacity in general.

There is still further potential for further reduction in investment costs in the future. According to technology assumption used in the reference scenario 2020 published by the Commission[61], investment costs for solar photovoltaic capacity are expected on average to decrease by about 20% until 2050, while onshore wind investment costs are expected to decline by about 10% over the same period. This will be due to the combination of innovations in terms of technologies, components and manufacturing improvements[62].

[60] Tsiropoulos I, Tarvydas, D, Zucker, A (2018).

[61] https://energy.ec.europa.eu/data-and-analysis/energy-modelling/eu-reference-scenario-2020_en

[62] IRENA (2016).

However, bottlenecks in supply chains may reduce the decrease in investment cost. The current geopolitical context has led to disruptions in some global supply chains of materials and resources. The prices of commodities needed for these technologies, like lithium and cobalt, more than doubled in 2021, while those for copper and aluminium increased by around 25% to 40%. This is affecting the competitiveness of wind and solar photovoltaic technologies[63].

5.2. COST-COMPETITIVENESS

5.2.1. General overview

Solar photovoltaic and onshore wind electricity is expected to be cost-competitive in a wide range of market situations in the EU by 2030. Cost-competitiveness is defined as a market situation where the revenues generated by a given technology on the day-ahead electricity market i.e. its market value are higher than its production cost. In this study, the production cost (LCOE) of newly installed solar photovoltaic and onshore wind electricity capacities[64], [65] in 2030 is compared to its market value in six representative European markets. These markets are based on a stylised representation of the technology mix of *the Czechia, France, Germany, Italy, Spain and Sweden,* taken for illustrative purpose. The market framework used for this analysis for 2030 is based on a policy scenario developed by JRC to model in a stylised way a European power system in line with the REPowerEU plan [66], [67]. Cost-competitiveness is achieved in all Member States analysed as shown in Graph 5.3 below as the market value is expected to be greater than the cost of production. Annex 3 provides a detailed overview of the model and methodology used.

The cost competitiveness of solar photovoltaic and onshore wind can be explained in a stylised way by the interaction between three mechanisms:

- the overall level of energy commodity and carbon prices
- the increase in the shares of wind and solar electricity (VRE)[68]
- and the level of flexibility of the power system.

Electricity prices are determined by the marginal cost of electricity production, which at the current juncture is often driven by the price of fossil fuels. The equilibrium price of the market is the price of the marginal power plant needed to meet demand, which corresponds to its marginal cost. Power plants are dispatched according to their order of merit. Demand is first met with technologies with the lowest cost of production. Technologies with higher generation cost are called in gradually with increased quantity until the demand is satisfied. The intersection of demand and supply reveals a uniform market clearing price that is obtained by each successful supply offer. Solar photovoltaic and wind generators have very low variable production costs[69]. This means that they are dispatched first,

[63] European Commission (2022h).

[64] It is noted that this is not the production cost of the solar fleet which will be higher as capacities deployed in the past had higher investment costs. Furthermore, the investment cost assumed in this study represents an average of the investment costs of several types of solar panels from small roof-top to utility scale systems. The recent increase in prices due to supply chain bottlenecks are also not accounted for.

[65] The LCOE represents the average revenue per unit of electricity generated that would be required to recover the investment and operating costs during the technical life of the project. The market value is calculated as the ratio of the annual revenue generated by the project over its yearly electricity production.

[66] The analysis does not hence represent a forecast of the power systems of these Member States.

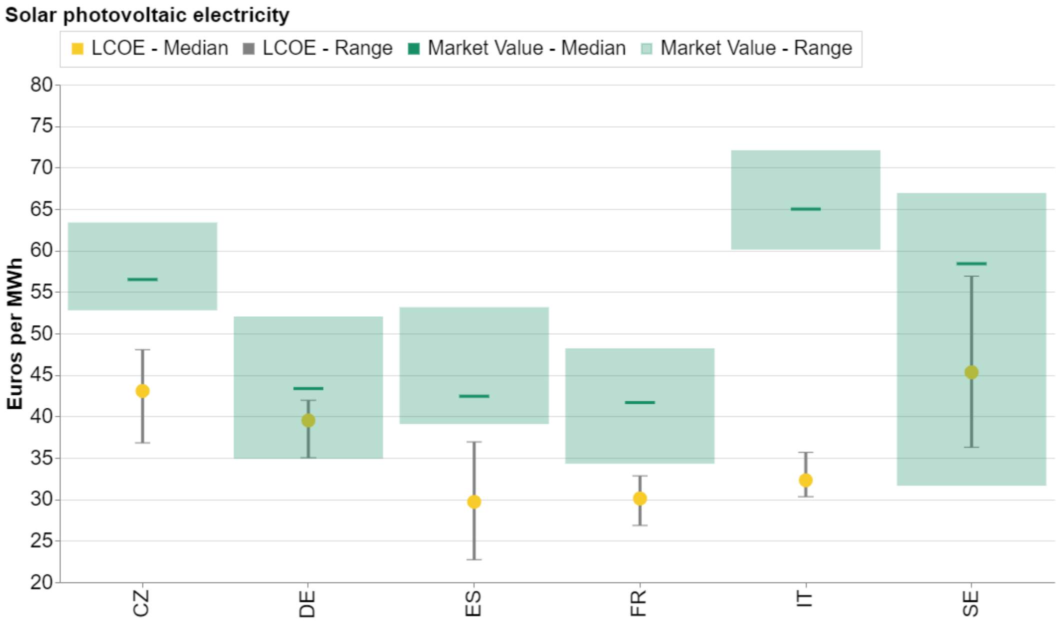
[67] European Commission (2022d).

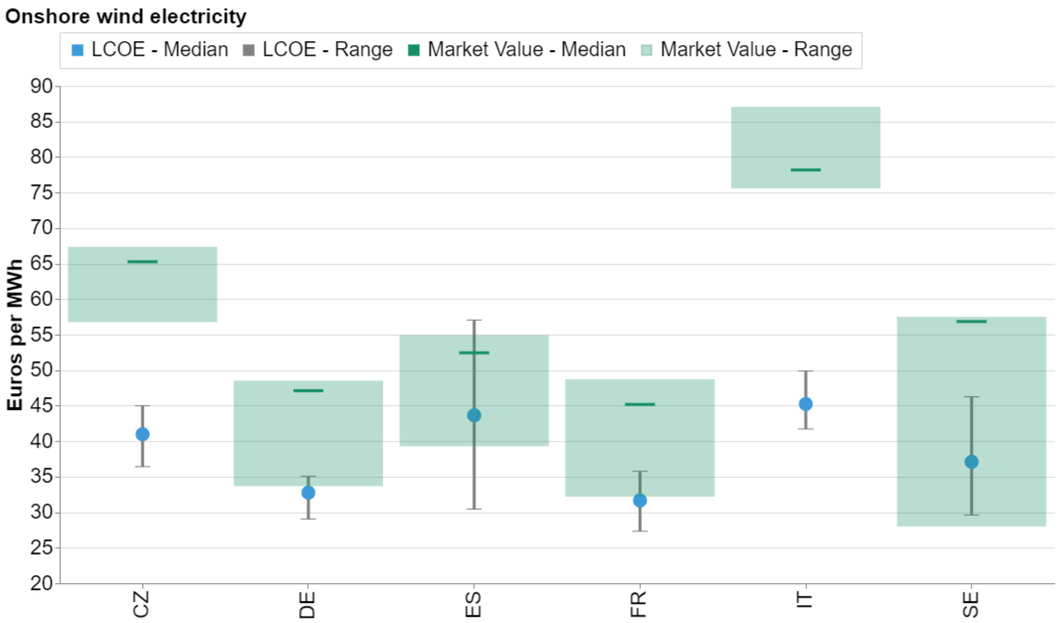
[68] VRE: Variable Renewable Electricity.

[69] However, balancing costs should be taken into account due to the fact that the production of solar and wind technologies is weather dependent.

i.e. before other energy sources, on the wholesale market when they operate. Flexible technologies such as natural gas turbines are usually dispatched last when the demand is high, implying that it is often these power-plants that set the electricity price. This implies that if the price of natural gas increases, the price of electricity will also increase.

Graph 5.3 **Comparison between the production cost (LCOE) and the market value of solar photovoltaic and onshore wind electricity generation in representative European market conditions by 2030.**





Source: European Commission's Joint Research Centre. The Green box represents the ranges of market values modelled; the vertical error bars represent the ranges of LCOE. Circles and dashes respectively indicate the median values across three selected climatic years.

However, the increase in the share of wind and solar electricity can counteract to some extent the increase in energy commodity and carbon price through a merit-order effect. As a basic trend, wholesale electricity prices are expected to increase in 2030 compared to pre-pandemic levels, mainly due to the increase in demand for electricity and the rise in commodity and carbon prices as envisaged in the REPowerEU related scenario. However, as solar photovoltaic and wind generators are dispatched first and their share in the market is increasing, they replace when they operate other generation capacities with a higher variable cost. In other words, they push the merit-order curve to the right, shifting high (flexible and short run) marginal cost capacities out of the market. This can result in a drop in wholesale prices, which can reach a value of zero when no thermal power plant is needed to meet the demand. It can also reach negative values if the benefit of subsidies or the costs of shutdowns of thermal baseload plants justify paying for continuing operating. This merit-order effect impacts both the overall wholesale price, and concomitantly, also the revenue of the renewable technologies. Indeed, as the price drops when renewable technologies operate, it means that the price they get in the market for their output is also lower. As the magnitude of this effect increases with their market share, this means that renewable technologies erode their own market value over time. This is the so-called cannibalisation effect of renewable energy[70].

One way to mitigate this effect, to a certain extent, is to increase the flexibility of the power system. Flexible solutions such as cross-border interconnections, demand response, electricity demand for hydrogen generation or energy storage can counteract this merit order effect. The main reason is that it allows demand to be shifted in time and space depending on the price signal. For instance, low prices incentivise consumers to consume more. This means that when the electricity price is reduced due to the production of renewable electricity the demand will be higher, resulting in a higher equilibrium price. Demand flexibility can therefore mitigate the decrease in prices due to an excess supply of renewable electricity. Long-term instruments are also important to consider alongside a more flexible power system to ensure stable streams of revenues for renewable producers and incentivise investments[71], [72].

5.2.2. Quantitative analysis

5.2.2.1. The cannibalisation effect

The evolution of the market value of solar photovoltaics and onshore wind electricity can identify the existence of a cannibalisation effect. A market value lower than the average price of electricity as the renewable capacity increases indicates a cannibalisation effect. The production of the fleet of a given renewable technology is correlated due to its weather dependency over large regional areas. As a result, and given their low variable cost of production, they are pushing other more expensive technologies out of the merit-order when they produce and the demand is not sufficiently flexible and/or the production capacity exceeds the demand. Following the methodology developed in Hirth (2013) [73], this effect can be quantified through a market value factor, which is a relative price calculated by comparing the actual revenue per unit of electricity produced obtained in the market to the average price of electricity or base price. The base price is calculated as the time weighted average wholesale day-ahead price. The market value of the renewable technologies is calculated as the sum of the hourly market price times the hourly production divided by its annual production (see Annex 3). The evolution of the market value factors of solar photovoltaics and onshore wind electricity from 2018 to 2030 is shown in Graph 5.4 below for each of the Member States analysed. The base price and market value of each technology that are used in the calculation of market value factors are also shown in this Graph.

The modelling results in Graph 5.4 confirms the existence of a cannibalisation effect for solar photovoltaic and onshore wind electricity. In 2018, the market value factors of solar photovoltaic and onshore electricity were around one. By 2030, the market value factor of solar electricity is, on average, lower than the base price by a factor between 0.7 – 0.8 in most Member States analysed. For wind energy, the market value factor slightly decreases and reaches values close to one or around 0.8 to 0.9 in several Member States. This means that the increase in renewable electricity capacity between 2018 and 2030 is expected to reduce their market value overtime. The difference between wind electricity

[70] Hirth L. (2013) and López Prol J. et al (2020).

[71] Fabra N. (2022).

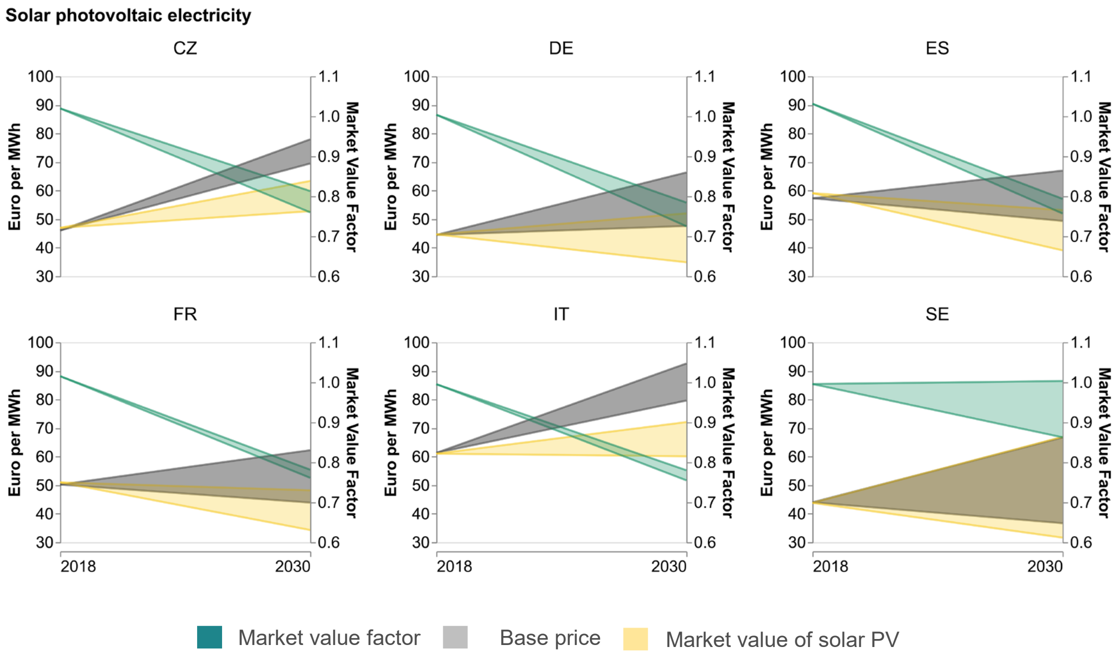
[72] Joskow, Paul L. (2019).

[73] This follows the methodology developed in Hirth L. (2013). Pages 218-236.

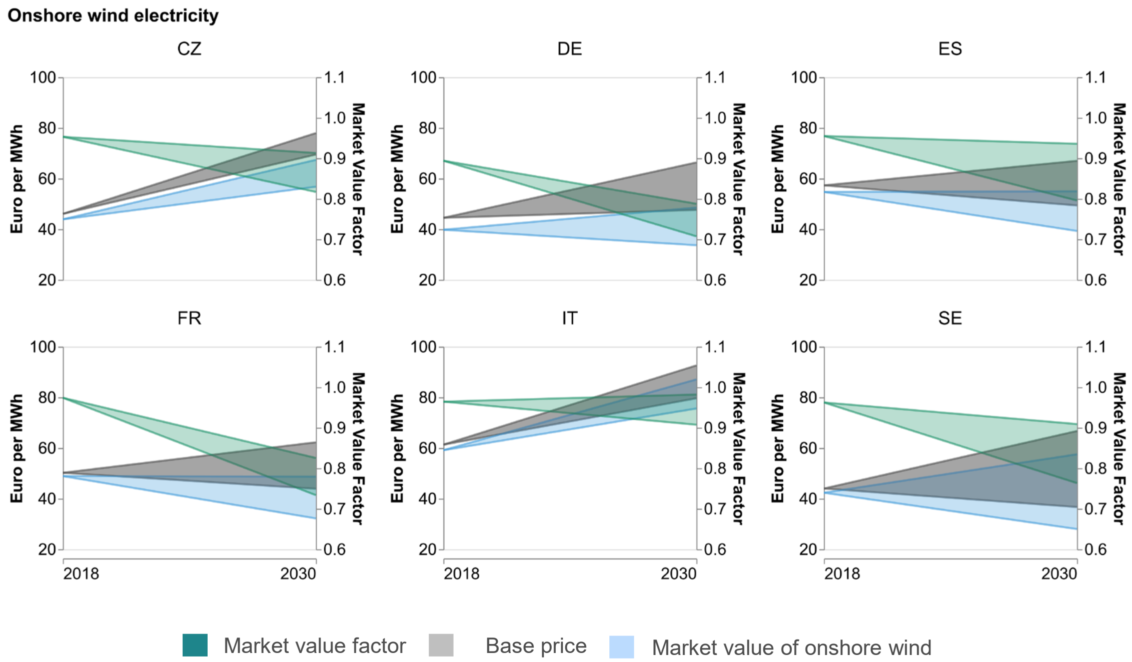
compared to solar electricity may be attributed to the fact that the solar generation is more concentrated during the day. This means that it is less correlated to demand, hence it has a higher impact on electricity prices[74] .

Graph 5.4 **Evolution of the wholesale electricity price, market value and market value factors of solar photovoltaic and onshore wind electricity from 2018 to 2030 in the selected Member States[75].**

Solar photovoltaic electricity



Onshore wind electricity



Source: European Commission's Joint Research Centre.

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[74] López Prol J. et al (2020).
[75] The data range for 2030 is due to modelling years with different climatic conditions.

5.2.2.2. The importance of a flexible power system

A more flexible power system has the potential to address the cannibalisation effect due to increasing shares of variable renewable electricity. As explained in section 5.2.1, flexibility allows demand to react to the price signal. Demand is increased when the price is low, and reduced when the price is high. This is counter-cyclical to the effect of renewable electricity on the electricity price. This dynamics has been confirmed in recent academic work. For instance, Ruhnau (2022)[76] has analysed the synergy in wholesale electricity markets between variable renewable electricity (VRE) such as wind and solar photovoltaic energy and flexible technologies such as electrolysers used to produce hydrogen. The modelling work has shown that the price decrease due to higher shares of variable renewable electricity would trigger investments in electrolysers for the production of hydrogen. Such investments would stabilise in turn the market value of renewable electricity through their demand for additional or excessive electricity. Indeed the competitiveness of electrolyser relies on its ability to use cheap electricity as an input to produce hydrogen. A higher share of very low electricity prices due to an increasing share of renewable electricity is therefore an incentive to invest in electrolysers. The study has also shown the existence of a threshold effect in terms of share of renewable electricity in the system for this to happen. In particular, there is limited impact of electrolysers on the market values of renewable electricity below a 40% market share of variable renewable electricity. This is explained by the fact that when the share of variable renewable electricity is too low, market prices are too high and zero-price hours are too few to trigger investments in electrolysers on a market basis.

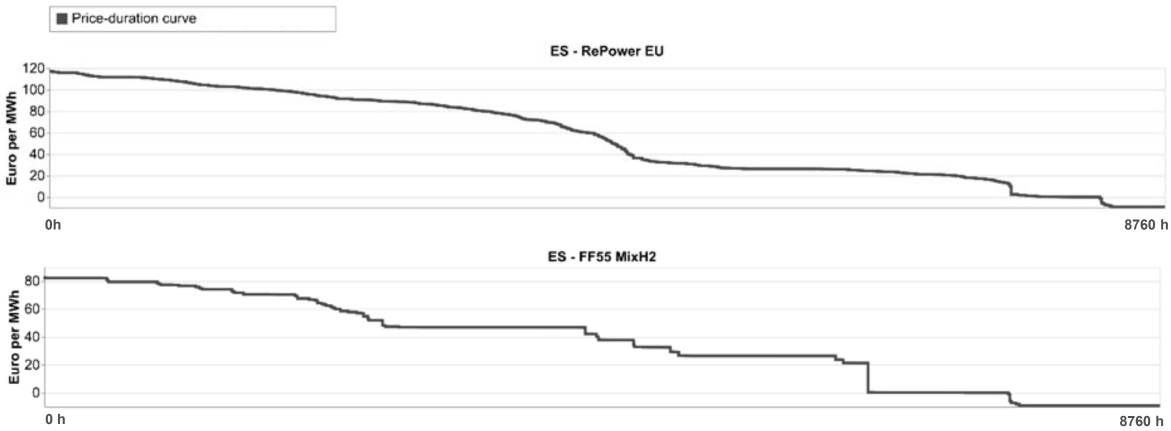
Although it does not constitute a causal analysis, this dynamics can be visualised using price duration curves. A price duration curve indicates the share of the year for which the price exceeded a certain price level. The left side of the price duration curve gather the highest prices in the market, reflecting the fact that for this part of the time distribution, it is high marginal cost technologies that set the price such as fossil fuel (e.g. gas) based power plants. The right side of the price duration curve shows the fraction of the year where low marginal cost technologies are setting the price. While the left part of the duration curve is expected to be influenced by an increase in fossil fuel commodity prices, the right part of the duration curve is in particular expected to be influenced by the net results between the renewable electricity production and the flexibility of the power system. To visualise this dynamic, price duration curves have been computed for the REPowerEU related scenario and the MIX-H2 scenario. The MIX-H2 scenario was used in the impact assessment of the fit-for-55 package adopted by the Commission in July 2021[77]. Compared to the MIX-H2 scenario, the REPowerEU related scenario features in particular an increase in the price for the energy commodities and carbon price as well as additional solar and wind capacity and also flexibility solutions such as electricity battery storage and electrolyser capacity to produce hydrogen.

Graph 5.5 illustrates the impact of higher flexible technology capacities on the price structure. Under the MIX-H2 scenario, the price duration curve for Spain exhibits a sizeable share of the time at a price level of zero or even negative. On the other hand, under the REPowerEU related scenario that has both a higher share of renewable electricity and a higher installed capacity of electrolyser, the shape of the price duration curve is changing substantially. First, the highest levels of wholesale prices have increased in line with the increase in commodity and carbon prices. Second, the share of zero price on the right-hand side of the curve is reduced and a plateau is appearing at price levels between €40/MWh and 20€/MWh. This could indicate the price effect provided by an increase in flexibility capacity, which results in higher demands when renewable electricity is generating at the margin at low cost. The overall impact on the market is thus higher prices. A more in-depth analysis would be required to confirm these assumptions.

[76] Ruhnau O. (2022).

[77] European Commission (2021d).

Graph 5.5 **Comparison of the price duration curves and the availability of the solar fleets between the MIX H2 and REPowerEU related scenarios for Spain in 2030**



Source: European Commission's Joint Research Centre.

5.2.2.3. Conclusion

With the necessary caveats related to the forward-looking nature of this study, the analysis shows that solar photovoltaic and onshore wind power would be cost-competitive on a market basis in a broad range of market situations encountered in Europe by 2030. The results underline the role of flexibility for their cost competitiveness in a context of increased deployment of renewable electricity capacity. This shows the importance to invest in solutions to make power systems more flexible. The study shows also that the level of profitability for renewable projects can be substantial in some markets. This calls for analysing market arrangements that are fit for power systems with high shares of renewable electricity in the future. This concerns both the need to improve the design of public support to avoiding excessive profits while incentivising investment, but also the need to promote market based instruments such as power purchase agreements.

6. CONCLUDING REMARKS

Renewables will play a key role in achieving our climate goals as a part of the Green Deal and the EU's ambition to reach net-zero emissions by 2050. Up to now, more than 80% of the electricity produced from wind and solar photovoltaic power received support from governments through support schemes to make these investments viable. However, already in the near future, solar photovoltaic and onshore wind power are likely to be cost-competitive on a market basis in a broad range of market situations encountered across Europe by 2030. This is due to a large decrease in production costs - with further potential for reduction in investment costs - as well as increased energy commodity and carbon prices. The current energy crisis, and the interruption of gas supplies, have accelerated this development, making renewable power production and investment very profitable in the current market. Going forward, when renewables will start dominating the electricity mix, a new set of challenges need to be addressed. This includes the cannibalisation effect of renewables when no thermal power plants are needed to meet demand and the increased need for flexible power production, including balancing and storage, due to their variable production.

In order to sustain investments in renewable energy technologies, reforms are required to address the way renewable technologies are financed. In terms of support schemes, contracts for difference (CfD) as financial Power Purchase Agreements (PPAs) should be further rolled out. By setting a reference tariff level on which the contract depends, CfD provide certainty on a minimum level of market revenue to renewable projects when prices are low, but at the same time avoids overcompensation by governments when price are high. Efforts should also be pursued to act on barriers for power purchase agreements (PPAs) between power consumers and producers. This provides a market-based alternative based on bilateral contracts between market operators, as opposed to the contracts for difference where the government acts as the direct counterparty guaranteeing the agreed price. Overall, all these types of long term and hedging instruments will be able to provide better price and revenue stability to producers and investors in an unstable future market, so that they can more easily commit to investment in long-term renewable energy projects. The availability and use of these long-term instruments should ultimately be market-based. However, public authorities have a role to play in promoting and facilitating their development. Moreover, due consideration should be given to the budgetary cost that this may entail.

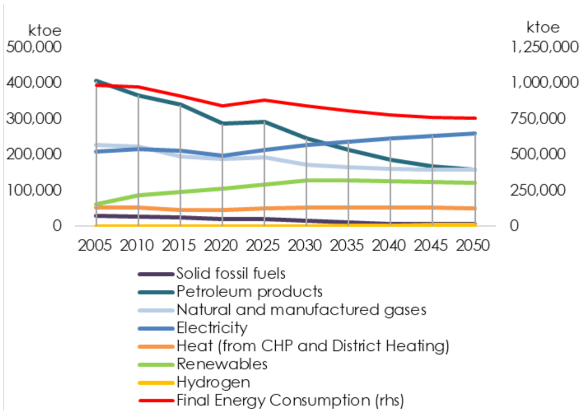
A greater use of long-term contracts need to be complemented by reforms to promote a more flexible power system. A power system with increased renewable and storage capacity will need to match supply to demand, providing baseload as well as peaking power, given any type of weather conditions in every hour of every day over many years. This will require large investments into flexible solutions such as cross-border interconnections or electricity storage, as well as greater penetration of demand-side flexibility through for instance electrolysers or demand side response. This can contribute also to counteracting the cannibalisation effect, as it allows demand to be shifted in time and space depending on the price signal. On top of this, the more electricity generation coming from renewables, the more prominent and important the flexibility of the power system becomes. The modelling results presented above indicate that a sufficiently flexible power systems, including for example hydrogen and batteries as storage, would be able to stabilise electricity prices by 2030, i.e. to increase electricity prices when there is a surplus of production of renewable electricity, and to contribute to smoothen the price hikes.

ANNEX 1: REFERENCE SCENARIO 2020

The choice of the optimal mix of policies for the 'Fit for 55' package was based on the EU Reference Scenario 2020[78], which served as the baseline for the Impact assessment. The EU Reference Scenario is one of the European Commission's key analysis tools in the areas of energy, transport and climate action. It allows policy-makers to analyse the long-term economic, energy, climate and transport outlook based on the policy framework in place in 2020. The Reference Scenario builds on policies at EU and Member State level, whose implementation intensifies until 2030 and continues afterwards, assuming no additional measures apply between 2030 and 2050. Compared to previous Reference Scenario, the representation of RES in the power sector has been updated. In order to better capture the diversity and improve the projection, the categorisation of solar PV, wind onshore and wind offshore has been modified. The categorisation is used for the representation of the technologies as well as for the split of the potential[79].

The Reference Scenario starts from the assumption that the EU energy system would need to evolve based on the EU legally binding target for RES in the RES Directive (at least 32% share of gross final energy consumption from RES by 2030). The Reference Scenario considered then the most recent available data on RES potentials by Member State and the projections on RES share trajectories by sector as expressed in the NECPs. According to the projection, the enabling conditions for the penetration of RES improve significantly, since the Reference Scenario incorporates known direct RES aids (e.g. FITs, FIPs) and other RES supporting policies, such as priority access, grid development and streamlining of authorisation procedures. Beyond 2030, no additional RES targets are set and therefore no additional specific RES policy support (direct incentives) is modelled, as a general rule, although investments in RES continue beyond 2030. In addition, some incentives for innovative technologies such as tidal, geothermal, solar thermal, and remote off-shore wind are phased out more gradually than for mature technologies.

Graph A1.1 **Final energy consumption by fuel** (Reference Scenario 2020)



Source: Fit for 55 modelling.

The modelling includes a shift towards flow-based allocation of interconnection capacities, assuming a market model purely relating trade to market forces throughout the EU internal energy market with perfectly operating market coupling across all participating countries. The EU target model is assumed to be successfully implemented from 2025. Consequently, the balancing of RES is assumed to occur in a very cooperative and cost-efficient manner, allowing to avoid excessive investments in peak devices.

According to the modelling results, electrification of final energy demand persists. The share of electricity in total final demand reaches 26% in 2030 and 33% in 2050 (compared to only 22% in 2015).

[78] European Commission (2021a). (PRIMES and PRIMES-TREMOVE are the main models used for the EU Reference Scenario 2020).

[79] the potential is categorised by e.g. shallow or deep for offshore or placement area for solar (residential, commercial, etc.) and the technology type is categorised based on e.g. hub height.

EU and national supporting policies as well as technology trends prompt a significant penetration of RES in power generation. By 2030, more than half of power generation comes from RES (59%) which is projected to reach 75% by 2050 under Reference Scenario conditions. In 2030, 42% of RES is projected to come from variable sources (wind and solar).

Reference Scenario modelling results by type of RES:

- **Wind**: The biggest increase in the EU power generation mix comes from wind, which more than triples compared to 2015 reaching 30% of total net electricity generation in 2030. Wind installed capacity increases from 127 GW in 2015 to 349 GW in 2030 and 508 GW in 2050. Offshore wind capacity grows exponentially; from just 5.9 GW of installed capacity in 2015 to 95 GW in 2050. Most of wind offshore investments takes place until 2030. Without supporting policies in place after 2030, wind onshore growth is still considerable with 40% capacity being added to the grid until 2050.

- **Solar:** Solar power also expands from 87.8 GW in 2015 to 307 GW in 2030 and 513 GW in 2050. Investment in new solar capacity is driven mostly by support schemes in the short term, the decreasing costs of solar panels and high sector competitiveness. Under Reference Scenario assumptions solar PV covers 18% of electricity generation in 2050.

- **Biomass** use increases slightly but the share of power generation from biomass remains between 5-6% throughout the projection period.

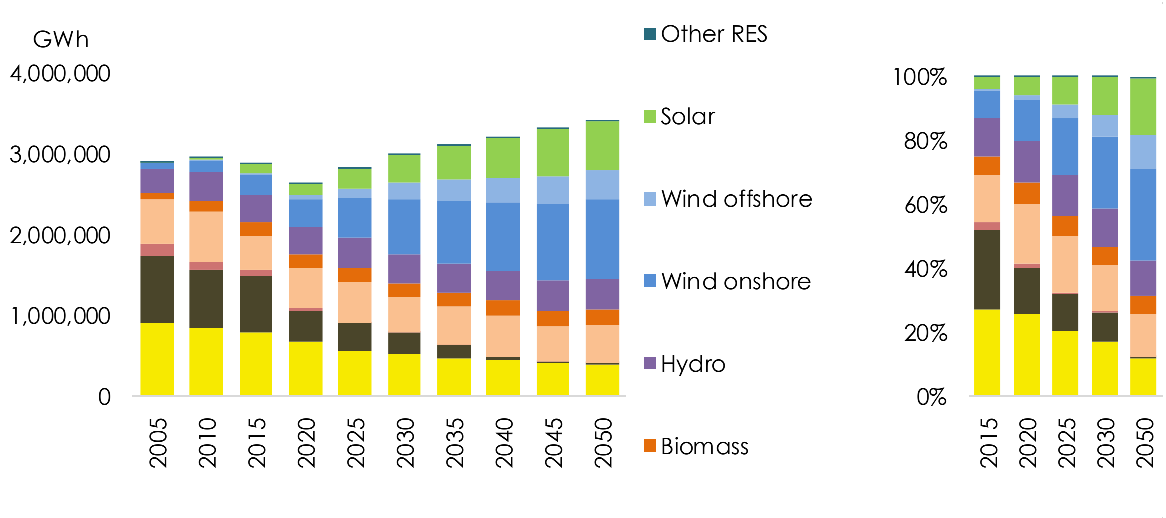
- **Hydro** generation remains rather stable. Net installed capacity increases by 8GW between 2015 and 2050 with 3.5 GW of investments in hydro-reservoirs planned until 2030. Beyond this period the majority of investments are in small run-of-river plants.

- **Geothermal, tidal and wave** energy are not expected to develop before 2050

- **Natural gas** continues to play a role in power generation throughout the projection period acting as bridge fuel. Total net investment in gas-fired plants in the period 2020-2050 amounts to 290 GW. These capacities (mainly CCGT plants) represent the main flexibility options.

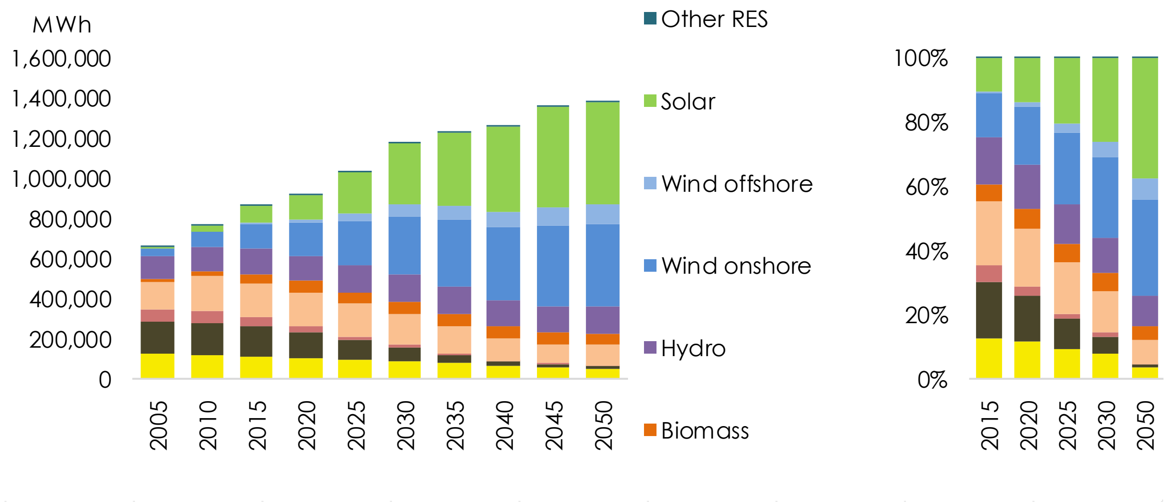
The increasing penetration of variable RES implies a significant increase in flexibility services in the power system. Gas plants, cross-border flows and storage plants are the main balancing resources. Storage facilities undergo an increase by 2030, which accelerates even afterwards: pumped storage, which develops further but has potential limitations; batteries that also develop considerably and benefit from decreasing costs over time; and power-to-X, which emerges in the longer-term. As hydrogen makes little inroad under Reference Scenario assumptions, power-to-X has a small contribution to total storage, even in the long-term.

Graph A1.2 **Gross electricity generation EU** (Reference Scenario 2020)



Source: European Commission, Fit for 55 modelling.

Graph A1.3 **Net electricity generation EU** (Reference Scenario 2020)

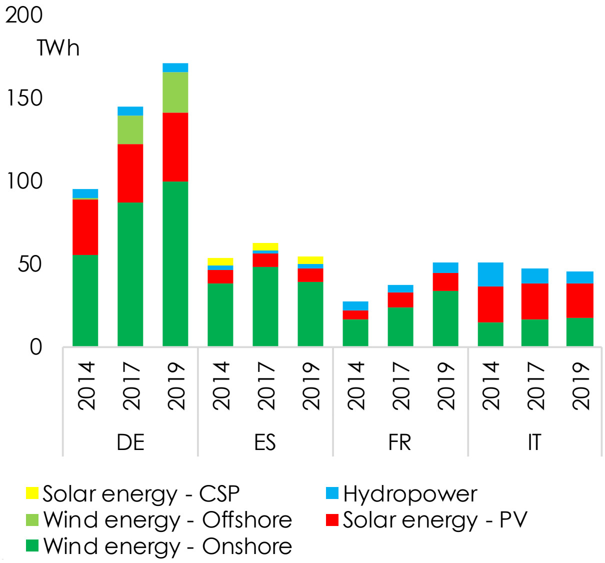


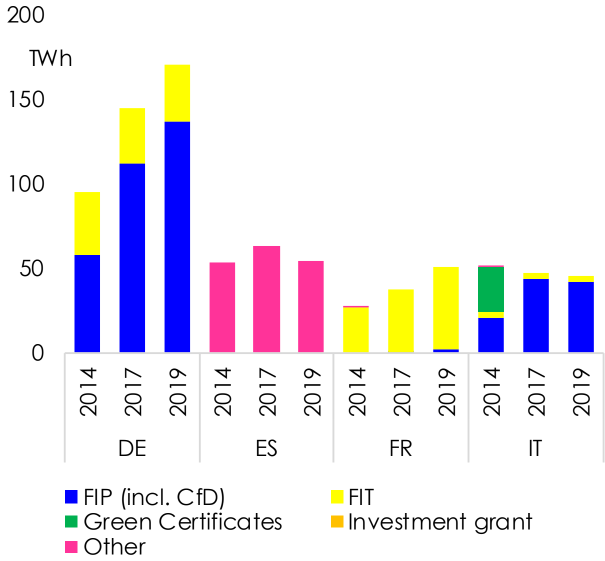
Source: European Commission, Fit for 55 modelling.

ANNEX 2: GRAPHS SUPPORTING ANALYSIS ON RENEWABLE ELECTRICITY SUPPORT SCHEMES

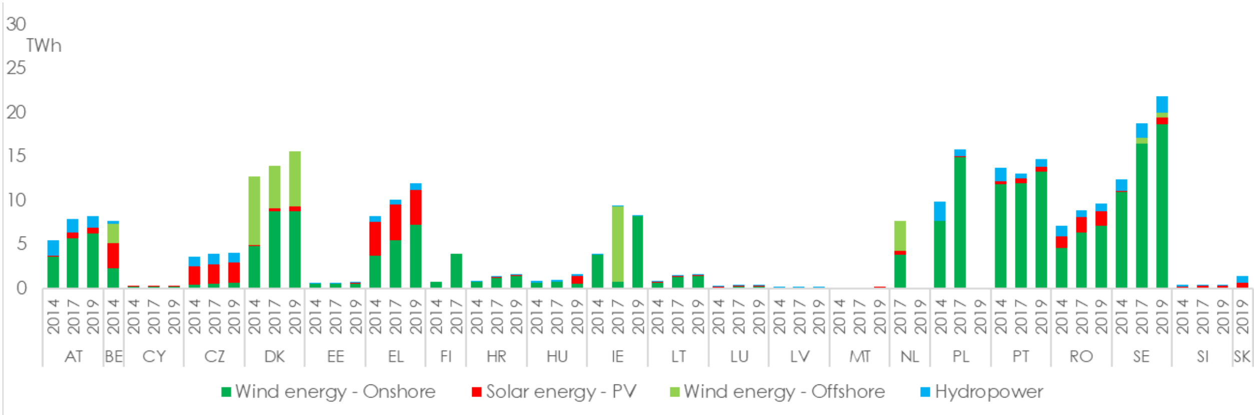
Source for all graphs: CEER (2021)

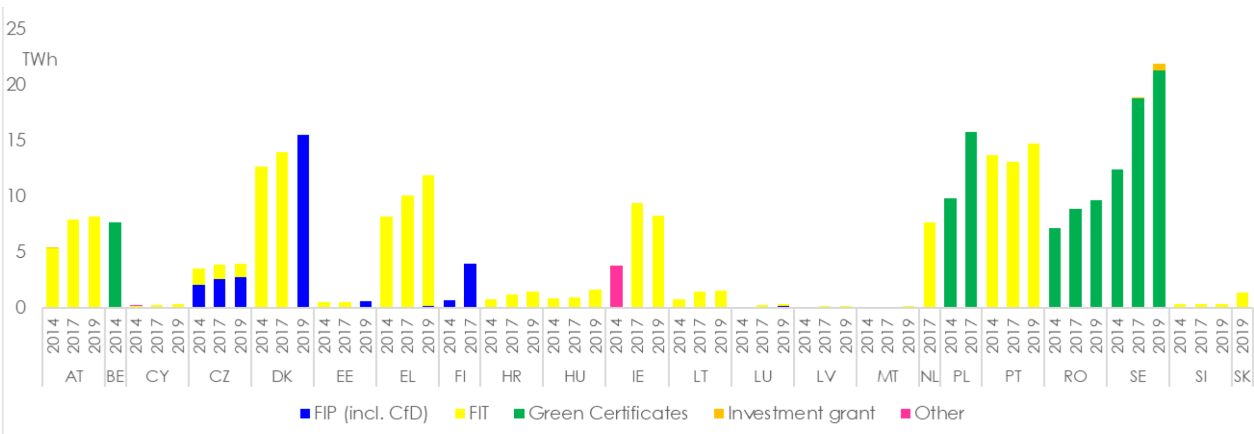
Graph A2.1 **Volume of renewable electricity receiving support and per support scheme - Big 4 MS**



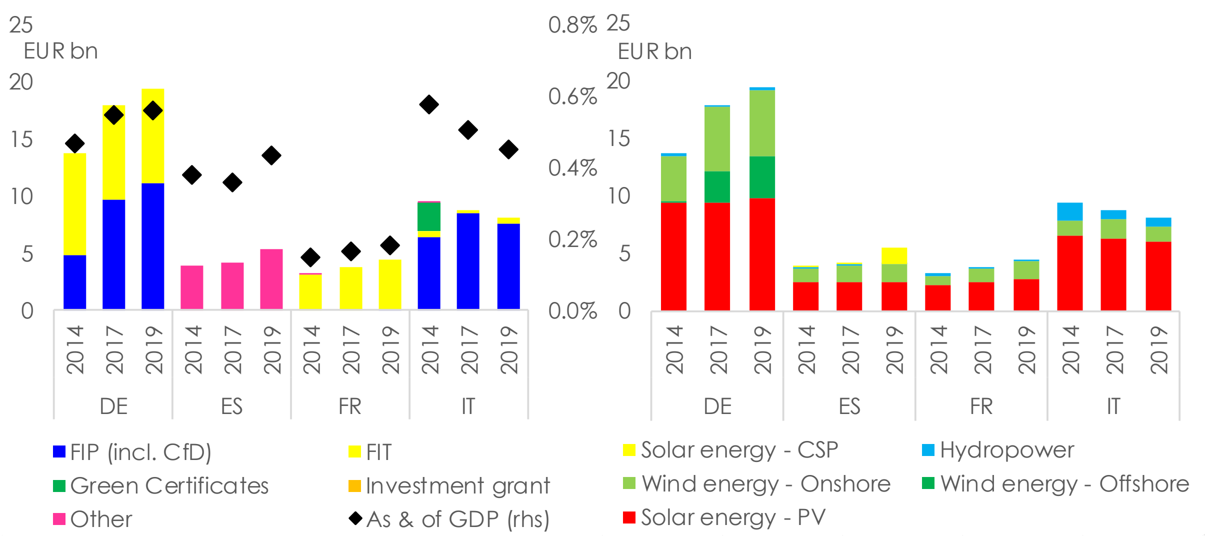


Graph A2.2 **Volume of renewable electricity receiving support and per support scheme - Other MS**

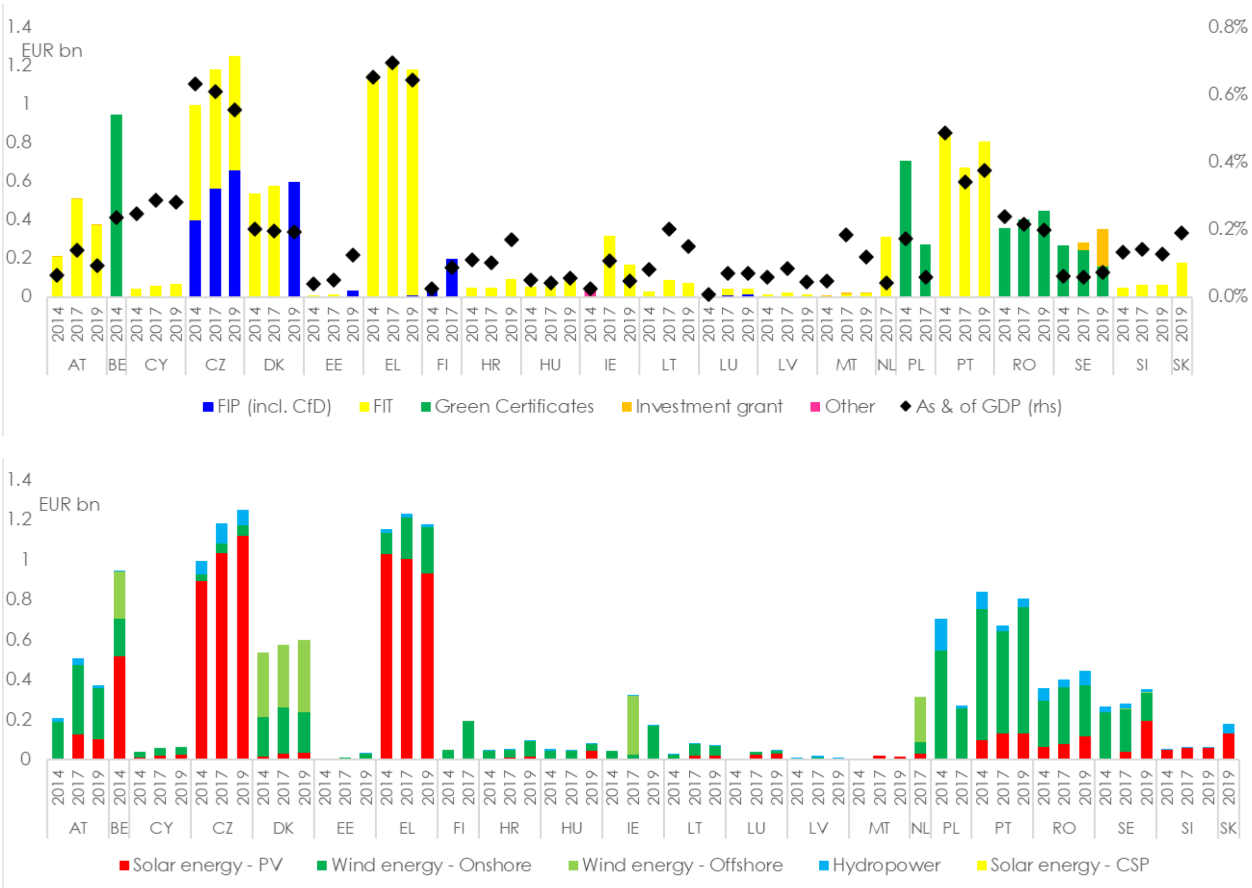




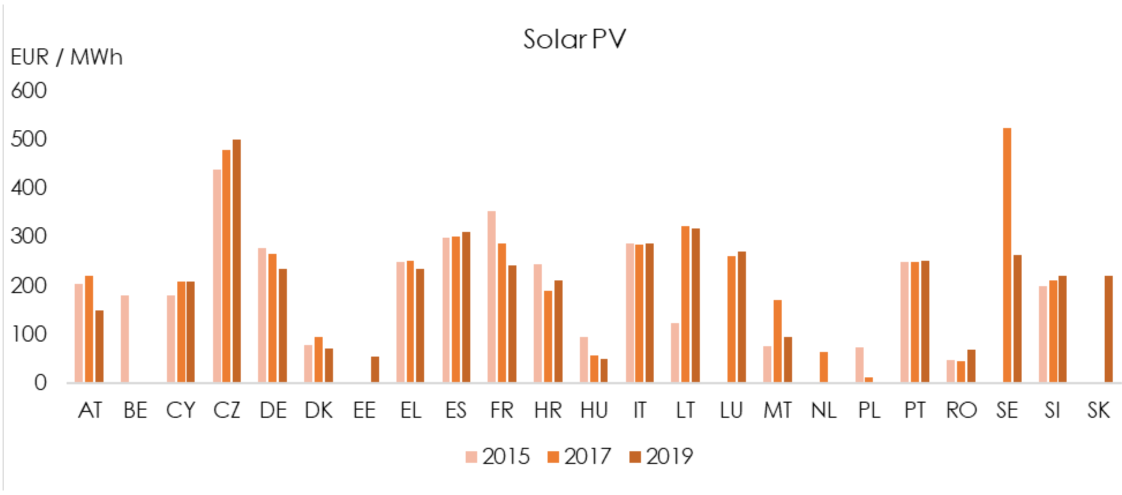
Graph A2.3 **Subsidies by support scheme and renewable energy technology – Big 4 MS**

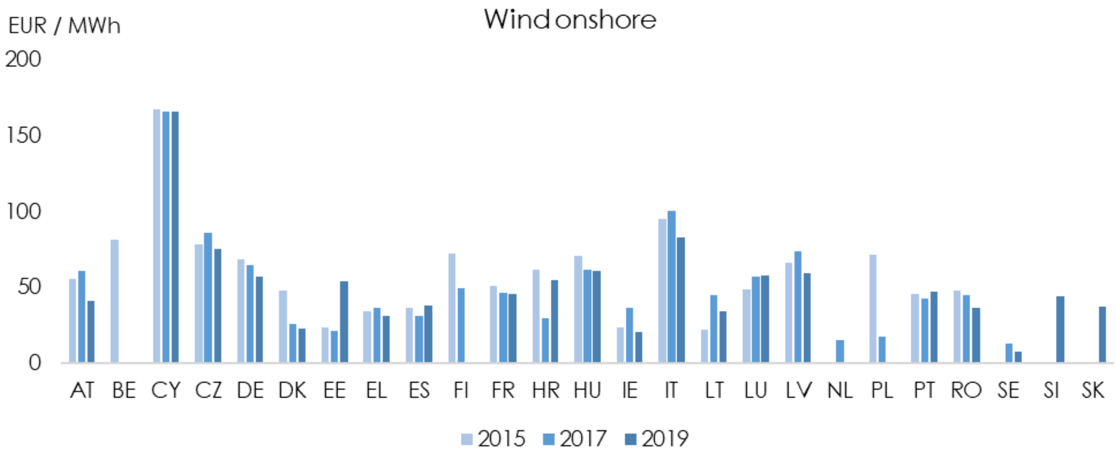


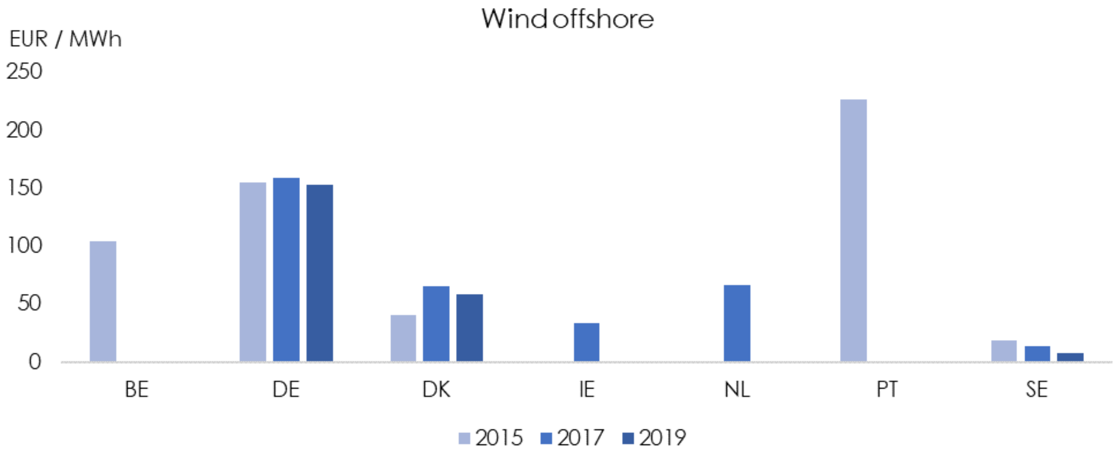
Graph A2.4 **Subsidies by support scheme and renewable energy technology – Other MS**



Graph A2.5 **Average support levels for electricity generated by renewable energy technology in MS**







ANNEX 3: COST-COMPETITIVENESS

The competitiveness of onshore wind and solar photovoltaic electricity projects is analysed in this study through two main indicators: the levelised cost of electricity (LCOE) and the market value of electricity. The LCOE represents the average revenue per unit of electricity generated that would be required to recover the investment and operating costs during the technical life of the project[80]. The market value is calculated as the ratio of the annual revenue generated by the project over its yearly electricity production. The revenues are assumed in this study to be derived from the day-ahead wholesale electricity only. It is therefore assumed that onshore wind or solar photovoltaic projects do not generate revenues from flexibility services in short-term markets, which is a simplification[81].

The indicators are calculated as follows:

$LCOE_i = \frac{INV_{ref} * CRF + FC_i^y}{\sum_{t=1}^{n} Q_t^{i,y}}$, levelised cost of electricity of technology i

$MV_i^y = \frac{\sum_{t=1}^{n} P_t^y Q_t^{i,y}}{\sum_{t=1}^{n} Q_t^{i,y}}$, annual average of the market value of the electricity produced by technology *i* during the year *y*.

Where the following notation applies

REF: reference year. 2030 in this study

INV_{ref}: investment cost and annual production in the reference year

CRF (Capital recovery factor): $\frac{d(1+d)^{PLT}}{(1+d)^{PLT}-1}$

PLT : project life time (in year)

i: technology – onshore wind or solar photovoltaic

d: discount rate

t: time increments (hours) for a year, *n* total number of hours per year

y: year

h: hour

P_t^y is the equilibrium price for demand *t* (in $\frac{EUR}{MWh_{el}}$) and $Q_t^{i,y}$ is the electricity quantity generated by technology *i* during the demand period *t* in MWh_{el} and in year *y*.

$Q_t^{i,y}$ hourly electricity generated by technology in a given year *y*.

FC_i^y Annual fixed cost of technology including investment cost, in EUR/yr, in year *y*.

[80] The weighted average cost of capital used to calculate the LCOE is country and technology specific. It ranges from 3% to 8%. AURES II (2021).

[81] Wind power or solar photovoltaics have the capability of providing services for balancing and grid stabilisation, which can make a complement to their revenues. These potential revenue streams will be technology and market specific and such information is so far proprietary. Source: Ramboll (2019).

A study from the consulting company Aurora estimated for the UK that revenues from ancillary services could make up around 9% of the total revenue streams of offshore wind farms. Source: Aurora Energy Research (2018).

Six European markets have been selected for this analysis that together are deemed representative of different market and climatic conditions in Europe. These are the Czechia, France, Germany, Italy, Spain, and Sweden. It is important to emphasise that this study does not provide a forecast. The following results should be interpreted in terms of possible trends in market conditions represented by this group of Member States.

The METIS model is used to explore the evolution of the market revenues of solar photovoltaic and onshore wind electricity in the 2030 time horizon. The METIS model is a mathematical model providing analysis of the European energy system for electricity, gas, hydrogen and heat. It simulates the operation of energy systems and markets on an hourly basis over a year, while also factoring in uncertainties like weather variations[82].

The technology capacities, commodity and carbon prices used in this analysis for the 2030 timeframe are taken from two scenarios. The first scenario is a policy scenario developed by JRC as an own elaboration to model in a stylised way a power system in line with the REPowerEU plan. It builds on the MIX-H2 scenario, which is the second scenario used in this analysis, that was used in the impact assessment of the fit-for-55 package adopted by the Commission in July 2021. The MIX-H2 scenario relies on both carbon price signal extension to road transport and buildings and strong intensification of energy and transport policies. It also considers high uptake of hydrogen in final energy demand sectors in 2030 in line with the goal of the European Hydrogen Strategy of 40GW of electrolyser capacity in the EU in 2030[83]. In both scenarios to account for climatic variability in the future, the first, second and third quartile in terms of aggregate renewable energy production from an ensemble of 36 climatic years are modelled. The electricity production varies according to climatic conditions due in particular to the weather dependency of renewable technologies.

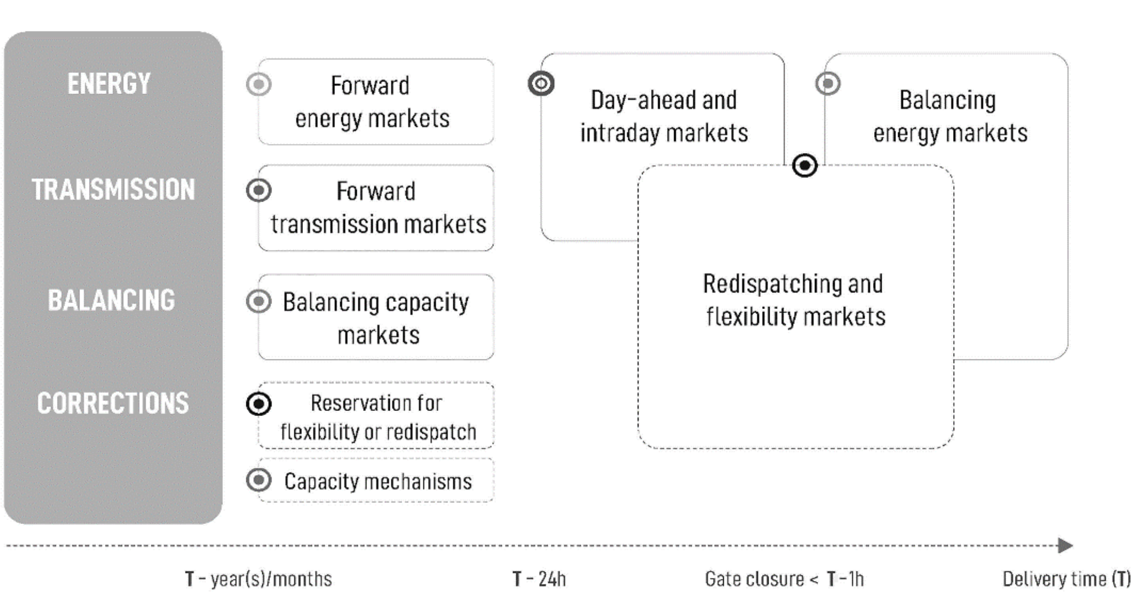
[82] https://energy.ec.europa.eu/data-and-analysis/energy-modelling/metis_en.

[83] European Commission (2021d).

ANNEX 4: WHOLESALE ELECTRICITY MARKET

The electricity market is complex and includes several markets and products that are linked over time[84]. Graph A4.1 shows the sequence of electricity markets in Europe. As described by Meeus 2020, wholesale markets are those where the price of electricity as an energy product is determined. They include forward markets for long-term electricity procurement with future or forward contracts as well as day-ahead and intraday markets for short-term electricity procurement. There are also separate markets to ensure the stability of the system, including for reserves or for balancing energy close to real time. Transmission capacities are also the object of a separate market in the long term or are integrated into the wholesale market in the short term. In general, the spot price on the wholesale market corresponds to the price set on the day-ahead market. The spot price on the wholesale market is used as a reference price on electricity for all other markets where power is traded, forward markets or bilateral agreements, as well as on the retail market. It is also used in determining public support for renewable energies granted in the form of long-term contracts.

Graph A4.1 **The sequence of electricity markets in Europe**

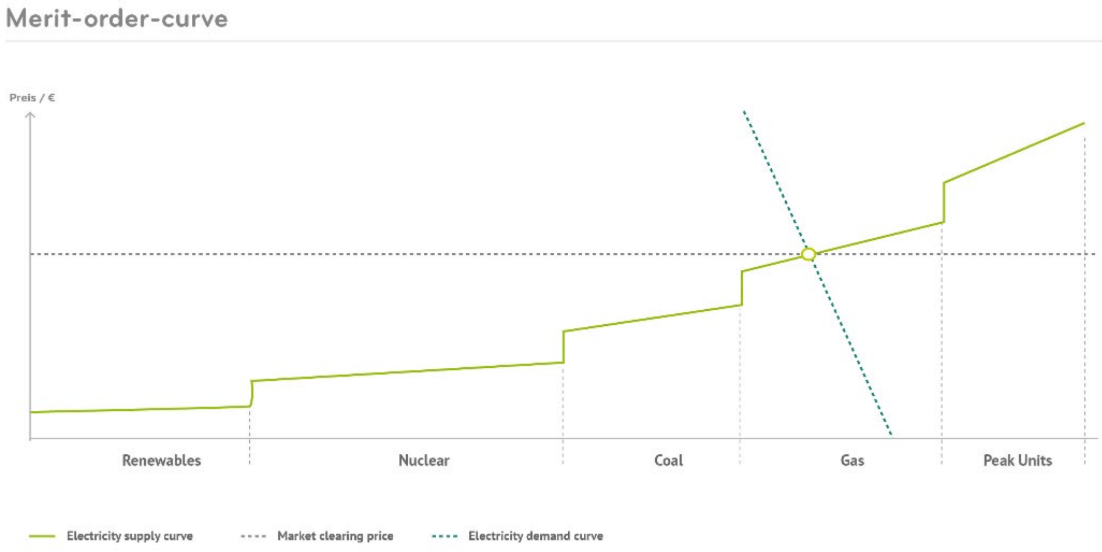


Source: Meeus L. (2020).

The electricity pricing model for the day-ahead market in the EU is based on marginal pricing. In this framework, the equilibrium price of the market is the price of the marginal power plant needed to meet demand, which corresponds to its marginal cost. Power plants are dispatched according to their order of merit (Graph A4.2). Demand is first met with technologies with the lowest cost of production. Technologies with higher generation cost are called in gradually with increased quantity until the demand is satisfied. The intersection of demand and supply reveals a uniform market clearing price that is obtained by each successful supply offer.

[84] Meeus L. (2020).

Graph A4.2 **Example of a merit-order curve**



Source: next-kraftwerke.[85]

A key principle of the EU electricity market enshrined in the EU regulation on electricity market[86] is that wholesale prices should be freely set. The Regulation clearly stipulates that prices shall be formed on the basis of demand and supply, and that market rules shall encourage free price formation and shall avoid actions which prevent price formation on the basis of demand and supply. There are nonetheless technical caps in power exchanges such as EPEX SPOT which set a price range between -500 €/MWh and +3000 €/MWh for the day-ahead market. These are not regulatory caps. The goal of these caps is for instance to ensure that market participants are not exposed to high financial risks. Market parties are generally required to provide collaterals to cover their potential exposure.

As part of the establishment of a single electricity European market, day-ahead markets are integrated on a transnational level[87]. This is called market coupling. In a price coupling, a single centralised system calculates the market prices and traded volumes of electricity based on the order books of all power exchanges in the coupled markets, taking account cross-border transmission constraints[88]. This means that there is an increasing price convergence between market areas in the EU.

[85] Next-kraftwerke, Merit order curve on energy markets. Examples and definition.

[86] European Commission (2019).

[87] Entsoe, single day-ahead coupling.

[88] Tennet, market coupling.

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