



Le réseau  
de transport  
d'électricité

# 2022 ELECTRICITY REVIEW

FULL REPORT

# 2022 Electricity Review

RAPPORT COMPLET

|                                                                                                                          |           |
|--------------------------------------------------------------------------------------------------------------------------|-----------|
| <b>In 2022, the power system proved resilient in the face of the most serious energy crisis since the 1970s</b>          | <b>4</b>  |
| <b>1. Consumption</b>                                                                                                    | <b>6</b>  |
| 1.1 Trend in recent years                                                                                                | 6         |
| 1.2 Trend in 2022                                                                                                        | 7         |
| 1.3 Gross consumption down sharply, reflecting exceptionally warm weather                                                | 10        |
| 1.4 Consumption fell in other European countries as well                                                                 | 12        |
| 1.5 Trend in power consumption by sector                                                                                 | 12        |
| <b>2. Generation</b>                                                                                                     | <b>16</b> |
| 2.1 Total electricity generation was at its lowest since 1992 due to limited nuclear and hydropower output               | 16        |
| 2.2 Low-carbon generation capacity expanded, mainly thanks to onshore and offshore renewables                            | 17        |
| 2.3 Nuclear power: Generation dropped to a historic low in 2022                                                          | 18        |
| 2.4 Hydropower: Output at its lowest level since 1976 due to exceptionally warm and dry weather conditions               | 25        |
| 2.5 Fossil-fired thermal: Generation increased, notably on the back                                                      | 28        |
| 2.6 Wind power: Despite relatively unfavourable weather conditions in 2022, output rose on the back of expanded capacity | 31        |
| 2.7 Solar: Sharp increase in output in 2022                                                                              | 36        |
| 2.6 Renewable thermal and waste                                                                                          | 40        |
| <b>3. Market prices</b>                                                                                                  | <b>41</b> |
| 3.1 Overview                                                                                                             | 41        |
| 3.2 October 2021 – March 2022: From rising tension on gas markets to the fallout from Russia's invasion of Ukraine       | 44        |
| 3.3 April – June 2022: Slight lull after a period of tension                                                             | 45        |
| 3.4 July – August 2022: Power system under real strain                                                                   | 47        |

|           |                                                                                                               |           |
|-----------|---------------------------------------------------------------------------------------------------------------|-----------|
| 3.5       | Sept. – Oct. 2022: Prices drop sharply in a more favourable environment                                       | 48        |
| 3.6       | Nov. – Dec. 2022: Gradual return to market fundamentals                                                       | 49        |
| <b>4.</b> | <b>Electricity exchanges</b>                                                                                  | <b>53</b> |
| 4.1       | Introduction: the power system, a European subject                                                            | 53        |
| 4.2       | In 2022, France was a net importer of electricity for the first time in 40 years                              | 55        |
| 4.3       | Electricity trade balances varied widely from one border to the next                                          | 57        |
| 4.4       | France's energy supply remains much more dependent on imports of fossil fuels than on imports of electricity  | 64        |
| <b>5.</b> | <b>Emissions</b>                                                                                              | <b>66</b> |
| 5.1       | Introduction                                                                                                  | 66        |
| 5.2       | Emissions from electricity generation increased in 2022 but remain below the levels seen in 2016 and 2017     | 66        |
| 5.3       | Even taking imports into account, the electricity consumed in France is among the most decarbonised in Europe | 67        |
| 5.4       | France's neighbours benefited less from exports of its low-carbon electricity                                 | 70        |
| <b>6.</b> | <b>Electrification of end-uses</b>                                                                            | <b>72</b> |
| 6.1       | Electrification of transport                                                                                  | 72        |
| 6.2       | Electrification of end-uses in buildings                                                                      | 75        |
| 6.3       | Electrification of industry                                                                                   | 77        |
| <b>7.</b> | <b>Flexibility and balancing</b>                                                                              | <b>80</b> |
| 7.1       | Flexible resources help guarantee that supply and demand are balanced                                         | 80        |
| 7.2       | Pumped storage plants                                                                                         | 81        |
| 7.3       | Battery storage                                                                                               | 82        |
| 7.4       | Demand response                                                                                               | 83        |
| 7.5       | Balancing mechanism                                                                                           | 85        |
| <b>8.</b> | <b>The transmission network</b>                                                                               | <b>87</b> |
| 8.1       | Evolution of the network                                                                                      | 87        |
| 8.2       | The energy transition will require doubling interconnection capacity by 2035                                  | 88        |
| 8.3       | Offshore networks                                                                                             | 90        |
| 8.4       | Evolution of the "S3REnR" regional schemes                                                                    | 91        |
|           | <b>Glossaire</b>                                                                                              | <b>93</b> |

# 2022 Electricity Review

RAPPORT COMPLET

## In 2022, the power system proved resilient in the face of the most serious energy crisis since the 1970s

The year 2022 saw a major energy crisis emerge, **on a scale not seen since the oil shocks of the 1970s**. France and Europe in fact faced three independent but simultaneous crises which compounded one another:

- **Soaring gas prices, amid concerns about Europe's security of supply in the wake of Russia's invasion of Ukraine.** Prices first surged in late 2021, as the economy was recovering from the COVID-19 crisis. They were then pushed even higher by the war in Ukraine and the resulting reduction of Russian gas supplies to Europe, at a time when the entire European continent was worried about security of supply;
- **A crisis of French nuclear power generation** after the discovery of a generic fault affecting the fleet's most recent reactors, following the discovery of a stress corrosion phenomenon, which led to the shutdown of numerous units for testing and repair starting late in 2021. This pushed nuclear power output down to a level that was the lowest on record since 1988 and 30% below the average of the past 20 years;
- **An lengthy drought that drove hydropower output in France down to its lowest level since 1976 and had a similar impact across much of Europe.**

Against this backdrop, the **power system proved resilient: France did not experience any supply disruptions**. This was attributable to a structural

decline in power demand in France and neighbouring countries, and to the fact that gas and electricity exchanges continued in accordance with European market rules.

In particular, short-term markets issued the right economic signals during periods of tight supply. This was notably the case during the summer, when hydropower and nuclear output dropped sharply, and market prices rose to reflect those economic fundamentals.

**The effects of the crisis were thus essentially economic.** In particular, forward markets revealed a risk premium for France, leading to unprecedented price increases for deliveries in the winter.

Starting in September, the management of the crisis by public authorities, the return of a large number of nuclear reactors on the grid, unseasonably warm weather, the observation that demand was dropping, and that interconnections were functioning properly, all contributed to gradually ease uncertainty.

However, the effects will continue to be felt in 2023, as many supply contracts signed in the latter half of 2022 for 2023 and beyond were based on those high prices. As a result, there will be a delay before the downward trend in market prices that began in late 2022 is felt by consumers that do not

benefit from the government's protection schemes (tariff shield, electricity shock absorber).

**The environmental cost of the energy crisis is real, but contained.** Direct emissions from electricity generation reached 25 Mt<sub>CO2eq</sub> (up from 21.5 Mt<sub>CO2eq</sub> in 2021). Coal-fired generation has been almost completely eliminated from the French power mix (it now accounts for just 0.6% of electricity generation in France). Gas-fired plants were dispatched more than any time in the past, though output was lower than what was feared in the event of a cold winter or if energy consumption had been maintained.

France's emissions remain well below those of comparable countries: emissions in Germany, for instance, were some ten times higher than in France in 2022.

Even when taking into account imports from neighbouring countries, there was no significant deterioration in the carbon footprint of the power

consumed in France: the carbon content of imports reflects the average content in neighbouring countries, as France imports in situations of heavy fossil-fired thermal plants, but also when wind or solar generation is high, for instance.

With all this in mind, it should be noted that **there was no pause in the energy transition in 2022.** A record 5 GW of renewable capacity were added.

An acceleration remains necessary if France is to meet its targets, but, similarly to other studies published recently in Europe, the 2022 Electricity Report shows that the power system transition continues and that renewable energy sources in France are now contributing both to the structural decarbonisation of the mix and to the security of supply.

In 2023, it will be essential that the situation of the French nuclear fleet improve to make the power system more resilient to international fossil fuel risks and return the broader economy to its decarbonisation trajectory.

# 1. Consumption

## 1.1 Trend in recent years

Electricity consumption in France, adjusted for weather and calendar effects, was relatively flat between 2010 and 2019. This trend, observed in France and throughout Europe over the period, was driven chiefly by:

- The economic slowdown that followed the 2008 financial crisis, coupled with slower demographic growth;
- The ever-increasing economic role of the service sector, which consumes less electricity than the industrial activities that have been declining in France since the 1990s, as well as changes in France's industrial fabric (stagnation of the manufacturing sector and a structural shift favouring high-tech industry);
- Stricter energy efficiency requirements in buildings and equipment performance standards, making it possible to use considerably less power to meet the same needs.

After this period of stability, demand contracted sharply in 2020 as the COVID-19 crisis led to lockdowns and reduced economic activity. The effects lingered through mid-2021. Consumption almost returned to pre-crisis levels in the latter half of 2021, thanks to a robust economic rebound in the last two quarters. Over 2021, consumption was slightly below pre-health crisis levels (-1.9% relative to 2019).

**Adjusted for weather and calendar effects** (to allow for meaningful year-on-year comparisons and help identify structural factors affecting power demand), **consumption reached 459.3 TWh in 2022**, down 1.7% from 2021. Consumption was thus lower than in 2020 (461 TWh), when lockdowns put real downward pressure on demand, as did the resulting drop in economic activity. The last time electricity consumption adjusted for climate effects was lower than in 2022 was in 2005 (453 TWh), before demand began to plateau in 2010.

Figure 1: Consumption adjusted for weather and calendar effects, average weekly values, only counting business days

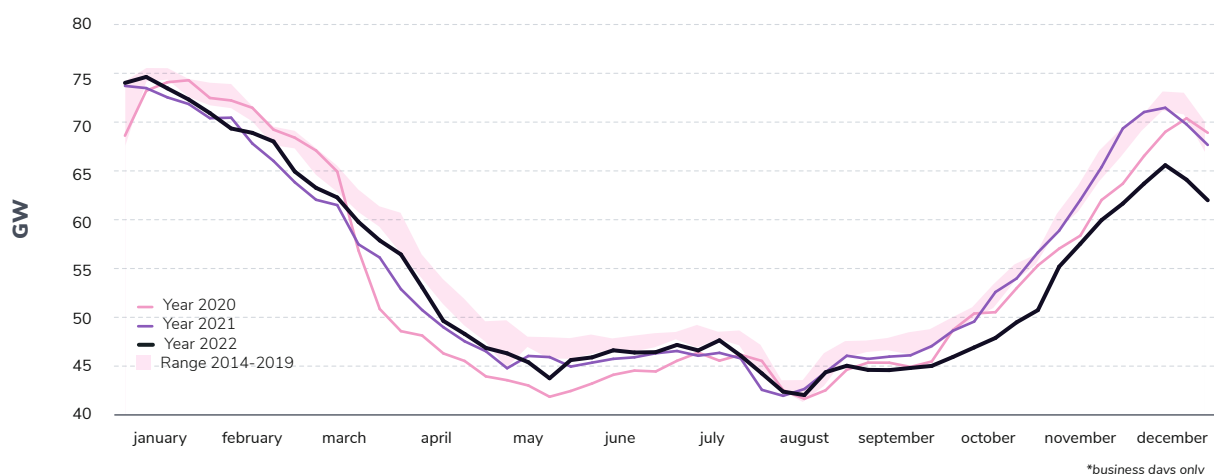
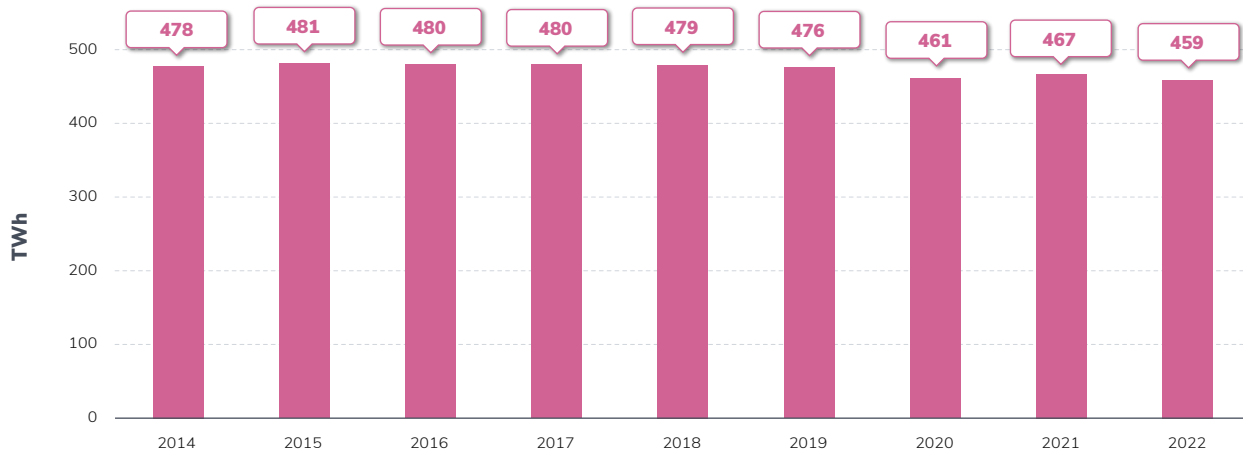


Figure 2: Annual electricity consumption adjusted for weather and calendar effects



## 1.2 Trend in 2022

In the first part of 2022, consumption was roughly in line with the lowest levels recorded in 2014-2019, even as prices surged on wholesale electricity markets. Indeed, higher wholesale prices only partially and gradually feed through to final consumer prices, depending on the type of rate schemes included in consumer contracts and the protective mechanisms from which they benefit. As a result of consumer protections put into place starting in the autumn of 2021 (capping of regulated tariffs via the introduction of the “tariff shield”, increase in the ARENH cap, decrease in the internal tax on final energy consumption, or TICFE), energy inflation rates in France were among the lowest in Europe, limiting the impact of higher prices, particularly on residential consumers (regulated tariffs in this segment only increased by 4% in 2022, starting in February).

Given the high level of strain that was forecast for the power system and for energy supply in general in the autumn and winter 2022/2023, calls were sent out starting late in the summer to consume less energy, both to reduce the risk to security of electricity supply and to keep gas inventories at a satisfactory level.

- In August 2022, the European Union adopted Regulation 2022/1369, calling on Member States to voluntarily reduce their natural gas demand by at least 15% between 1<sup>st</sup> August 2022 and 31<sup>st</sup> March 2023 and authorising the Council to declare an alert that would make the reductions mandatory.
- On 6 October 2022, the French government unveiled a national energy saving plan<sup>1</sup> with a target of cutting the country’s energy consumption by 10% by 2024. The plan relies both on incentives to encourage individual energy saving efforts, for instance lowering thermostat settings in homes or waiting to turn the heat on, as well as actions to be taken in business premises, public buildings and by local governments, including reducing the use of domestic hot water in buildings, lowering thermostat settings, or limiting the “on time” and intensity of public lighting. The energy saving plan also incentivises consumers to shift their electricity uses away from peak demand hours.
- Also on 6 October 2022, the European Union voted in favour of an emergency intervention to address the impacts of high energy prices (Regulation 2022/1854). The adopted

1. [dp-plan-sobriete.pdf \(ecologie.gouv.fr\)](https://ecologie.gouv.fr/dp-plan-sobriete.pdf)

regulation included a series of measures relative to consumption, market revenues and price setting. It obliged Member States to decrease their electricity consumption by at least 5% during the peak hours identified in each country and recommended that they reduce their total electricity consumption by 10% between 1<sup>st</sup> December 2022 and 31<sup>st</sup> March 2023.

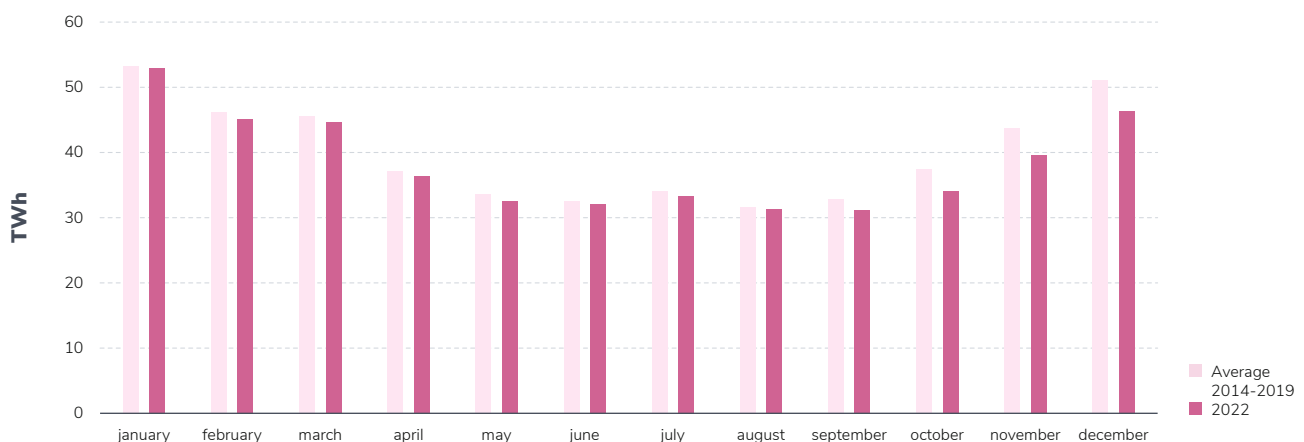
- A temporary measure (in effect for six months, from 15 October 2022 to 15 April 2023) shifting the hours during which hot water tanks are heated from the off-peaks hours of 12:00pm to 2:00pm to overnight off-peak hours also took effect mid-October, helping to smooth midday demand.
- At the same time, RTE made adjustments to the EcoWatt<sup>2</sup> app (available nationwide since 2020 and on a regional basis since 2012) in such a way as to be able to give consumers advance notice (three days) of periods when the power system might be strained so they can make extra efforts to reduce or shift their consumption and thus help prevent power cuts. Some 350<sup>3</sup> French companies, local governments and other actors from the public and private sectors also

agreed to help boost security of supply by signing the EcoWatt Charter, pledging to reduce or postpone their power consumption as needed.

Against this backdrop, consumption began to deviate from historical precedent starting in September: adjusted for weather effects, consumption was 5.5% below the average for September over the 2014-2019 period. The decrease was initially visible in industrial sectors, which had more exposure to rising energy prices, particularly the most energy-intensive segments like chemicals, metallurgy and steelmaking (where consumption decreased respectively by 12%, 10% and 8% between 2021 and 2022), in line with a trend observed across Europe.

The downward trend in consumption accelerated over the following months. In October, consumption adjusted for weather fell by 3.3 TWh (-8.7%) relative to the same period before the health crisis (2014-2019 average). Like in September, the industrial sector led the way, but was followed by the residential and service sectors, though the energy savings potential there was relatively

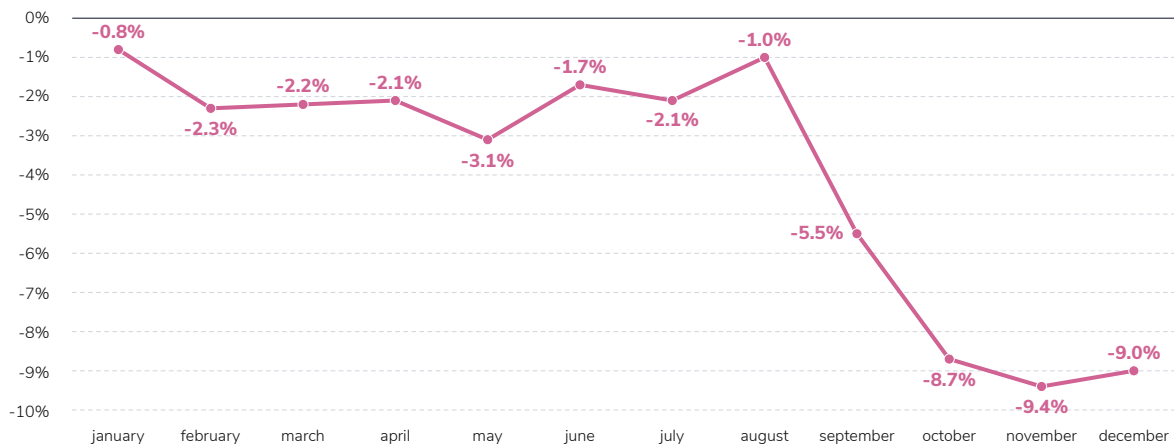
Figure 3: Monthly electricity consumption adjusted for weather and calendar effects



2. Ecowatt | monecowatt.fr

3. As of early February 2023.

Figure 4: Gap in percentage terms between monthly adjusted consumption in 2022 and average values for the 2014-2019 period



limited there since the heating season had yet to begin.

November and December 2022 saw even bigger reductions from the comparable periods before the health crisis, with decreases of 9.4% and 9.0%, respectively. The downward trend, now consolidated, was visible across all sectors (industrial, services, residential). Aggregated consumption in the tertiary and residential sectors (which make up a majority of total consumption in terms of energy) declined relative to 2021 by 6 to 7% in November and December (representing about 7 TWh). Consumption in heavy industry dropped by 15% in the last four months of the year (about 2 to 3 TWh). In the chemicals, metallurgy and steelmaking segments mentioned above, the decline was close to 20% between September and December.

It remains difficult to separate the effects of purely economic constraints from those of energy saving actions. Indeed, despite the “electricity tariff shield” put into place for residential consumers, inflationary pressures impacted households’ overall budgets and may have incentivized energy savings, even in the absence of price hikes on residential contracts. At the same time,

the government’s successful efforts to mobilise residential and business users to reduce their consumption played a central role.



#### A CLOSER LOOK

### Tracking electricity consumption in France

The tracking of electricity consumption in France was stepped up starting in September. RTE published its forecasts for the autumn and winter of 2022-23 mid-September (*Perspectives pour le système électrique pour l’automne et l’hiver 2022-2023*) then updated them monthly to provide a more accurate security of supply analysis, taking into account changes in weather forecasts and the availability of generation resources, as well as the broader European context. Starting mid-October, RTE also began publishing weekly overviews of consumption trends to track this indicator while public authorities, and the European Commission on a larger scale, encouraged energy savings.

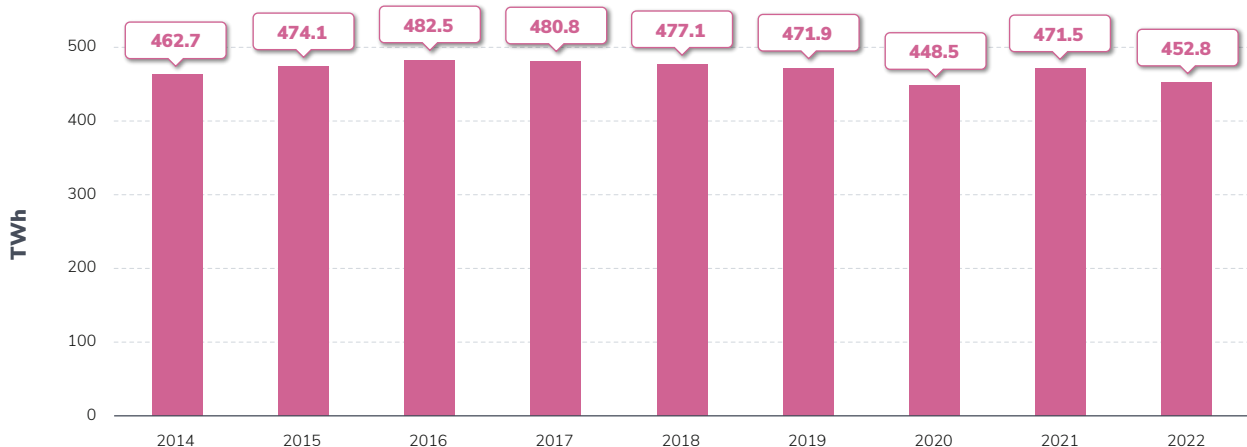
### 1.3 Gross consumption down sharply, reflecting exceptionally warm weather

In addition to the drop in consumption attributable to the energy crisis and energy saving efforts, as outlined in the above analysis of consumption adjusted for weather, abnormally warm temperatures also had an impact. The decline in gross consumption—i.e. consumption not adjusted for weather effects—was thus even more pronounced in 2022. It ended the year at 452.8 TWh, 4% below the 2021 level (and down 4% from 2019).

The year 2022 was the hottest on record since the beginning of the 20<sup>th</sup> century, surpassing 2020, which previously held the record<sup>4</sup>. Temperatures were unseasonably warm throughout most of the year. The average annual temperature was 14.5°C, which is 1.6°C above the seasonal norms calculated for the 1991-2020 period.

These very warm temperatures, particularly during the summer heat waves and drought, had a notable impact on the power system, particularly in terms of water reserves and the waivers nuclear power plants needed to discharge water that was warmer than normally allowed during certain periods (see Generation section). The effect on gross electricity consumption was also remarkable, especially during the autumn and winter, when warm weather reduced the need for heating. The month of October was the warmest on record since 1900<sup>5</sup>. Temperatures were also particularly high in the summer (the second hottest on record, after 2003), which drove up consumption slightly due to the use of air conditioning. Conversely, on some particularly cold days in winter, demand climbed above 80 GW, with an annual high of 87.3 GW recorded on 14 January, 2022, at 9:30am (in 2021, the maximum was 88.7 GW, reached on 11 January, at 7:00pm).

Figure 5: Annual gross electricity consumption in France in TWh



4. Météo-France, annual climate statement 2022 2022: les bilans climatiques | Météo-France (meteofrance.fr)

5. Météo-France, annual climate statement 2022

Figure 6: Reference temperatures and actual temperatures (based on Météo-France data)

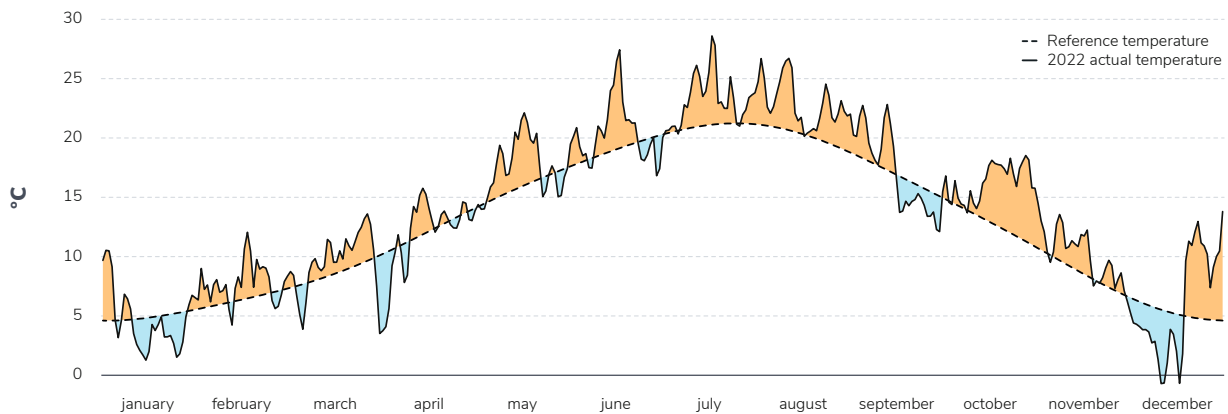
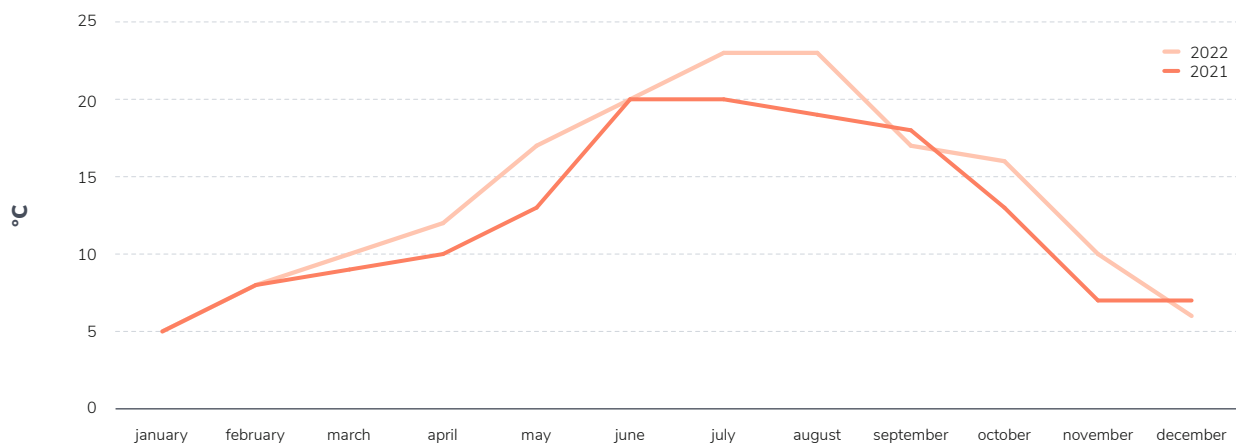


Figure 7: Average monthly temperatures for 2021 and 2022 (based on Météo-France data)



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### Why is consumption adjusted for weather effects?

Consumption adjusted for weather effects corresponds to the power that would have been consumed if temperatures had been in line with norms for the period. It is calculated every year based on consumption data. This process makes it possible to draw a distinction between variations in consumption that are due to structural trends (demographics, economic activity) or temporary factors (health crisis, energy saving measures, etc.) and those that only reflect variations in temperatures and the temperature-sensitivity of the French power system. For instance, if temperatures are above average during one week in winter, gross consumption (i.e. consumption before adjustments) will be lower than what it would have been at normal temperatures.

## 1.4 Consumption fell in other European countries as well

Like in France, the energy crisis had a major impact on electricity consumption in other European Union countries in 2022.

Governments in each country implemented a variety of protective measures that limited, to different degrees, the crisis's impact on final consumers. For comparison's sake, Eurostat data on price increases show that, between late 2021 and early 2022, prices charged to residential consumers rose by 37.9% in Italy, by 32.2% in Spain and by 25% in Belgium, compared with 7.2% in France and 2.7% in Germany<sup>6</sup>.

Measures encouraging energy savings were also implemented across Europe with the European Union adopting two regulations. The first urged Member States to voluntarily reduce their natural gas consumption by 15% between August 2022 and March 2023, and to aim to reduce their overall electricity demand by 10% between December 2022 and March 2023. The second set

a mandatory 5% reduction target for electricity consumption during peak hours.

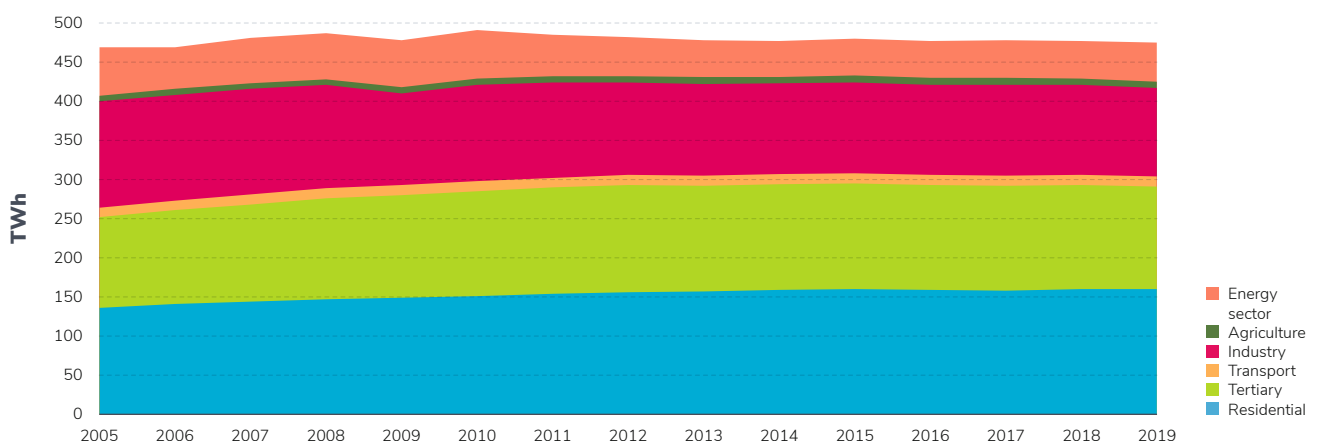
Each European country rolled out an energy saving plan to help meet these targets. Designed to reduce overall energy consumption, these plans notably encouraged adjusting thermostat settings for heating and air conditioning, shortening hours for retail stores (some stores in Spain are required to close earlier), and regulating street lighting (for instance, in Germany, landmarks that do not contribute to road safety are no longer illuminated at night)<sup>7</sup>.

Lastly, other European countries also experienced unprecedented weather. The year 2022 was the hottest on record since 1881 in Germany, since 2020 in Belgium (where the previous record was set in 1833), since 1916 in Spain and since 1800 in Italy<sup>8</sup>.

## 1.5 Trend in power consumption by sector

Power consumption was relatively stable in the 2010s, following a period of robust growth in the

Figure 8: Trend in electricity consumption in France by sector between 2005 and 2019



6. <https://ec.europa.eu/eurostat/fr/web/products-eurostat-news/-/ddn-20221031-1>

7. <https://www.touteleurope.eu/economie-et-social/sobriete-energetique-queelles-sont-les-mesures-prises-par-nos-voisins-europeens/>

8. <https://meteofrance.com/actualites-et-dossiers/actualites/2022-annee-la-plus-chaude-en-france>

second half of the 20<sup>th</sup> century. However, this period of stabilisation masked contrasting consumption trends in different sectors, which counterbalanced one another to a certain degree.

#### **1.5.1 Residential: Demand up slightly in 2022 but growth will be contained going forward**

The residential sector consumes more electricity than any other in France. Its share of total consumption has risen from 29% to 34% since 2005, due to widespread adoption of electric heating and electronic and computer equipment, while at the same time, power demand for lighting and appliances has decreased thanks to energy efficiency gains. Electric heating accounts for a significant share of demand in the sector: in 2019, it alone represented 28% of total residential electricity consumption in France.

Given the progress that has been made with making appliances more energy efficient, as well as the binding measures the European Union has adopted in this area, and taking into account the targets set by governments regarding the thermal renovation of buildings (See the *Electrification of end-uses* section below), the rise in consumption in the residential sector can be expected to remain contained over the coming years, even with the anticipated increase in demand associated with ventilation and air conditioning.

#### **1.5.2 Industry: Decline in consumption over several years could reverse thanks to electrification**

The structure of power consumption in France has changed due to major shifts in the French economy. Demand in the industrial sector has notably been declining in recent decades due to structural factors: deindustrialisation has led to the closure of certain very energy-intensive industries; economic activity has continued to shift toward

services, which use less electricity than industry; and France's industrial fabric has changed (stagnation of manufacturing and a structural shift favouring the high-tech industry). The downward trend in consumption was thus uneven across the different subsectors. The biggest decreases were seen in the paper and cardboard industries (-4/5 TWh), mineral chemicals (-3.5 TWh) and steelmaking (-2.6 TWh), though the latter nonetheless remained the second biggest power consumer in 2019 behind agri-food.

Based on the trajectories analysed by RTE<sup>9</sup>, industrial power consumption will increase over the coming years due to the electrification of certain processes, and even onshoring, with this additional demand only being partially counterbalanced by energy efficiency gains and the effects of the structure of production shifting toward less energy-intensive industries.

#### **1.5.3 Services: Flat demand, but real potential for energy efficiency gains**

The services sector began using more power than industry in 2009, and remains to this day the second largest electricity consumer behind residential. Demand has been trending higher for several decades while economic activity increasingly shifted toward services and new electricity uses were adopted (electrification of thermal uses, increased use of IT equipment, etc.). However, demand has been flat in the sector since 2010, due to a combination of factors with opposite effects (energy efficiency, development of ICT, etc.). Like in the residential sector, heating accounts for a large share of consumption. There is considerable potential for energy efficiency gains in the services sector, and tapping into it could gradually drive down demand, even as digital uses continue to expand (datacentres, ICT, etc.)<sup>10</sup>.

9. Energy Futures 2050, Chapter 3, "Consumption", RTE, 2022

10. Energy Futures 2050, Chapter 3, "Consumption", RTE, 2022

#### 1.5.4 Transport: Electricity demand will rise as fossil fuels are replaced

As of today, rail transport and mass rail transport account for the bulk of power demand in the transport industry. Demand has hovered at around 13 TWh for several years. But the electrification of mobility has accelerated in recent years: all-electric and plug-in hybrid electric vehicles made up 18.5% of the market in 2022 (up from 15% in 2021), representing close to 346,000 new registrations, out of a total of 1.9 million light vehicles (passenger and light utility) brought into circulation during the year<sup>11</sup>. RTE estimates the power consumption of these vehicles reached between 1 and 2 TWh in 2022.

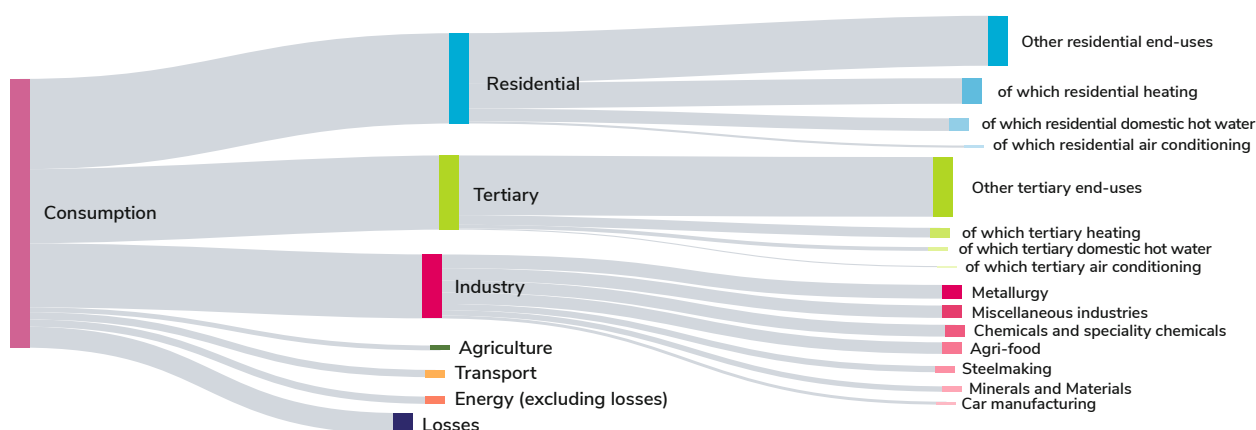
The electrification of mobility will continue, driven by incentives and regulations adopted in France and Europe to encourage the shift away from fossil fuels in transport, notably the ban on sales of new internal combustion engine vehicles from 2035. RTE published an in-depth analysis of the challenges the development of electric mobility will

pose for the power system by 2035<sup>12</sup>, analysing several development trajectories out to 2050<sup>13</sup>.

#### 1.5.5 Low-carbon hydrogen: Demand is very low for now but poised to increase sharply

Hydrogen is primarily used by industry for now, including for oil refining and fertiliser production. The hydrogen used for these purposes is mostly produced by steam reforming of fossil fuels, a process that emits 9 kg of CO<sub>2</sub> per kilogramme of hydrogen produced. Within a low-carbon power system, water electrolysis can represent a low-carbon alternative to large-scale hydrogen production. Hydrogen can be used to help decarbonise sectors in which direct electrification is difficult or costly. Its potential use for electricity storage (power-to-gas-to-power) also makes it a factor of flexibility for the power system, complementary to the development of renewable energy sources. The scenarios in France's National Low-Carbon Strategy (*Stratégie nationale bas carbone* – SNBC) assume growth in the production and consumption of hydrogen, putting related power consumption at around 50 TWh

Figure 9: Breakdown of electricity consumption in France by sector in 2019 presented as a Sankey diagram. Industrial sectors are aggregated to facilitate reading of the diagram.



11. AVERE data

12. Integration of Electric Vehicles into the Power System, RTE, 2019

13. Energy Futures 2050, Chapter 3, Consumption

in 2050. RTE has identified and clarified the role the development of electrolyzers would play in consumption and power system flexibility in several reports<sup>14</sup>. The prospect of decarbonising the current uses of hydrogen, together with its great potential as a carbon-free replacement for fossil fuels, has led several European countries (Germany, Spain, the Netherlands, Belgium and France) to adopt strategic plans for hydrogen production.

#### **1.5.6 Prospective demand trajectories point toward growth as efforts continue to decarbonise the economy and reach carbon neutrality by 2050**

Power demand growth forecasts have been revised upward across the globe in recent years, notably in Europe, as a result of more ambitious

climate targets (emissions cut by 55% by 2030, carbon neutrality reached by 2050).

In its *Energy Futures 2050* report published in the autumn of 2021, RTE looked at different possible power demand trajectories based on the plans currently in place in France (SNBC, hydrogen plan, sector policies). It found that, even factoring in energy efficiency measures (automatically resulting from electrification, continued steady gains in the energy efficiency of electric equipment and a sharp acceleration in the thermal renovation of buildings), demand will rise from current levels in all trajectories between now and 2050, with increases ranging between 555 TWh and 755 TWh depending on assumptions made about energy savings and reindustrialisation, for a central scenario of 645 TWh.

<sup>14</sup>. *Energy Futures 2050*, Chapter 3, Consumption and Chapter 7, Security of Supply, RTE, 2022, and *The Transition to Low-Carbon Hydrogen in France*, RTE, 2020.

## 2. Generation

### 2.1 Total electricity generation was at its lowest since 1992 due to limited nuclear and hydropower output

During what was an atypical year, electricity generation in France deviated from historical precedent in 2022, in terms both of volumes and the breakdown between different technologies.

Total electricity generation reached 445.2 TWh, representing a decline of about 15% from the prior year (-77 TWh). This was the lowest level of output on record since 1992, before the full nuclear fleet was in service.<sup>15</sup>

Figure 10: Total electricity generation in France between 1995 and 2022

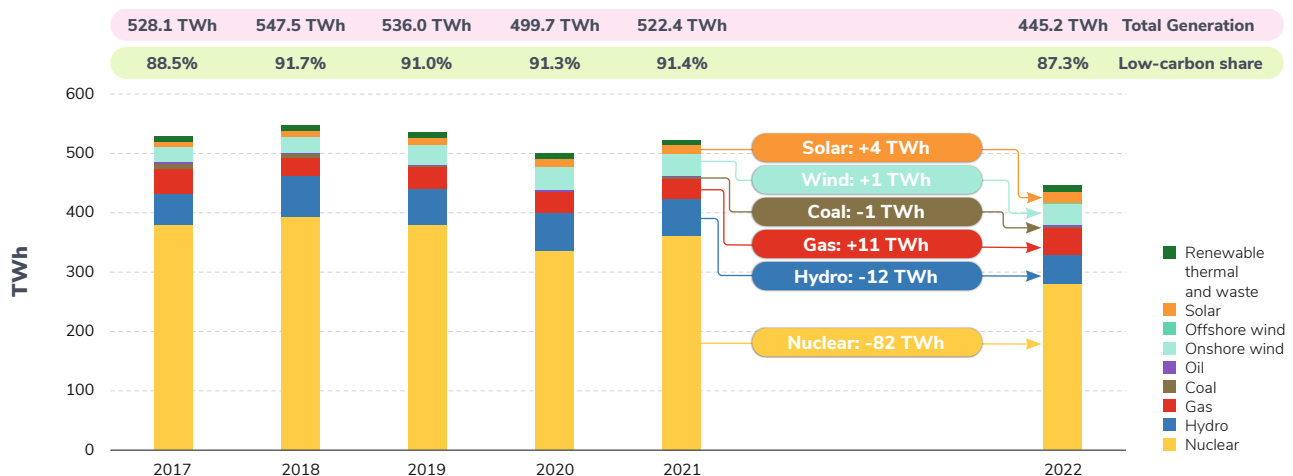
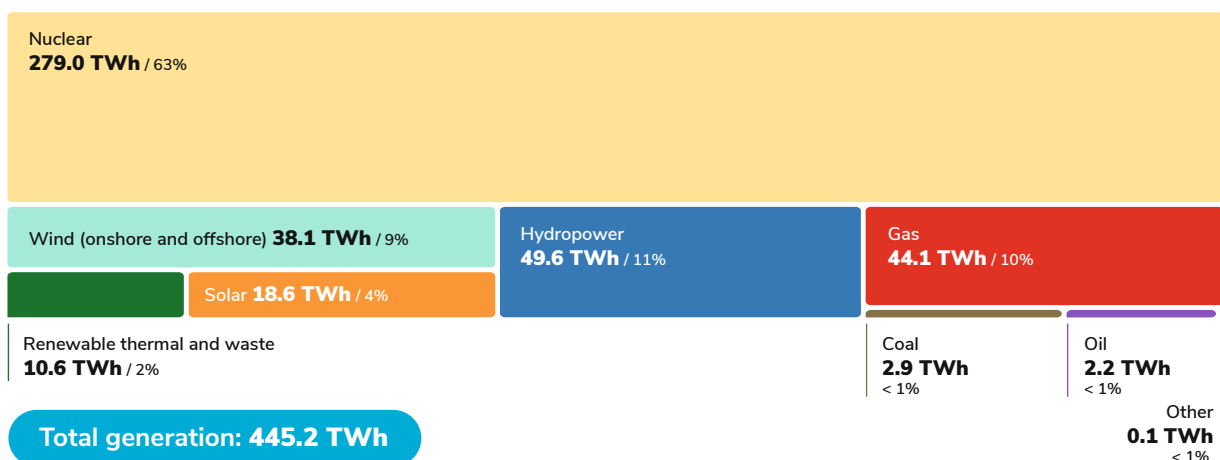


Figure 11: Total electricity generation in France in 2022 and breakdown by technology



15. Six reactors were brought into service after 1992 (Penly 2, Golfech 2, Chooz B 1, Chooz B 2, Civaux 1, Civaux 2) and two have been taken offline (Fessenheim 1 and Fessenheim 2).

Output was depressed by the reduced availability of the nuclear fleet, which produced 82 TWh less than in 2021, as well as constraints affecting hydropower production (-12 TWh). Declines in output from these sources were partially offset by increased renewable power generation (+4 TWh for solar and +1 TWh for wind) and gas-fired generation (+11 TWh), together with higher imports (see *Electricity trading* section) and lower consumption. Total output was also below the level recorded in 2020 (-50 TWh), which had been the record low of the previous 20 years.

## 2.2 Low-carbon generation capacity expanded, mainly thanks to onshore and offshore renewables

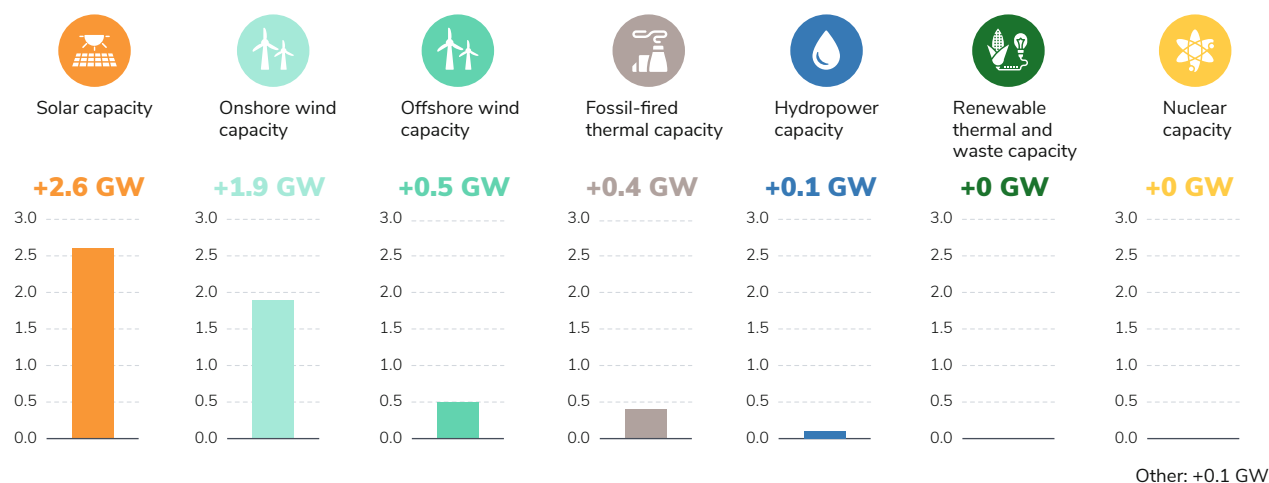
French power production capacity continued to change in 2022, driven by growth in renewable energy sources. As of 31<sup>st</sup> December 2022, installed capacity stood at 144.3 GW, up 5.6 GW over one year with wind and solar representing 5 GW of that growth. Installed solar capacity notably reached 15.7 GW on 31<sup>st</sup> December 2022 (+2.6 GW over one year), while onshore wind capacity jumped to 20.6 GW (+1.9 GW). France also brought its first offshore wind farm into service in Saint-Nazaire (0.5 GW). Hydropower capacity increased very slightly (+0.1 GW).

Installed nuclear capacity remained at 61.4 GW, unchanged since the closure of the two Fessenheim reactors in 2020.

The only change to fossil-fired thermal capacity in 2022 was the commissioning of the 0.4 GW combined-cycle gas turbine plant in Landivisiau.

Electricity generation capacity in France is slated to undergo major changes in the near term. The country will be updating its Energy Climate Strategy (*Stratégie française énergie climat – SFEC*) over the coming months, laying out the roadmap to carbon neutrality in 2050 and setting new objectives for French energy policy. In preparation for that update, on the initiative of the Ministry of Ecological Transition, a national consultation on the energy mix was held between October 2022 and January 2023 to inform the parliamentary debates that will take place in 2023 ahead of the next energy-climate programme law (*Loi de programme énergie climat – LPEC*). Once adopted, the law will notably set out guidelines for the new Multiannual Energy Plan (PPE 3), which will define targets for the evolution of the French energy mix between 2024 and 2033.

Figure 12: Change in installed electricity generation capacity in France in 2022



## 2.3 Nuclear power: Generation dropped to a historic low in 2022

### 2.3.1 Output was at the lowest level on record since 1988

Nuclear generation was much lower in 2022 than in previous years, with output ending the year at 279 TWh (i.e. 62.7% of total power generation), down from 360.7 TWh in 2021 and 379.5 TWh in 2019. It was also lower than in 2020 (335.4 TWh), which had been an exceptional year due to the health crisis.

The drop in generation is explained by the historically low availability of the fleet during the year. The gap with previous years was particularly wide in the summer, because outages for maintenance and inspections related to stress corrosion cracking were concentrated in these months in order to have maximum capacity available during the coldest periods. Availability fell to an all-time low of 21.7 GW on 28 August 2022, when 65% of the fleet was offline. It rebounded later in the year, with availability averaging 39.4 GW in December (36% of the fleet offline), but remained well below the

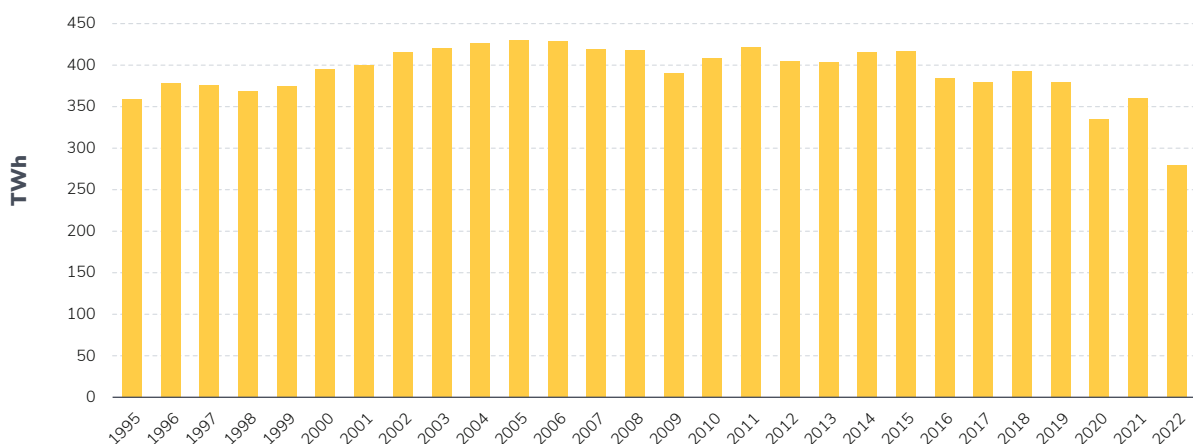
levels seen in previous years. That being said, the fact that the various shutdowns were concentrated during the summer made it possible to maximise availability during the winter.

This was the first time since the construction of the existing nuclear fleet was completed that annual output was this low. In absolute terms, it is the lowest level on record since 1988, when installed nuclear capacity in France stood at just 51 GW, or 83% of today's total (eight fewer reactors).

### 2.3.2 Outages planned as part of the Grand Carénage refit programme still being impacted by the health crisis

All nuclear reactors in France are shut down at regular intervals, especially for refuelling (typically every 12 to 18 months, outage lasting about 40 days<sup>16</sup>). These outages are scheduled several years in advance. The plants are also shut down to undergo inspections to confirm that the reactors are safe: partial inspections (every 3 to 4 years, lasting nearly three months, done concomitantly with refuelling) and ten-year inspections (once a decade, outage lasting at least six months).

Figure 13: Annual nuclear power generation between 1995 and 2022



16. Anticipated duration habitually declared by EDF in previous years per the Transparency Regulation. Actual lengths may vary.

As part of the *Grand Carénage* refit programme launched in 2014, EDF is carrying out maintenance and upgrades to extend the operating lifetime or improve the safety of its reactors, mostly concomitantly with the fourth ten-year inspections. This work involves replacing large reactor components such as the steam generators, or adding new equipment to enhance safety<sup>17</sup>, which makes the interventions more time-consuming and complex.

The timing of the scheduled outages is decided based on reactor safety criteria, industrial organisation factors (components/type of work being done), and the need to maintain sufficient availability to ensure security of supply. These outages are therefore spread out over time, and usually scheduled outside the winter months.

In the 2019 edition of the *Generation Adequacy Report*, published before the health crisis<sup>18</sup>, RTE had identified the winters of 2021-2022 and 2022-2023 as being periods of significant stress in terms of security of supply. Beyond uncertainty surrounding the commissioning of the Flamanville EPR, this forecast was based on concerns that the four ten-year inspections scheduled for this period would affect availability in the middle of the 2021-2022 winter if these outages were extended by two months, while three ten-year inspections were scheduled in January 2023. Moreover, the tendency for outages to be extended, and the increase in the number of outages outside of ten-year inspections, were identified at the time as a factor that could affect reactor availability the following years.

The length of scheduled ten-year inspections did increase in 2022. Additionally, four reactors in the 900 MW series underwent their fourth ten-year inspections during the year (Gravelines 3, Dampierre 2, Tricastin 3 and Blayais 1) all at the

same time, which was a first. The maintenance schedule should continue to intensify over the coming years: in 2023, for instance, five fourth ten-year inspections are scheduled to be done simultaneously.

In addition to this already busy schedule, the health crisis that began in March 2020 caused some scheduled outages to be pushed back to later years, and these postponements had an impact in 2021 and 2022.

### 2.3.3 Unscheduled outages due to stress corrosion cracking

Late in 2021, a generic problem was characterised in the newest reactors in the nuclear fleet, involving cracking in certain pipes of the auxiliary circuits of the main primary circuits due to stress corrosion. The phenomenon was first detected in October at reactor 1 of EDF's Civaux nuclear power plant (1,450 MW<sub>e</sub>), during tests done as part of the ten-year inspection<sup>19</sup>. In November 2021, Reactor 2 at Civaux was shut down preventatively, ahead of the scheduled second ten-year inspection, to conduct tests<sup>20</sup> that detected the same problem. Mid-December, EDF reported the results of the tests conducted on the pipes in question, identifying the phenomenon as stress corrosion cracking (SCC). Between December 2021 and January 2022, evidence of SCC was found in the two reactors at the Chooz power plant, which use the same technology as Civaux<sup>21</sup> (N4 series, 1,450 MW<sub>e</sub>), leading them to be shut down preventatively. Evidence of SCC was also found in reactor 1 at Penly (P'4 series, 1,300 MW<sub>e</sub>) while it was already shut down for a ten-year inspection.

EDF subsequently developed a strategy for testing the other reactors in the fleet, during outages that were already scheduled or planned specifically. French nuclear safety authority ASN deemed the

17. For instance, construction of a core catcher beneath each reactor.

18. Published on 1<sup>st</sup> March 2020.

19. *Phénomène de corrosion sous contrainte détecté sur certains réacteurs* – 04/11/2022 – ASN

20. Since tests are invasive (cutting of pipes), they could not be conducted while reactors were in operation, and the section of piping where cracks were found had to be replaced before the reactors could be restarted. In July 2022, EDF unveiled its strategy to inspect all reactors by 2025 and said it intended to start systematically performing non-destructive (ultrasonic) tests from January 2023. *Note d'information d'EDF, mise à jour du 27 juillet 2022*

21. Reactors within a same series are homogeneous. All units in the French fleet use the same technology, but that technology evolved over time.

strategy “appropriate” late in July 2022. As a result, a significant portion of the fleet was taken offline to conduct extensive testing and accurately diagnose the problem, and to complete repairs on reactors found to have an unacceptable defect. EDF concluded from its tests that the reactors with the most sensitivity to SCC were those in the N4 (four reactors, 1,450 MW<sub>e</sub>) and P’4 (12 reactors, 1,300 MW<sub>e</sub>) series, which are the newest in the French fleet and also the most powerful. These designs were not given priority in the *Grand Carénage* refit programme or EDF’s efforts to extend the operating lifetime of existing plants.

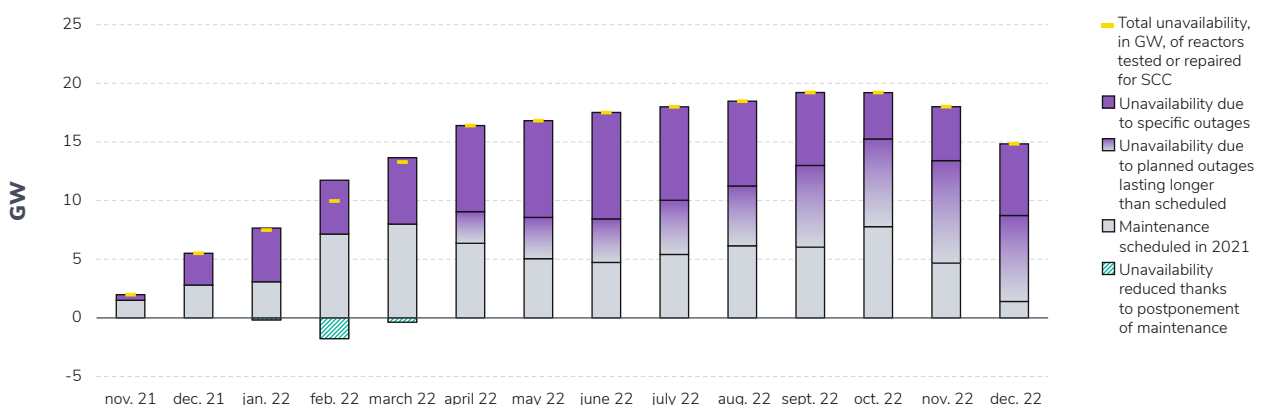
Of these 16 N4 and P’4 reactors, ten were tested in 2022, and treatment has been completed on three<sup>22</sup> (Civaux 1 and 2, where SCC had been detected, and Cattenom 4, where no signs of SCC were found). EDF indicated that all reactors in the N4 and P’4 series will have been treated by the end of 2023. Reactors in the 900 MW and P’4 series not tested in 2022 will undergo tests between 2023 and 2024 during scheduled outages<sup>23</sup>.

Early in 2022, in an effort to limit the number of reactors offline at a time when the power system could be under considerable strain, some scheduled maintenance was postponed. This optimisation of scheduling by the operator maximised the availability of the fleet during the winter months.

Over the year, outages related to testing for SCC had a major impact on fleet availability forecasts, which had to be revised as tests and analyses were completed by the operator. For instance, the average fleet availability forecast for August 2022 stood at 44.9 GW on 1<sup>st</sup> October 2021, but was lowered to 40.9 GW on 1<sup>st</sup> February 2022, and actual availability was 26.4 GW. Updates to nuclear plant availability declarations had a direct impact on trends in spot and forward prices (see *Prices* section).

The availability of the nuclear fleet remained within the range forecast by RTE in its seasonal adequacy study<sup>24</sup> for the winter. Beginning toward the end of November, availability was slightly above the

**Figure 14: Nuclear capacity unavailable per month between November 2021 and December 2022 and breakdown by cause for reactors subjected to tests associated with stress corrosion cracking.**

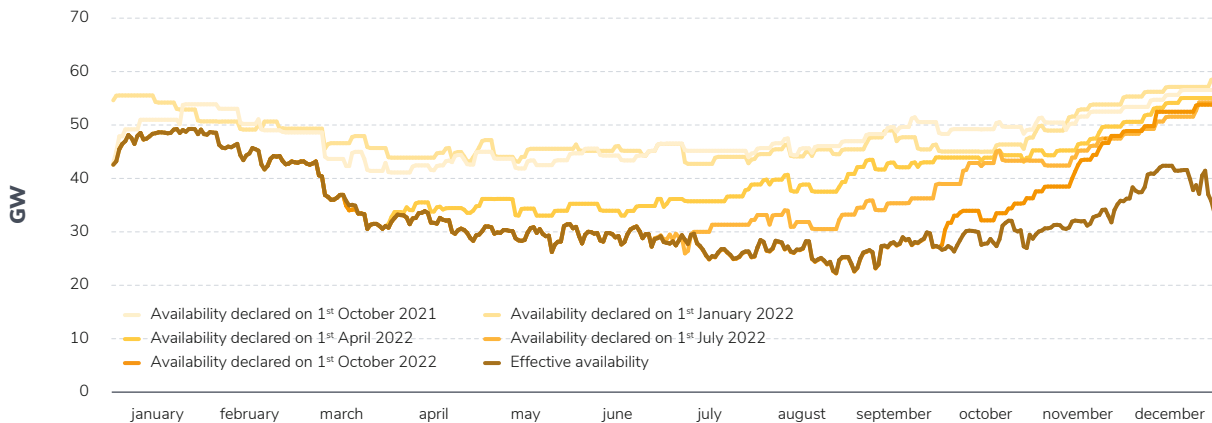


<sup>22</sup>. EDF Statement, update of 16 December 2022 and EDF Statement, update of 3 November 2022

<sup>23</sup>. EDF Statement, update of 3 November 2022

<sup>24</sup>. RTE- Analyse pour l'hiver 2022-2023

**Figure 15: Forecast daily availability in 2022 declared by the operator for several timescales and effective availability (declared availability does not, by nature, include unplanned outages)**



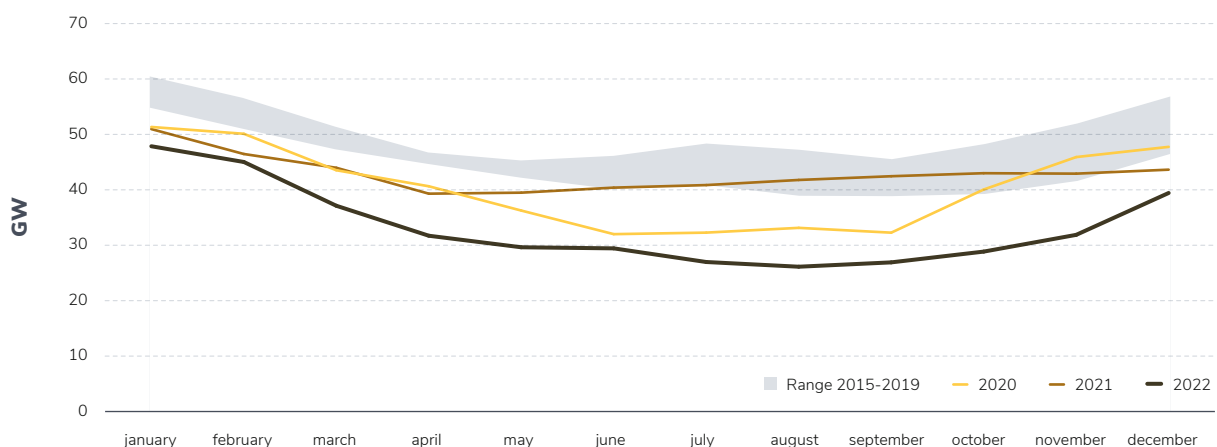
central forecast as of mid-November since a number of reactors were back online by then.

Late in December, due to unusual market conditions with extremely low electricity consumption and prices, effective availability decreased again. Indeed, since the situation was very favourable for the supply-demand balance, short outages were

scheduled by the operator to optimise the overall performance of the nuclear fleet without impacting security of supply.

It was thus possible to avoid the bleakest scenarios for the power system, though the availability of the nuclear fleet did remain below the levels seen in previous years during the same months.

**Figure 16: Average monthly nuclear capacity availability between 2015 and 2022**



### 2.3.4 Breakdown of nuclear capacity unavailability in 2022

Outages in the nuclear fleet occurred in 2022 due to different factors that, taken together, represented close to 14 GW of unavailable power on average over the year as a whole:

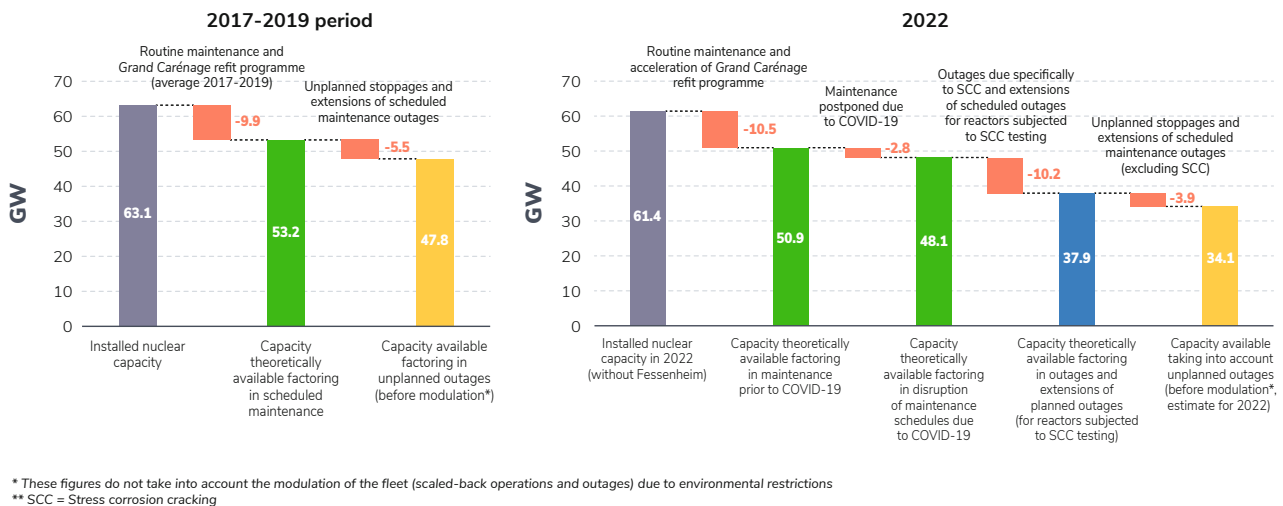
- Increase in the pace and duration of maintenance outages carried out as part of the Grand Carénage refit programme;
- Disruption in the maintenance schedule due to the health crisis;
- Discovery of evidence of SCC.

By analysing declarations of unavailability and their evolution over time, it is possible to draw

a distinction between the effects of the Grand Carénage refit programme and those of the health crisis, which were factored into schedules, and instances where planned outages were extended, due in part to the discovery of SCC and the tests and repairs that required. These repairs had a significant impact on the availability of the fleet (see below).

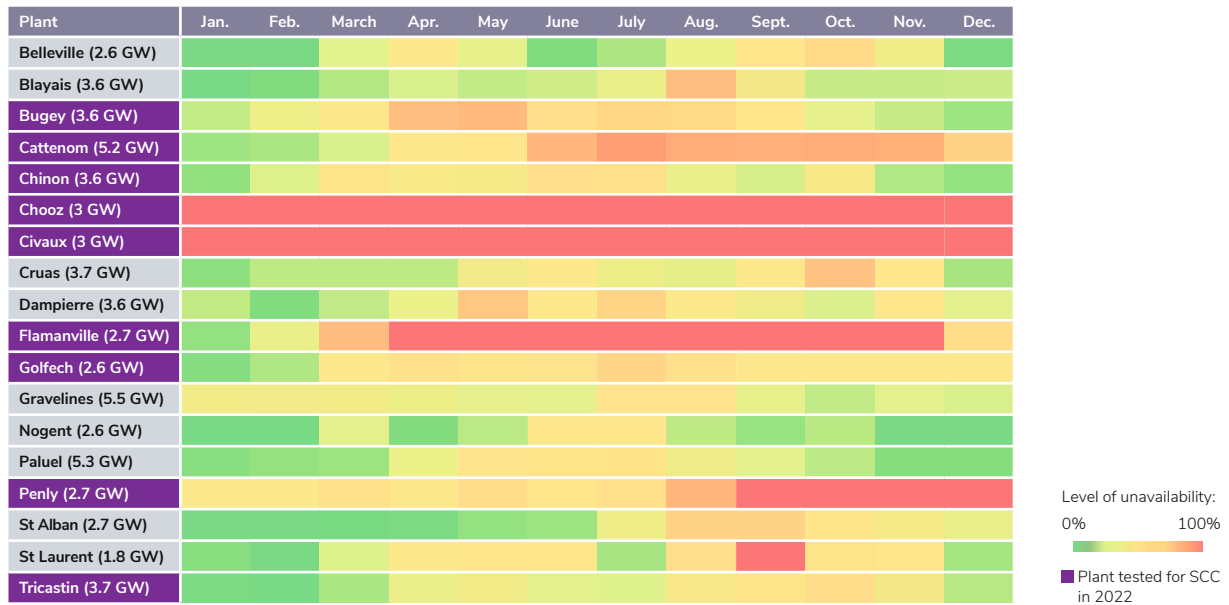
Over 2022 as a whole, the nuclear power plants with the highest rates of unavailability were those where SCC-related tests and repairs were required. The Chooz and Civaux plants in particular (N4 series) were unavailable throughout 2022.

Figure 17: Factors underlying nuclear capacity unavailability in 2022<sup>25</sup>



25. These figures do not reflect modulations (scaled-back operation and stoppages) implemented due to environmental, social or regulatory constraints, to consumption profiles, or to the provision of system and optimisation services. Figures for maintenance schedules are obtained on 1<sup>st</sup> December of the prior year.

Figure 18: Heatmap of total unavailability by plant and month of the year. Green = 0% and Red = 100% unavailability. The plants highlighted in purple are those that were subjected to SCC testing in 2022.





## A CLOSER LOOK

**Waivers for water discharges from nuclear power plants during heat waves**

In the summer of 2022, when security of supply was tight due to a combination of low nuclear capacity availability and heat waves, some nuclear power plants were granted waivers allowing them to continue to operate even as the temperatures of the cooling water they drew from local waterways was above the regulatory limit set for environmental reasons.

Nuclear power plants located near the sea or waterways use these cold sources to cool the steam vapour released from the turbines that generate electricity. In an open circuit, the water thus used is returned directly to the sea or waterway at a slightly higher temperature than when it was drawn. With these systems, the maximum temperature of the discharged water is regulated to reduce the environmental impacts. The same process can take place in a closed circuit, where the water is cooled in air-cooling towers before being discharged.

On hot days, it may be necessary to reduce the power of reactors operating in an open circuit to avoid exceeding the maximum temperature allowed. Two thresholds can be applied, depending on weather conditions and the state of the power system:

- A first temperature threshold that is normally applied;
- A second threshold that applies on days when the weather is warm and the plant needs to produce a minimum quantity of electricity to ensure the safety of the power system. This second threshold is applied at the request of RTE.

The heat waves of July and August 2022 made it necessary to make exceptions to water discharge rules at certain plants, beyond this second threshold, since conforming to the latter might not have sufficed to ensure security of supply. This special waiver, allowed under article R 593-40 of the environmental code and subject to authorisation by the ASN, was granted to the Blayais, Golfech, Saint-Alban and Bugey plants from 13 and 15 July through 11 September 2022, and to the Tricastin plant from 4 August to 11 September 2022. The Bugey plant was the only one that operated (on 19 and 20 July) under the provisions of the ASN decision of 15 July 2022. During this time, the natural environments around the plant were monitored more closely. This increased monitoring programme did not reveal any consequences for the environment. The other plants operated without exceeding the first or second thresholds.

Source and additional information: Modification temporaire des prescriptions encadrant les rejets thermiques de 5 centrales nucléaires - 06/09/2022 - ASN

## 2.4 Hydropower: Output at its lowest level since 1976 due to exceptionally warm and dry weather conditions

### 2.4.1 Production at a record low since 1976

Output from hydropower plants in France reached 49.6 TWh in 2022, representing 11.1% of total generation. Due to low precipitation in the 2021-2022 winter and periods of drought during the spring and summer, output was much lower than in 2021 (62.0 TWh, a 20% year-on-year decrease) and below the average for the 2014-2019 period (61.6 TWh). The 2022 level of production was the lowest on record since 1976, when Europe was also affected by a major drought. Nonetheless, hydropower remained the second leading source of electricity after nuclear and the leading source of renewable generation.

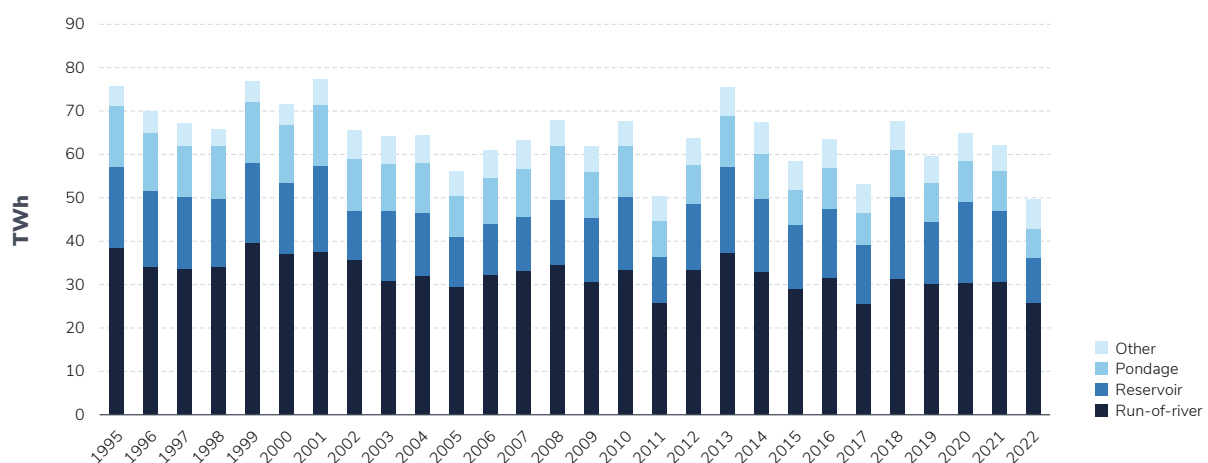
Production declined across all types of facilities (except pumped storage stations). Plants with water storage were the most affected, including reservoir plants, which are often located in high

mountain areas: their output contracted by 35.4% relative to 2021. Pondage plants (mostly located in mid-mountain ranges) saw a 27.8% drop in production. Output from run-over-river plants, which do not have reservoirs, decreased by 16.3%. Their production is highly dependent on rainfall. Output was very limited between May and September then started improving in October, after the return of the rain.

### 2.4.2 A particularly dry year

The weather in 2022 diverged sharply from historical patterns in several ways. First, it was the hottest year on record, with several regions seeing their warmest and sunniest years ever. It was also the driest year since 1959, with rainfall ending the year almost 25% below average<sup>26</sup>, the period between May and July having been particularly dry. Moreover, the snow water equivalent of the snowpack in the winter of 2021-2022 was close to normal in the Pyrenees but well below average in the Alps, which limited dam fill rates when the snow melted.

Figure 19: Annual hydropower generation between 1995 and 2022



26. Based on the final annual climate statement published by Météo-France 2022: Les bilans climatiques | Météo-France (meteofrance.fr)



## A CLOSER LOOK

**Water reserve management optimised based on use values**

Though operating hydropower plants with dams does not entail any fuel costs, they can in some cases rank below thermal power plants in the merit order due to constraints relating to reservoir contents, intake potential and depletion risk. The production schedules of facilities subject to reserve constraints are managed based on the use value of the reserves, i.e., in the case of hydropower, water reserves.

Managing an asset based on use value is common for production plants with limited fuel reserves. The goal is to spread generation out over time in an optimal way, choosing between use straight away or at a later time, when it can be substituted

for costlier generation sources. The basis is the estimation of the opportunity cost of later use. The unit will only be fired up if the market value of the output exceeds this opportunity cost. The value will depend on the point in time considered, the level of demand, the level of remaining reserves, and the level of other reserves modelled and the anticipated future prices of fuels and electricity. It is thus possible that at some point, the use value of a reservoir plant will be higher than the cost of operating a thermal power plant. Other generation sources can also be managed based on use value, such as nuclear power plants (fuel stockpiles) and thermal power plants if they are subject to emissions limits.

**2.4.3 Water reserves dropped to a record low during the summer, but were rebuilt ahead of the 2022-2023 winter**

Water reserves started 2022 close to historical averages<sup>27</sup>, but deteriorated steadily during the year due to unfavourable hydrology conditions. Different climate factors combined to prevent reserves from being sufficiently replenished between April and July, during the main snowmelt period. Reserve levels thus began to dip from mid-July, reaching historic lows in August.

In anticipation of tight power supply during the winter months, operators took extra care in managing water reserves during the summer, limiting production at reservoir and pondage plants (see *Prices* section). Their responsible management approach, together with the return of the rain in September (when rainfall was higher than normal<sup>28</sup>), meant that by October, reserve levels were less critical than in previous months, though they remained relatively low. Starting in November, which also saw higher-than-average rainfall, the situation improved greatly, with reserves rebounding to above the average for the past five years.

27. Bulletins de situation hydrologique | Eaufrance

28. Météo-France climate statement for September 2022: [https://meteofrance.fr/sites/meteofrance.fr/files/files/editorial/Bilan\\_septembre\\_2022\\_241022.pdf](https://meteofrance.fr/sites/meteofrance.fr/files/files/editorial/Bilan_septembre_2022_241022.pdf)

Figure 20: Weekly water reserves

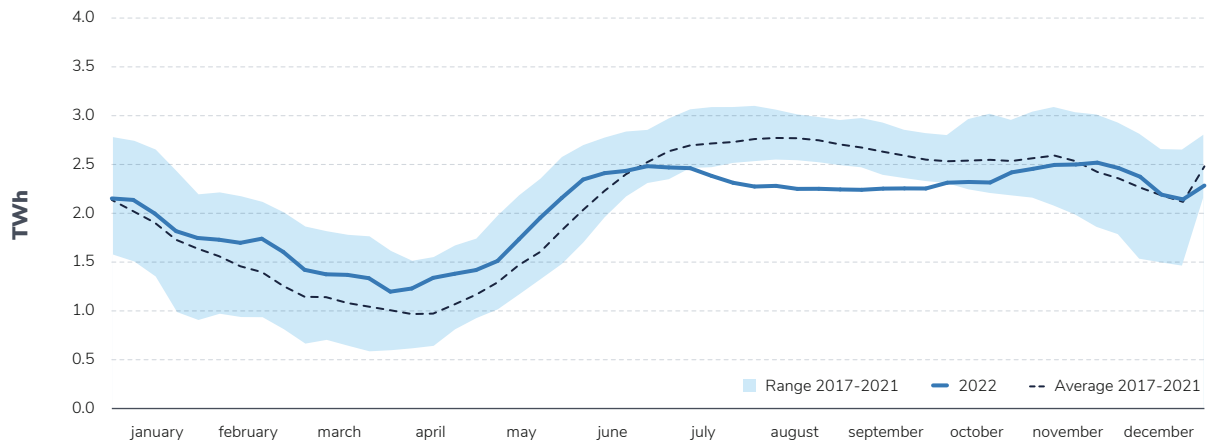
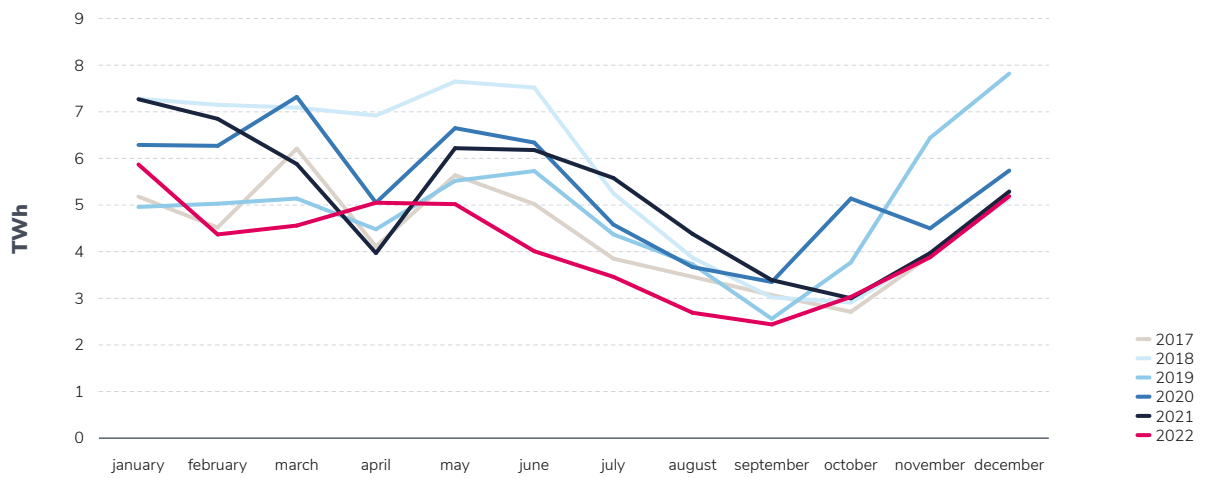


Figure 21: Monthly hydropower generation between 2017 and 2022



## 2.5 Fossil-fired thermal: Generation increased, notably on the back

Fossil-fired thermal power plants made a substantial contribution to electricity supply in France in 2022, offsetting the historic drop in nuclear and hydropower output.

### 2.5.1 Gas-fired generation up sharply despite high fuel prices

**Output from gas-fired plants was high in 2022,** ending the year at 44.1 TWh (which was 9.9% of total generation). During the spring and summer months, when thermal power plants usually operate infrequently, production from gas-fired plants systematically topped the highs of previous years.

Figure 22: Electricity generation from fossil-fired thermal plants<sup>29</sup>

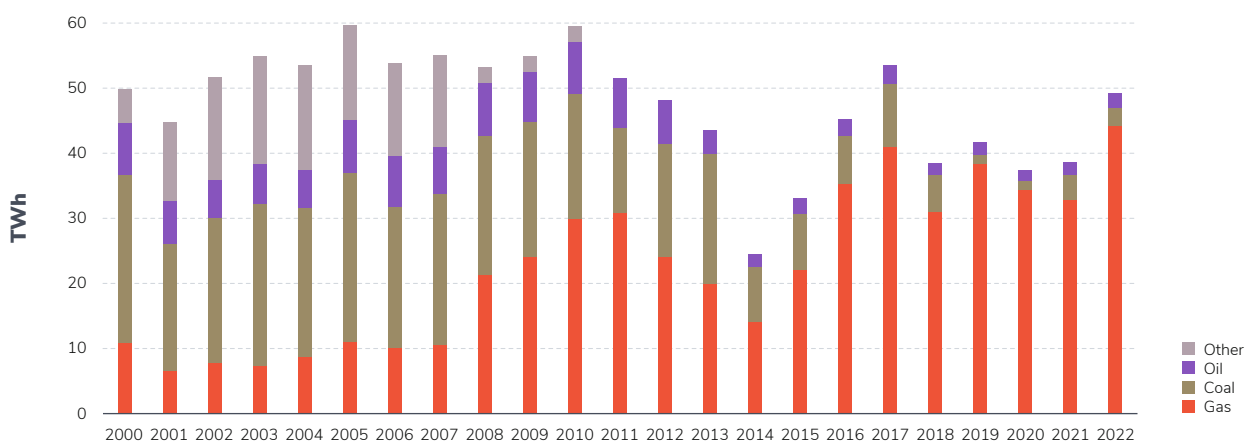
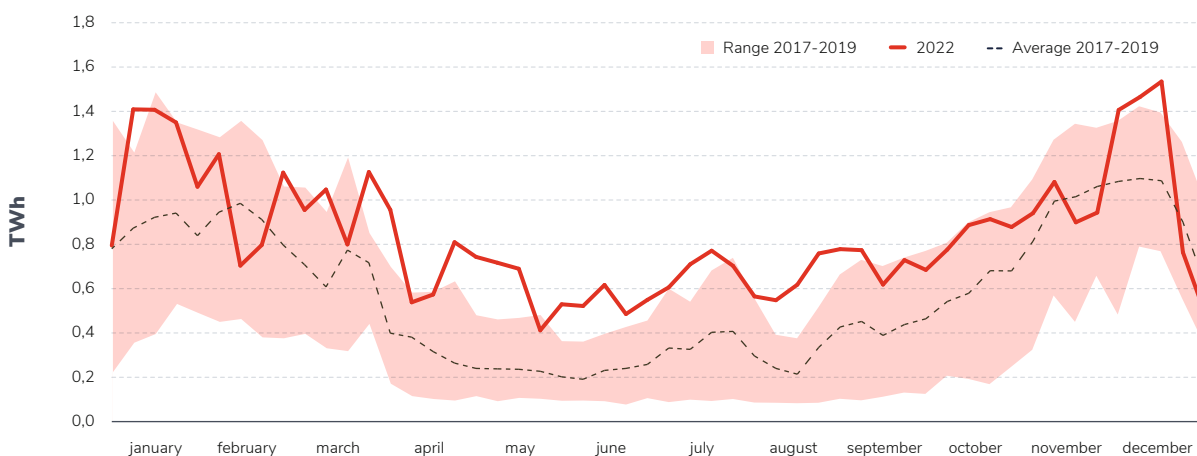


Figure 23: Weekly output from gas-fired plants in 2022 compared with previous years



29. From 2001 to 2007 (included), the timeseries "Other" consisted of generation on the distribution network, generation from by-product gases and one installation running on "miscellaneous" fuels. From 2008 to 2010, it consisted of by-product gases and miscellaneous fuels only, and generation on the distribution network was spread between the oil and gas timeseries. From 2011 onwards, all the components of the "Other" timeseries were spread between the gas, oil and coal timeseries.

## A CLOSER LOOK

### Commissioning of the Landivisiau power plant

The combined-cycle gas power plant in Landivisiau (Brittany), with a production capacity of 446 MW, was commissioned on 31<sup>st</sup> March 2022. This technology uses a steam turbine with a gas turbine to produce electricity, thus delivering greater efficiency than conventional gas-fired plants.

At the beginning and end of the year, gas-fired production remained relatively high but within the range observed in the past, as gas plants are used to maintain security of supply during the winter months.

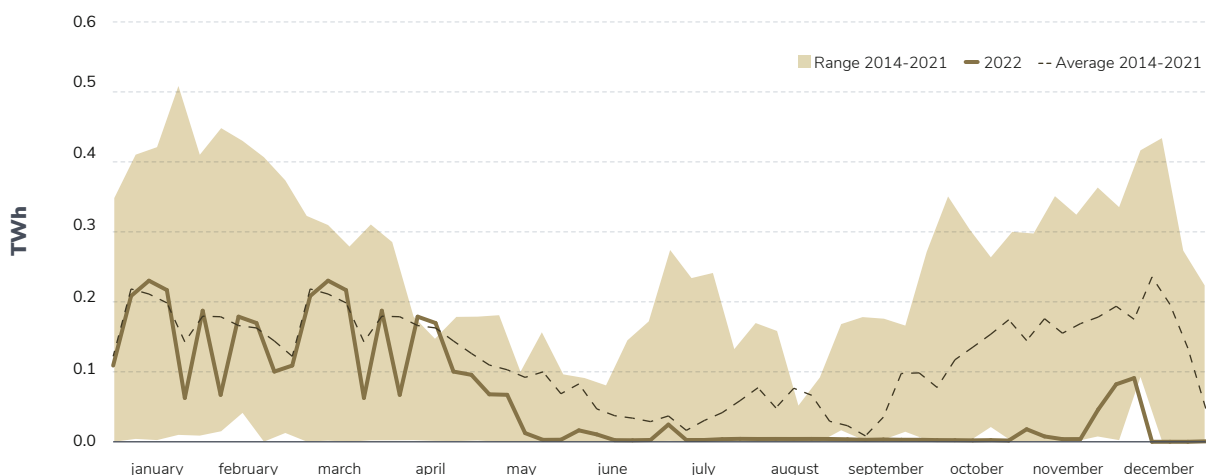
#### 2.5.2 Coal-fired generation decreased

Though France's coal plants were authorised to operate for more hours in anticipation of the 2022-2023 winter, when security of supply was

expected to be particularly tight, their output was ultimately lower than in 2021, reaching 2.9 TWh (0.6% of total generation). Also significantly, output was well below the levels observed up until 2017, before the coal-fired unit at the Gardanne plant was taken offline (non-operational since 2018, decommissioned in 2021) and the last coal-fired unit in Le Havre was shut down in 2021.

As of today, only two coal-fired plants remain active in France: Cordemais (two units with combined installed capacity of 1.2 GW) and Emile-Huchet (one unit with installed capacity of 0.6 GW), located in Saint-Avold. Their hours of operation are restricted<sup>30</sup> by an emissions cap corresponding to about 700 hours of operation at full capacity for each plant. Early in February 2022, after RTE issued a warning about a possible weakening of security of supply that month, the cap was raised by government decree to a level corresponding to about 1,000 hours of operation at full capacity from 1<sup>st</sup> January through 28 February 2022, and to about 600 hours of operation for the rest of the year. Another change was made in September 2022: a new emissions cap was set at 3.1 kilotons of carbon dioxide equivalent per MW of installed

Figure 24: Weekly output from coal-fired plants in 2022 compared with previous years



30. The cap corresponds to 0.7 kt<sub>CO2eq</sub>/MW (French Energy Code, art. D. 311-7-2)

capacity from 1<sup>st</sup> March 2022 to 31<sup>st</sup> March 2023, which corresponds to about 3,100 hours of operation. Even with these new caps on operating hours for the two remaining plants, output remained low, given the amount of residual capacity still in place.

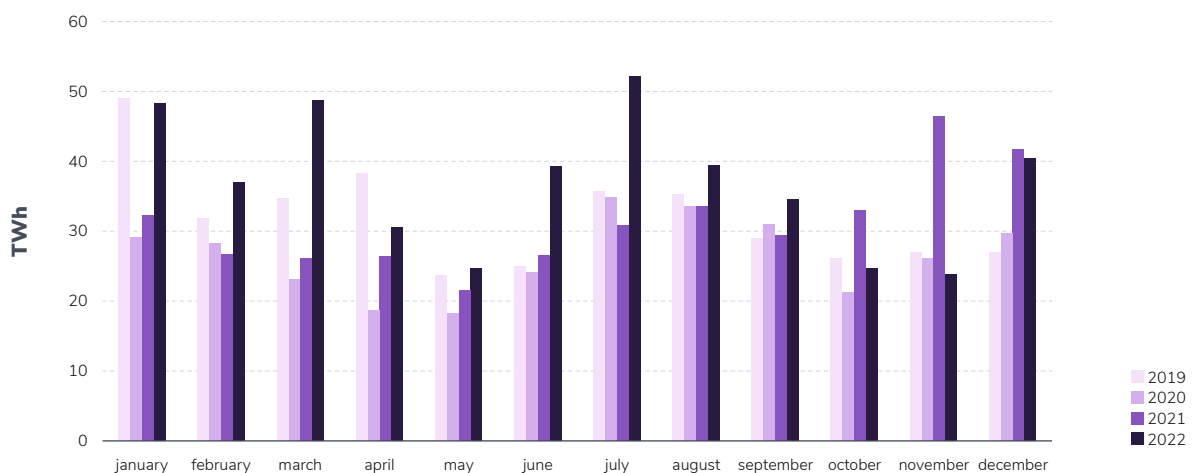
In keeping with the broader objective of decarbonising the power sector, the Emile-Huchet plant was scheduled to be shut down at the end of March 2022, but the closure was ultimately postponed to 2023 to allow that plant to contribute to security of

supply in the 2022-2023 winter months. It started producing electricity again on 29 November 2022 after undergoing maintenance work.

### 2.5.3 Oil-fired generation rose in 2022

Electricity produced by oil-fired plants reached 2.2 TWh in 2022, which corresponded to 0.5% of total generation. This was the highest level on record since 2017, and represented an 18.4% increase over 2021, with a notable jump in output between January and September.

Figure 25: Monthly output from oil-fired plants between 2019 and 2022



## 2.6 Wind power: Despite relatively unfavourable weather conditions in 2022, output rose on the back of expanded capacity

### 2.6.1 Onshore wind capacity increased considerably, but must expand even faster to meet the national targets set for the 2020-2030 period

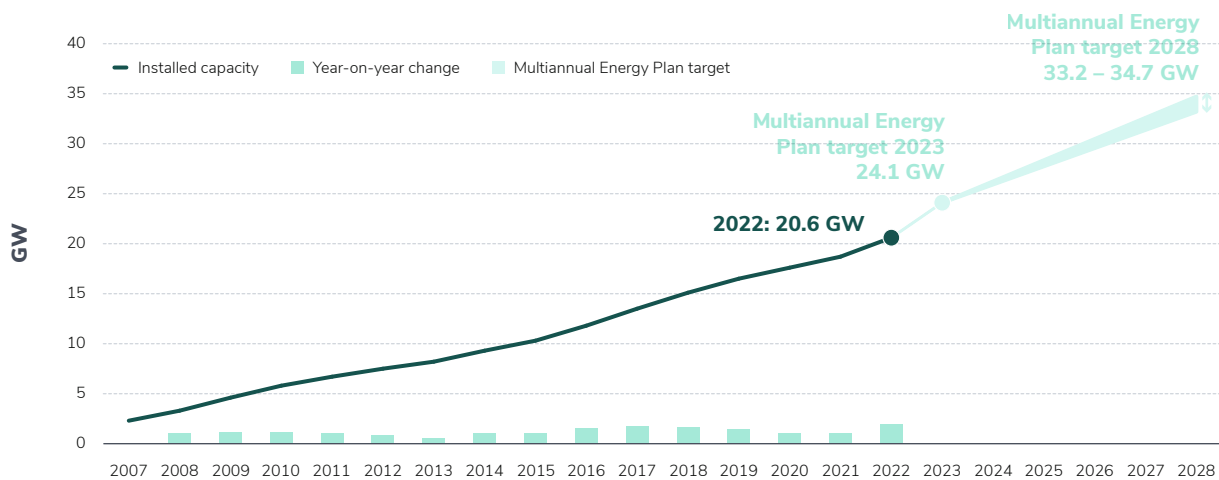
Installed onshore wind capacity rose from 18.7 GW on 31<sup>st</sup> December 2021 to 20.6 GW on 31<sup>st</sup> December 2022, for a 12-month increase of 1.9 GW (compared with a rise of 1.7 GW in 2017). This growth rate will nonetheless not suffice to allow the government's targets to be met: the Multiannual Energy Plan calls for installed onshore wind capacity to reach 24.1 GW by the end of 2023, meaning 3.5 GW would need to be

added in 2023. By 2028, the plan targets a range of between 33.2 GW and 34.7 GW. That implies average annual growth of between 2.1 GW and 2.4 GW in the 2023-2028 period, meaning the growth rate would also have to accelerate from historical levels<sup>31</sup> during that period.

Over longer timeframes, wind power capacity will need to continue to expand in order to help the government meet its goals for the decarbonisation of energy end-uses. For instance, the trajectories analysed in RTE's *Energy Futures 2050* report consider several electricity mix scenarios for 2050, with installed wind power capacity ranging between 43 GW and 74 GW.

Capacity in development<sup>32</sup> rose slightly in 2022, ending the year at 10.6 GW<sup>33</sup>.

Figure 26: Trend in wind power capacity (total installed capacity and annual growth) and comparison against government targets

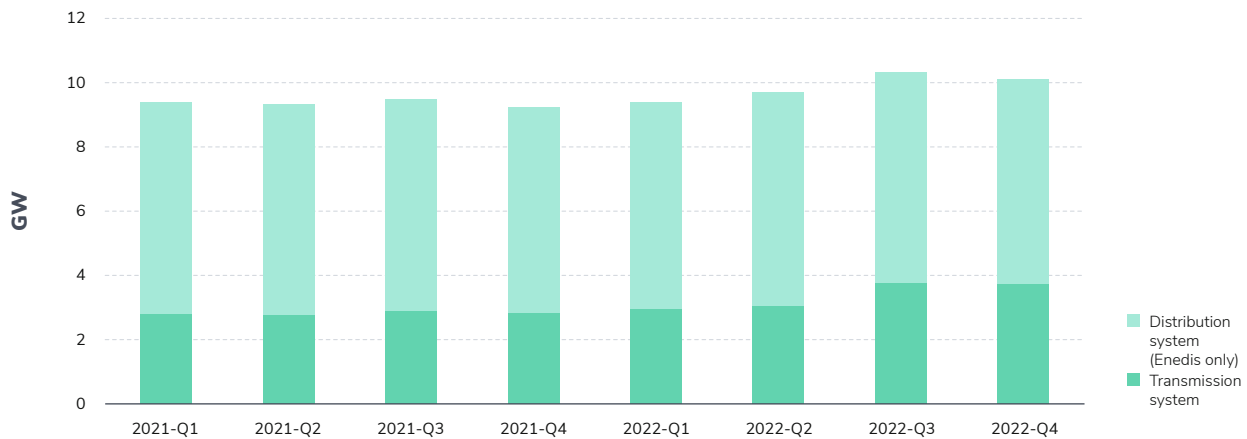


31. The development of new wind power capacity is subject to certain administrative, regulatory and territorial constraints that must be taken into account in project siting decisions, above and beyond a location's wind potential. For example, it is currently forbidden to install wind turbines on 50% of French land due to the presence of air lanes overhead (according to the FEE association, which defends wind energy in France. *Observatoire de l'éolien 2022 – France Énergie Éolienne* ([fee.asso.fr](http://fee.asso.fr))).

32. Where the RTE grid is concerned, these are projects that have received a "proposal to enter the queue" or a "technical and financial proposal" that has been accepted, or that were selected through a call for tenders. Capacity in development on the Enedis grid refers to projects for which a request for grid connection has been deemed complete by the distribution system operator.

33. RTE data for the transmission grid and ENEDIS data for the distribution grid (*Demande de raccordement – Demandes en cours par tranches de puissance et modalités d'injection – Historiques cumulés – Enedis Open Data*)

Figure 27: Wind capacity projects in development on the public transmission grid (RTE) and the distribution grid (Enedis only)

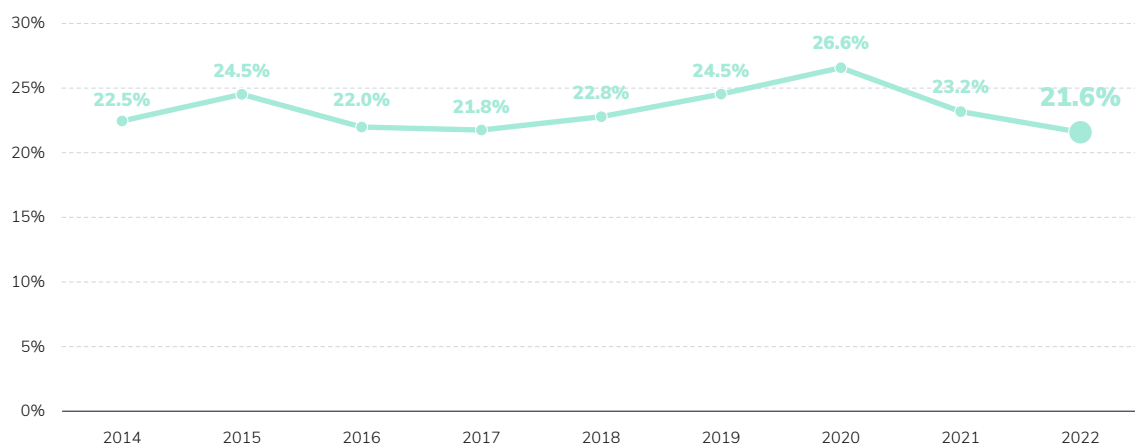


### 2.6.2 Wind capacity factor at its lowest level in ten years

Weather conditions were not favourable for wind power generation in 2022: the wind capacity factor for onshore wind was 21.6%<sup>34</sup> for the year, down from 23.2% in 2021 and 26.6% in 2020.

Though the capacity factor decreased, onshore wind power generation was higher in 2022 (37.5 TWh) than in 2021 thanks to the addition of new installed capacity, though it remained below the 2020 level (39.6 TWh). Coverage of demand by onshore wind power averaged 8.4% for the year<sup>35</sup>.

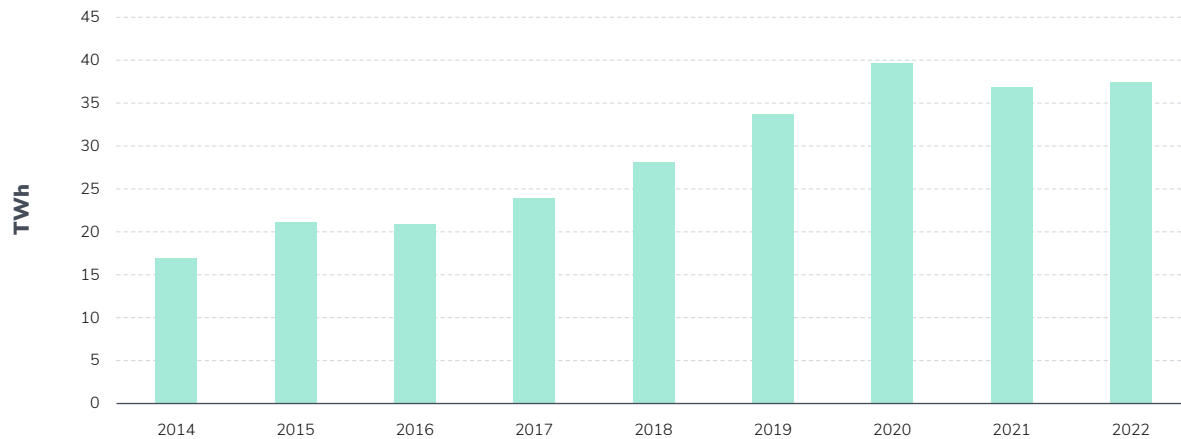
Figure 28: Annual capacity factor for onshore wind



<sup>34</sup>. Average annual rate calculated as the average capacity factor at 30-minute time steps

<sup>35</sup>. Average annual rate calculated as the average coverage rate at 30-minute time steps.

Figure 29: Onshore wind power generation

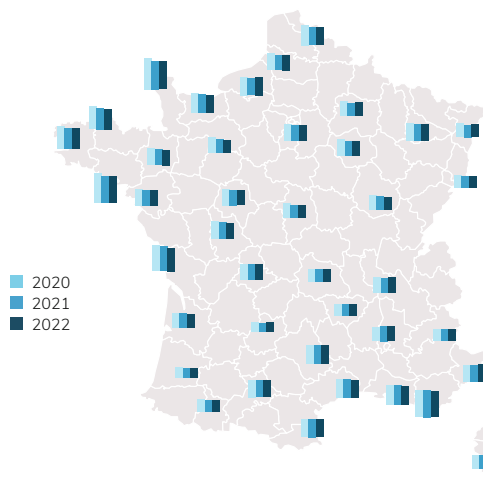


## A CLOSER LOOK

## Trends in wind conditions over the past three years

Wind speed is an essential determinant of wind turbine efficiency. Wind conditions were particularly good in 2020, notably near the Atlantic coast and English Channel. On the other hand, wind speeds were lower across the different French regions in 2021 and 2022.

Figure 30: Trend in average annual wind speeds at each weather station between 2020 and 2022  
(Data taken from the Observation météorologique historiques France (SYNOP) – Opendatasoft)



## 2.6.3 First offshore wind farm brought into service in 2022

A key highlight of 2022 was the commissioning, on 23 November, of France's first offshore wind farm off the coast of Saint-Nazaire. This farm comprises 80 fixed-bottom turbines located 12 to 20 km off the coast with combined capacity of 480 MW<sup>36</sup>. It produced 647 GWh of power in 2022<sup>37</sup>. In December, the capacity factor averaged 48%, notably thanks to strong output in the second half of the month, when onshore wind power generation was also robust.

The Multiannual Energy Plan calls for offshore wind capacity to reach 2.4 GW by the end of 2023 then rise to between 5.2 and 6.2 GW by the end of 2028. Several offshore wind farms are scheduled to come online over the coming years (see *Transmission Network* section). Connections can be expected to ramp up in 2023 with the planned commissioning of the Saint-Brieuc and Fécamp farms, each representing capacity of close to 500 MW.

36. Mise en service complète du premier parc éolien en mer de France | EDF FR

37. The farm had begun producing electricity before commercial service began.

#### 2.6.4 France lags its European neighbours on the wind power development front

Installed wind capacity in France remains well below the levels seen in Germany, Spain and the United Kingdom. Moreover, between 2019 and 2022, it added new capacity at a slightly slower pace than Germany or Spain (+1.4 GW/year in France compared with +1.6 GW/year in Spain and +1.5 GW/year in Germany). Capacity growth has been slowing in the United Kingdom in recent years, but its offshore wind capacity growth has

been robust. Installed onshore wind capacity in Italy remains below that of France.

Coverage of demand by wind power (onshore) is much higher in Germany and Spain than in France, since those countries have more installed capacity. On the other hand, Italy covers almost as much of demand with wind power as France even though it has less installed capacity, since Italy consumes less electricity than France.

Figure 31: Installed wind capacity in select European countries at the end of 2022, and in Q3 2022 for the United Kingdom (Sources: Fraunhofer Institute, REE, RTE, BEIS UK, Terna)

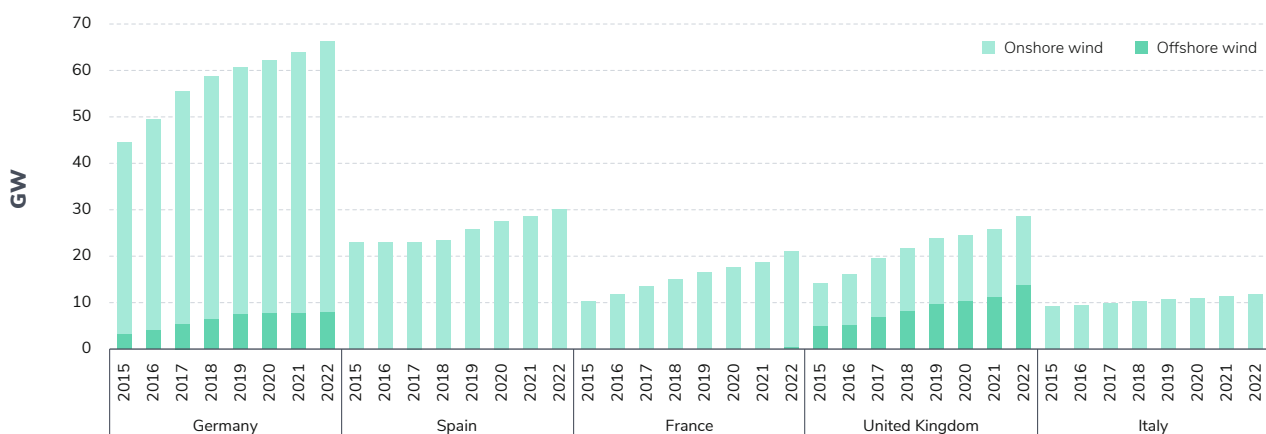
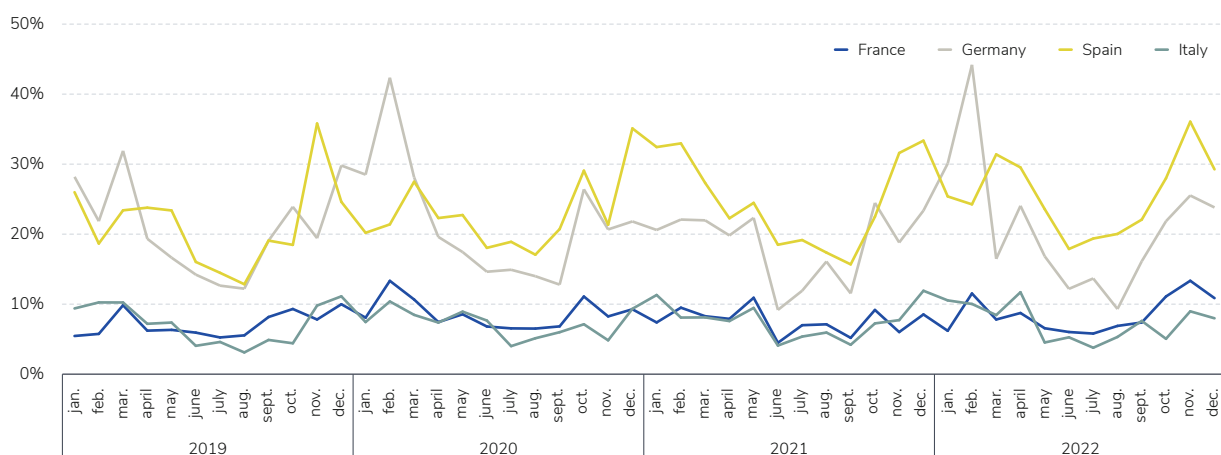


Figure 32: Share of demand covered by onshore wind power in select European countries, monthly average (source: ENTSO-E)



### 2.6.5 Feed-in tariffs brought in revenue to the state for the first time

Most wind and solar capacity benefits from incentives in the form of feed-in tariffs (FITs) designed to support the development of these technologies. This financing, which varies based on market electricity prices, comes from the state. In 2022, for the first time, the FIT mechanism generated revenue for the state, as wholesale electricity prices were on average higher than the FITs. According to estimates by French Energy Regulatory Commission CRE, onshore wind will have brought in €8.9 billion in 2022<sup>38</sup>, which corresponds to 77% of the

subsidies the industry has received via the “electricity public service contribution” (CSPE in French) over the past 20 years<sup>39</sup>. By the start of 2023, the wind power industry will likely have contributed more to the national budget than it has received, but it will still benefit over the coming decades from other subsidies based on wholesale electricity prices, which are impossible to estimate today. CRE also reports that in 2022, solar brought in €724 million to France, representing 3% of past subsidies, whereas offshore wind will have brought in €169 million in the first year of operation.



#### A CLOSER LOOK

### A closer look: Renewable Energy Acceleration Bill

A bill intended to accelerate renewable energy production in France<sup>40</sup> introduced temporary measures intended to speed up the completion of renewable energy projects (the facilities in question will be specified in a decree), which will notably make it possible to recognise certain projects as serving an “overriding public interest”. It also introduces a “visual saturation of the landscape” criterion that must be considered before new onshore wind projects are

approved, this to avoid having new projects grouped together in regions that are already home to multiple farms, thereby creating a sentiment of territorial injustice<sup>41</sup>.

To foster the development of new solar projects, the bill will require the installation of solar panels on all car parks of more than 1,500 square metres (already mandatory for car parks of more than 2,500 m<sup>2</sup>)<sup>42</sup>.

38. Délibération de la CRE du 3 novembre 2022 relative à la réévaluation des charges de service public de l'énergie pour 2023

39. Annexe 7 de la délibération de la CRE – Historique des charges de service public de l'énergie

40. Passed on first reading in the National Assembly in January 2023.

41. Projet de loi énergies renouvelables éolien solaire | vie-publique.fr

42. Projet de loi énergies renouvelables éolien solaire | vie-publique.fr

## 2.7 Solar: Sharp increase in output in 2022

### 2.7.1 Solar power generation rose sharply on the back of expanded capacity and good sunlight

Solar power output reached 18.6 TWh, a 30.6% increase (+4.4 TWh) compared to 2021. The main contributors were the Nouvelle-Aquitaine (+0.9 TWh), Occitanie (+0.8 TWh) and

Auvergne-Rhône-Alpes (+0.6 TWh) regions, though output rose sharply year-on-year across all regions except for Corsica, where the growth was more moderate.

The primary driver of the increase in solar power generation was the addition of new capacity, which accelerated in 2021 and 2022 (see next section). Sunshine conditions were also better in 2022 than

Figure 33: Annual solar power generation

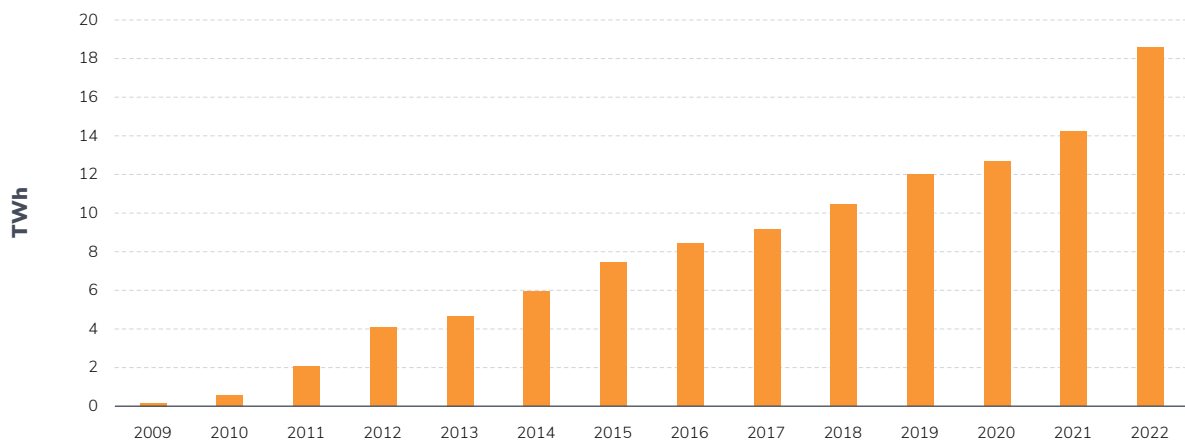
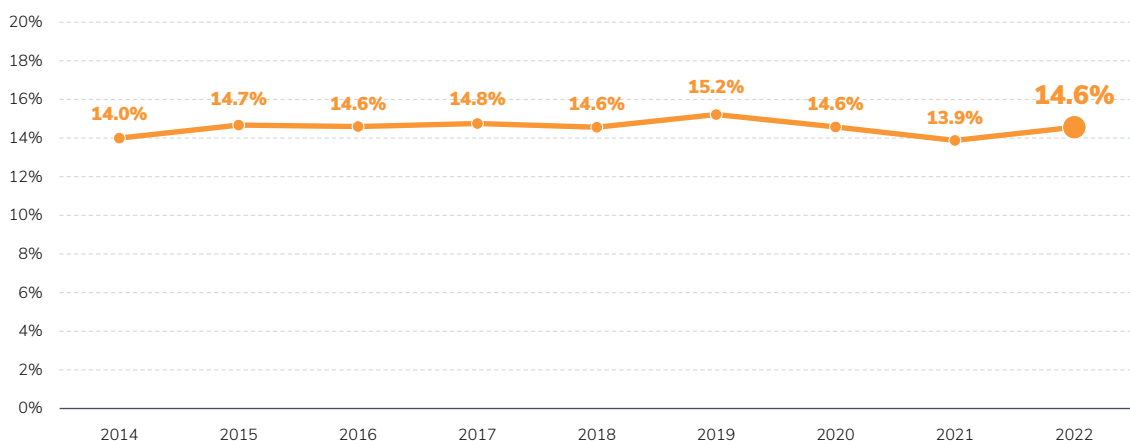


Figure 34: Annual solar capacity factor



in 2021, which lifted the capacity factor to 14.6%, up from 13.9% in 2021. Coverage of demand by solar power averaged 4.2%<sup>43</sup> in 2022.

### 2.7.2 Further growth in installed capacity ahead, though the pace will need to increase if the Multiannual Energy Plan targets are to be met

France was home to 15.7 GW of installed solar capacity at the end of 2022, which was 19.9% higher than a year earlier (+2.6 GW). 2021 had seen a slightly more robust increase, with 2.8 GW of new capacity installed<sup>44,45</sup>. One reason for the slowdown appears to be that some projects originally scheduled to come into service in 2020 had been postponed to 2021 due to the COVID-19 crisis. The solar power industry was also hit hard in 2022 by rising commodity prices and supply chain issues affecting some components<sup>46</sup>.

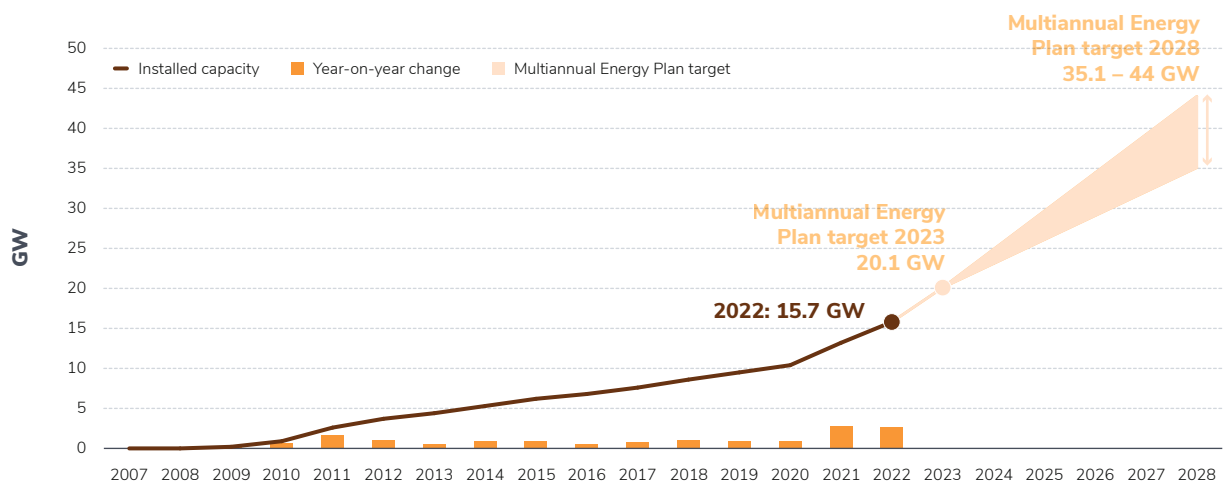
Though the pace of capacity growth was robust in 2022, it will not, as such, be enough for the

20.1 GW target set in the Multiannual Energy Plan for 2023 to be met: for that to happen, 4.4 GW of new solar capacity would need to be installed in 2023. Looking ahead, the targets set out in the Multiannual Energy Plan for 2028 range between 35.1 GW and 44.0 GW, which would require the addition of between 3.2 and 4.7 GW a year starting from the end-2022 level.

Over longer timeframes, solar capacity in France will need to be developed further to meet public authorities' objectives in terms of decarbonising energy end-uses. For instance, the trajectories analysed in RTE's Energy Futures 2050 report consider an installed capacity of between 70 GW and 214 GW in 2050, depending on the scenario.

Solar capacity in development rose sharply in 2022, reaching more than 16.2 GW<sup>47</sup> at the end of 2022. Capacity growth can thus be expected to accelerate considerably over the coming years.

Figure 35: Annual trend in solar power capacity



43. Average annual rate calculated as the average coverage rate at 30-minute time steps.

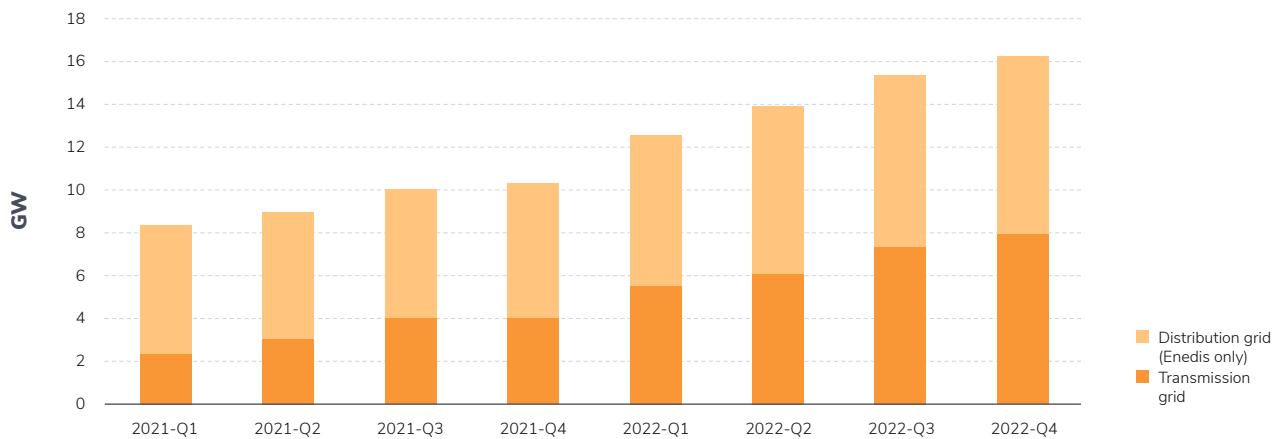
44. The numbers differ from the 2021 Electricity Report since final data are now being used.

45. Note that self-consumption units without grid injection are not included in total capacity or generation figures. Self-consumption units with grid injection count toward total capacity, but only the power injected is counted. The number of these types of units rose sharply during the year, though they still make up only a small share of total solar capacity. Graphique Enedis Open Data

46. 2022 barometer of renewable electricity in France, Observ'ER

47. RTE data for the public transmission grid, ENEDIS data for the distribution grid (Demande de raccordement – Demandes en cours par tranches de puissance et modalités d'injection - Historiques cumulés – Enedis Open Data)

Figure 36 : Solar power projects in development on the transmission grid (RTE) and distribution grid (Enedis alone)

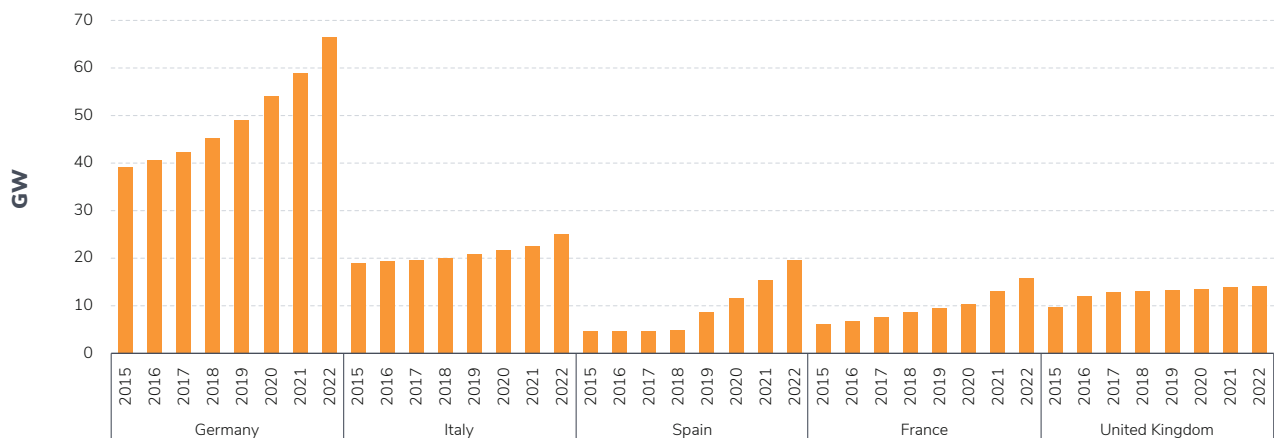


### 2.7.3 Solar power development in France is lagging behind other European countries

France added sufficient solar capacity in the past two years to overtake the United Kingdom in 2022, but it is still running well behind Germany, Italy and

Spain. The pace of capacity additions in France since 2019 (+1.8 GW/year) is far below that of Germany (+5.3 GW/year) and Spain<sup>48</sup> (+3.7 GW/year) but above that of Italy (+1.2 GW/year).

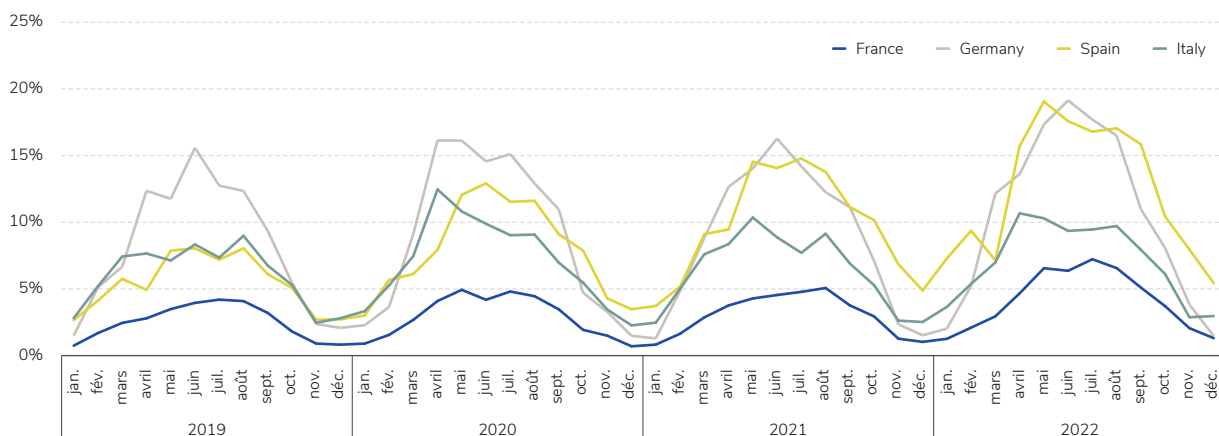
Figure 37: Solar power capacity in a selection of European countries at the end of 2022 and in Q3 2022 for the United Kingdom<sup>49</sup>. (sources: Fraunhofer Institute, REE, TERNA, BEIS UK, RTE)



<sup>48</sup>. The figures for Spain do not take into account residential or business self-consumption units, which have seen very robust growth in recent years (+2.5 GW in 2022 according to industry data).

<sup>49</sup>. The figures for Spain do not take into account residential or business self-consumption units, which have seen very robust growth in recent years.

**Figure 38: Share of demand covered by solar power in select European countries, monthly average.**  
(source: ENTSO-E)



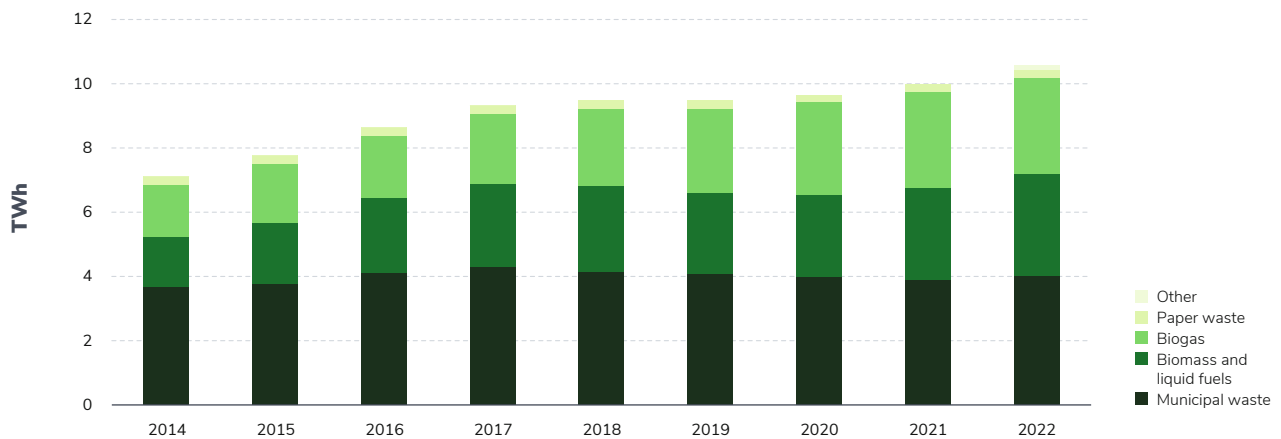
According to industry data<sup>50</sup>, Union-wide solar capacity growth set new records in 2022, with capacity additions rising by 47% (41.4 GW) relative to 2021 (28.1 GW), leading to a 25% year-on-year increase in total installed capacity (from 167.5 GW to 208.9 GW). Germany notably stood out with 7.2 GW of capacity added during the year.

Though coverage of demand by solar remains lower in France compared to neighbouring countries, significant progress was made in 2022, with the French coverage rate jumping from 3.1% in 2021 to 4.2% in 2022, reflecting strong growth in installed capacity since 2021.

50. SolarPower Europe - EU Market Outlook 2022

## 2.6 Renewable thermal and waste

Figure 39 : Annual generation from renewable thermal and waste-to-energy capacity



Thermal generation from bioenergy and waste continued to rise in 2022 (+5.7% year-on-year), reaching a yearly total of 10.6 TWh.

Renewable thermal and waste includes plants that produce electricity from biomass or biogas, which count as renewable sources, and those that produce electricity from waste, through incineration (of which 50% is considered renewable<sup>51</sup>).

51. Arrêté du 8 novembre 2007 pris en application de l'article 2 du décret n° 2006-1118 du 5 septembre 2006 relatif aux garanties d'origine de l'électricité produite à partir de sources d'énergie renouvelables ou par cogénération. – Légifrance (legifrance.gouv.fr)

## 3. Market prices

### 3.1 Overview

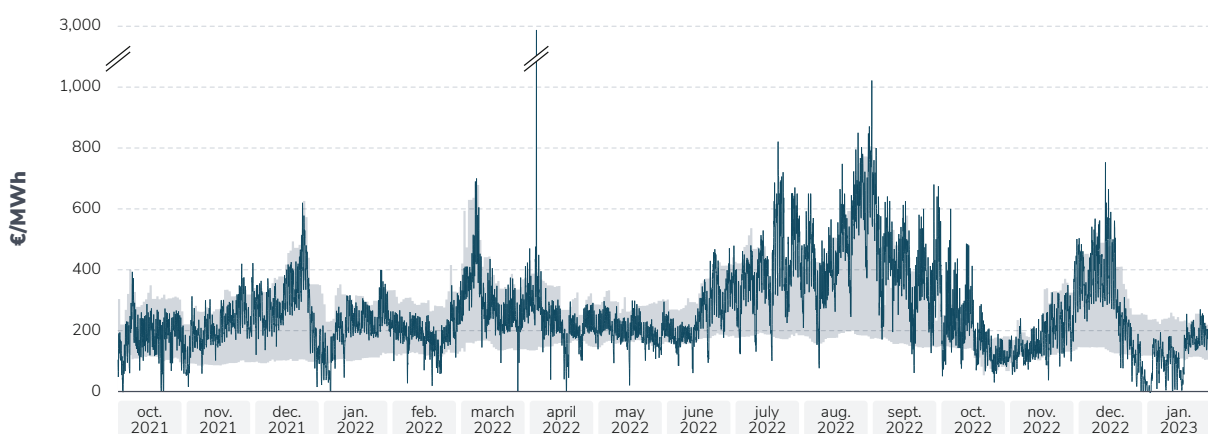
The energy crisis linked to the international context and high fuel prices led to an **unprecedented increase in electricity prices in Europe**, particularly between the spring and summer of 2022. This followed a period late in 2021 when supply was already tight, as the economic rebound post-COVID-19 crisis caused tensions between available gas supply and demand, which caused upward pressure on gas prices and, ultimately, electricity prices.

France's electricity mix has structural advantages that allow it to withstand periods when the fuels needed to produce electricity are in tight supply: it is usually a net exporter of electricity, and its generation mix is dominated by nuclear and renewables, both of which have low variable costs. However, the reduced availability of the French

nuclear fleet, starting in late 2021 and continuing into 2022, together with the drought that affected hydropower output, combined to reduce domestic electricity production. This led to a significant increase in imports from neighbouring countries with generation mixes that rely more on gas and coal, while also driving up gas-fired generation in France.

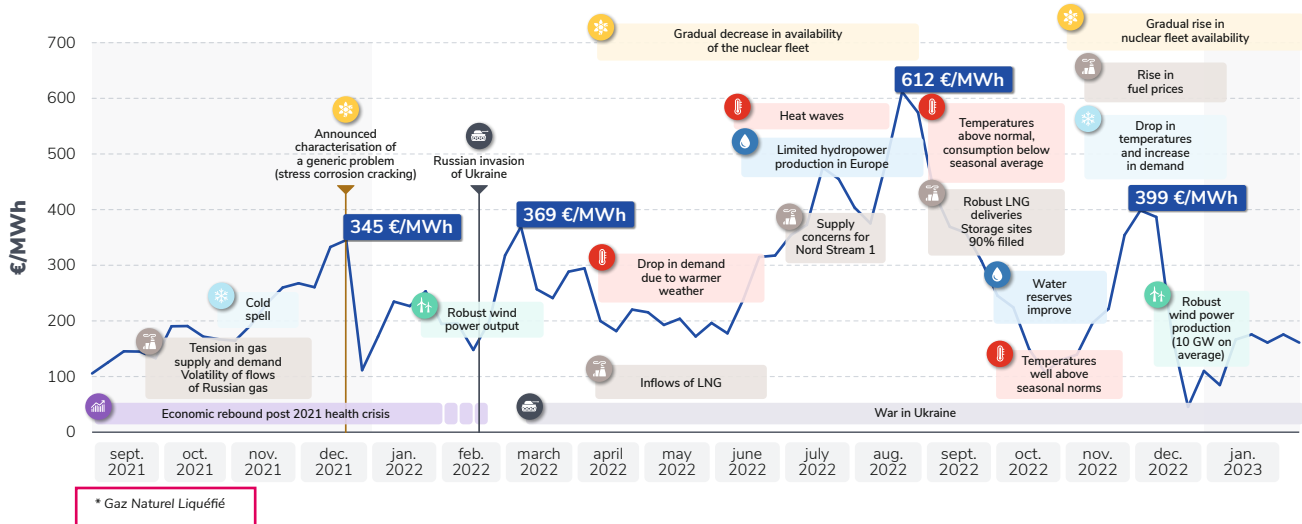
As a result, electricity prices rose sharply during the year, both on the spot and forward markets (see *Explainer* below). The analyses published by RTE in its seasonal report on security of supply for the autumn and winter of 2022-23<sup>52</sup> showed that these price increases were broadly in line with market fundamentals, meaning they reflected the increased reliance on fossil-fired thermal generation sources and imports, and mirrored trends in fuel prices.

**Figure 40: Hourly spot prices in France and comparison with the range of variation of variable production costs for thermal power plants in France**



52. «Perspectives du système électrique pour l'automne et l'hiver 2022-23» (septembre 2022 et actualisations mensuelles à partir d'octobre)

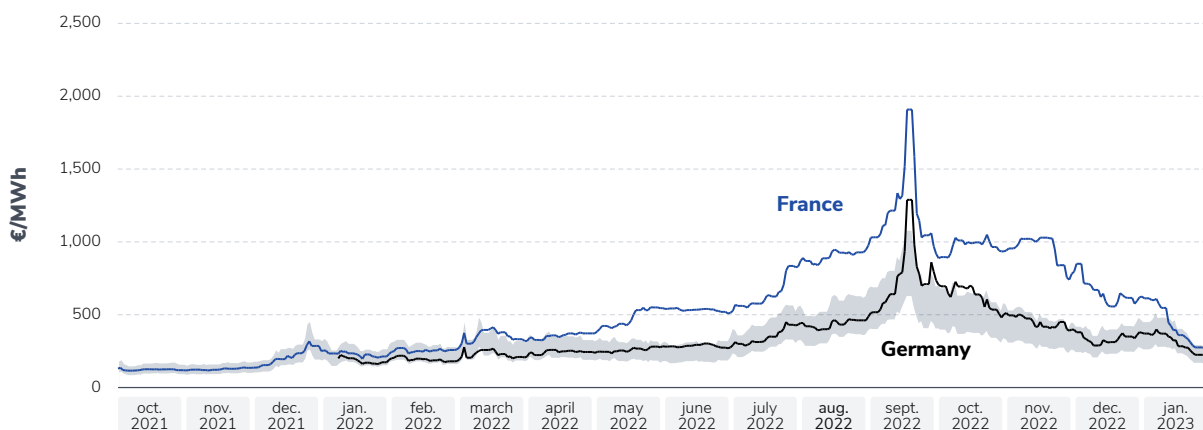
Figure 41: Trend in the average weekly spot price in France between September 2021 and January 2023 (EPEX data)



Conversely, between the spring and autumn of 2022, forward prices for electricity deliveries in the 2022-2023 winter were often higher in France than in neighbouring countries, largely exceeding the variable production cost range of gas-fired thermal power plants. This reflected the fact that market actors were applying a very high “risk premium” for France when it came to security of supply

in the autumn-winter of 2022-2023. This risk premium reflected both “price risk” and “volume risk”. The “price risk” incentivises market actors to hedge against the risk of fluctuations in spot and intraday prices. For instance, suppliers may enter into forward contracts to hedge a significant share of the consumption of their customer portfolios. A “volume risk”, within a context of existing price tension,

Figure 42: Trend in forward prices for the first quarter of 2023, baseload electricity, in France and Germany, between October 2021 and January 2023 (daily averages – source: EEX data, Calculations: RTE)



encourages suppliers to secure additional volumes in anticipation, for instance, of extra consumption during a cold period, knowing that it could be very costly to buy electricity later on the spot or intraday market, especially if they also need to settle costs resulting from imbalances within their portfolios.

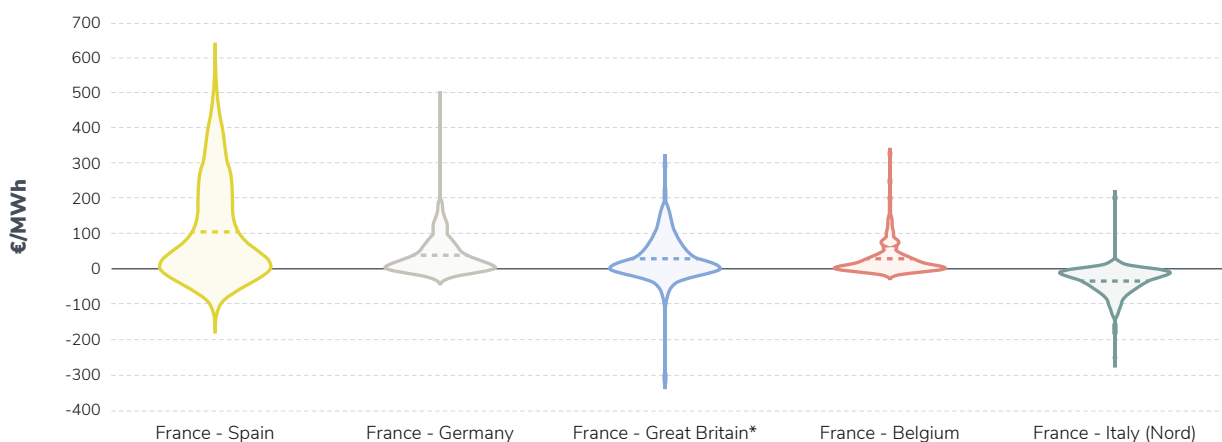
RTE underscored, beginning with the publication of its security of supply analysis for the autumn and winter of 2022-23 in September 2022, and in subsequent updates, that the risk premiums actors were pricing in corresponded to projected shortfall situations much more severe than the worst-case scenario anticipated by RTE. This phenomenon of “over-hedging” thus translated a risk perception that deviated widely from the fundamentals of power system operations, reflecting a lack of confidence among actors when it came to security of supply risks and the projected timeframes for bringing nuclear reactors back online. The analysis

the CRE published in December 2022 confirmed this observation<sup>53</sup>. Subsequently, a gradual easing of uncertainty around security of supply (nuclear reactors restarted in December, air temperatures higher than normal in the first part of winter) resulted in a sharp drop in the risk premiums priced in by market actors, which brought forward prices closer into line with other European countries toward the end of 2022.

Over 2022 as a whole, “wholesale” spot and forward prices in France were higher than in most neighbouring countries for the reasons outlined above. The average spot price for the year was €275.9/MWh (compared with €109.2/MWh in 2021).

Households and small businesses were largely protected from these higher prices thanks to the implementation of a “tariff shield” that capped the

**Figure 43: Distribution of gaps between spot prices in France and neighbouring countries (source: EPEX, calculations: RTE)**



\*For Great Britain, the gap is adjusted to reflect losses on the IFA and IFA2 interconnectors

**Reading:** The chart represents the distribution of differences between spot prices in France and another country. The thickness of the shapes depends on the number of time steps in the year characterised by the difference shown on the axis. The “thickest” section of the shape corresponds to the difference recorded most often. The more “elongated” the shape, the more the gaps varied during the year. The dotted line represents the average gap for each border. For instance, the price in France was €109/MWh higher than in Spain on average. Most of the time, the gaps fell within a range of €50/MWh to -€50/MWh. Deviations above the average were less frequent, but at times approached €600/MWh.

53. CRE, « Les prix à terme de l'électricité pour l'hiver 2022-2023 et l'année 2023 », décembre 2022.

increase in regulated tariffs at 4% in 2022. Without that measure, prices should have risen by 44%<sup>54,55</sup>. Other measures, such as the increase in volumes allowed under ARENH<sup>56</sup> and cuts to certain taxes (TICFE), kept the price rise in check for businesses and local governments<sup>57</sup>. Very high prices nonetheless took a toll on electricity demand, notably in energy-intensive industries (see Consumption section).

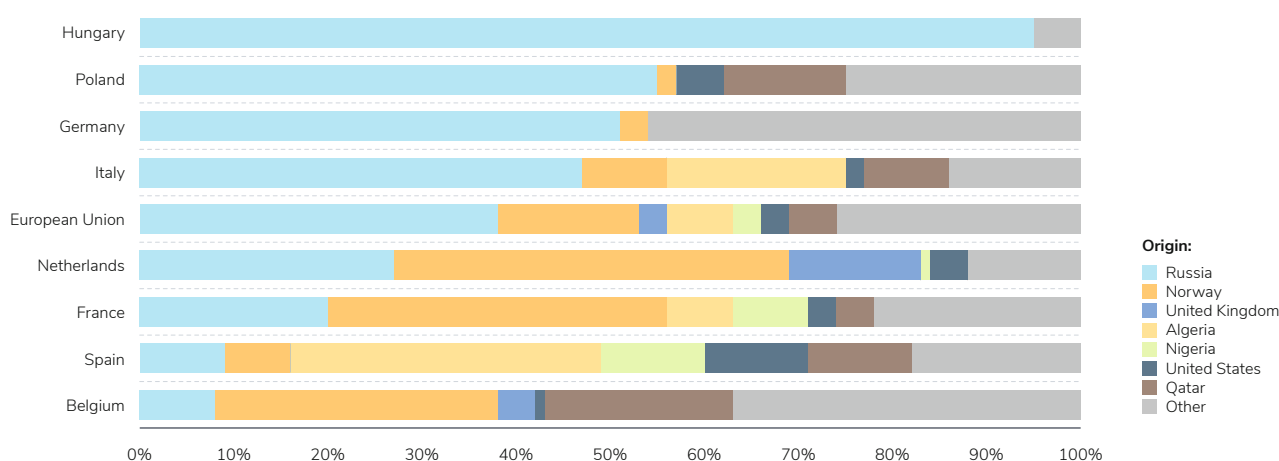
### 3.2 October 2021 – March 2022: From rising tension on gas markets to the fallout from Russia's invasion of Ukraine

The sharp economic rebound that occurred in the second half of 2021, as the health crisis was winding down, boosted demand for fossil fuels across the globe. This strained the balance between demand and available supply, and the resulting competition between European and Asian

countries for liquefied natural gas (LNG) drove up gas prices. Uncertainty around the flow of Russian gas also put upward pressure on prices, pushing them up from €15-20/MWh at the start of 2021 to around €80 to €100/MWh by the end of the year (at times with spikes as high as €150/MWh). These tensions on fuel markets impacted electricity prices, which averaged more than €450/MWh on 22 December while, at that same time, the discovery of defects due to stress corrosion cracking made it necessary to take certain nuclear reactors offline for testing (See Generation section).

Early in 2022, electricity prices on the spot market held below the December 2021 level thanks to falling gas prices (made possible by abundant LNG shipments), even as more nuclear capacity gradually became unavailable. In February, very robust wind power generation in France and Europe, together with unseasonably warm weather,

Figure 44: Origin of gas imports in 2019 (source: Eurostat)



54. Proposition d'évolution des tarifs réglementés de vente d'électricité au 1<sup>er</sup> février 2022 – CRE

55. For 2023, the rise in regulated tariffs is 15%, but should have been 107% according to the CRE analysis. La CRE calcule l'évolution théorique des tarifs réglementés de vente d'électricité au 1<sup>er</sup> février 2023 avant application du bouclier tarifaire – CRE

56. Allowing alternative suppliers to buy electricity from EDF at below the market price in 2022 and 2023.

57. An "electricity shock absorber" scheme also went into effect on 1<sup>st</sup> January 2023.

allowed France to rely less on thermal generation and to import less electricity, thus reducing the dependence of French prices on the cost of operating thermal power plants outside its borders. February was the only month during which France had a large net export balance.

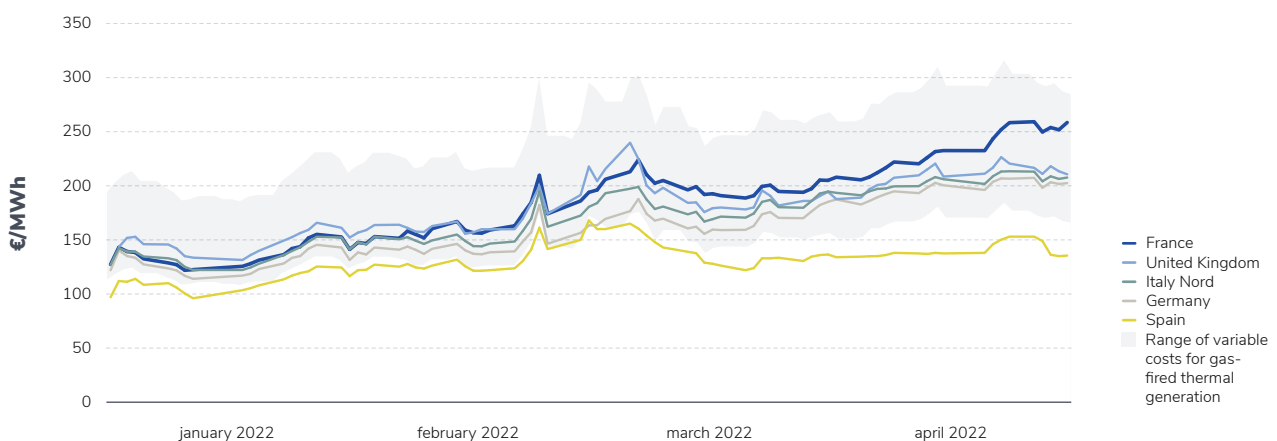
Russia's invasion of Ukraine on Thursday 24 February marked a turning point in the energy crisis. Insofar as Russia was a main supplier of European gas (38% in 2019<sup>58</sup>), coal (41% in 2019<sup>59</sup>) and oil (23% in 2019<sup>60</sup>), market actors became even more concerned about potential supply disruptions. These concerns pushed prices up to levels rarely seen until then (+31% for gas, +25% for coal on 24 February alone). Shortly after that, on Tuesday 8 March, spot prices spiked on power markets across Europe. In France, the average spot price for the day exceeded €540/MWh, well above the peak of December 2021.

### 3.3 April – June 2022: Slight lull after a period of tension

From March onward, the availability of the French nuclear fleet began to worsen considerably as tests conducted to check for stress corrosion cracking led to more reactors being taken offline, in addition to scheduled maintenance outages and other, unscheduled shutdowns (see Generation section).

Amidst this already challenging situation, on Monday 4 April, a late cold spell descended on France, putting significant strain on the supply-demand balance. On that day, the ability to import electricity from Germany and Belgium was limited both by constraints on Germany's internal grid and by the very strained situation in other Central European countries. The hourly spot price in France approached the €3,000/MWh ceiling at 8:00am and averaged more than €550/MWh for the day, exceeding the peak of March.

Figure 45: Trend in forward prices for 2023, baseload (source: EEX, calculations: RTE)



58. Source: Eurostat

59. Source: Eurostat

60. Source: Eurostat

This upward pressure on fuel prices, together with fears about security of power supply in the autumn and winter of 2022-23, also impacted forward prices for the 2022-23 winter and for 2023. Prices in France climbed above those in neighbouring countries, but remained within the range of variable production costs for gas-fired thermal power plants.

After spiking early in April, electricity prices on the spot market declined through mid-June, but remained high relative to the pre-energy crisis period (around €200/MWh on average). This reflected a relative easing of tension on gas markets over the period. Despite continued uncertainty about the flow of Russian gas (demand for payment in roubles, stoppage of shipments to certain European countries), deliveries remained

substantial. At the same time, the availability of LNG in Europe increased thanks to attractive prices.

Other factors that helped bring down prices were a reduction in electricity consumption due to warmer weather and more abundant renewable generation, with particularly robust wind power production in April and high solar generation in May and June. This made it possible to rely less on thermal power plants than in previous months, though thermal output remained substantial during the period owing to the subsequent decline in the availability of the nuclear fleet, and allowed France to import less electricity. May was one of two months during the year when France was a net exporter, though the balance was lower than in February.



## A CLOSER LOOK

### The price capping mechanism for the spot market

Per market rules, the price spike observed on 4 April led to an automatic increase in the electricity price cap for the spot market from €3,000/MWh to €4,000/MWh. Until recently, the price cap on the day-ahead market could rise by €1,000/MWh when prices hit 60% of the current cap. Thus, the ceiling should have been increased to €5,000/MWh before end-September 2022. Yet, during an extraordinary meeting of the Transport, Telecommunications and Energy Council called to address energy-related challenges on 9 September

2022, most European Union Member States opposed such an increase, fearing a power price boom. The NEMO (Nominated Electricity Market Operators) committee confirmed in September that the cap would be frozen at its then-level of €4,000/MWh; in January 2023, the European Commission proposed revising the mechanism to make it more gradual. Today, if the spot price reaches 70% of the cap in effect (€4,000/MWh) for at least two hours over two days within a rolling 30-day period, then the cap is lifted by €500/MWh within 28 days<sup>61</sup>.

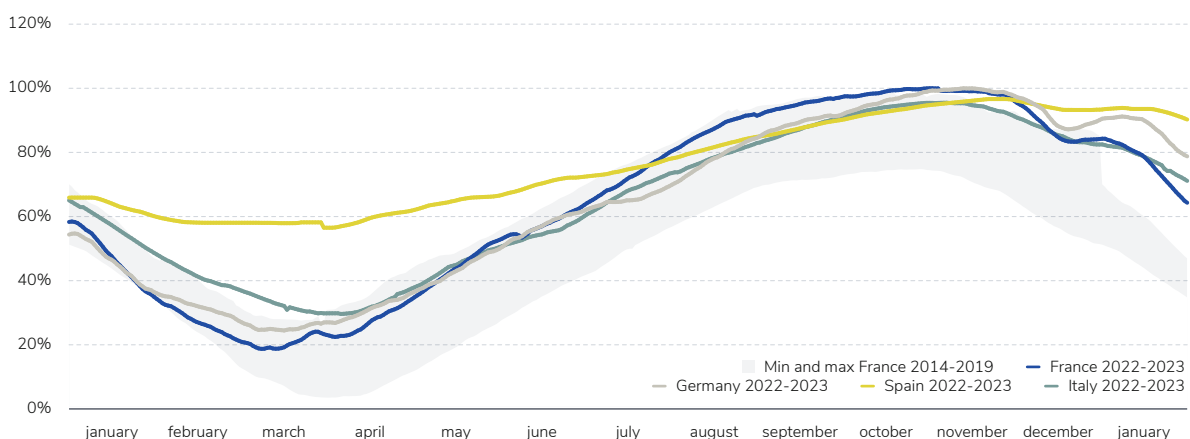
61. <https://acer.europa.eu/news-and-events/news/acer-approves-new-automatic-maximum-price-limit-adjustment-mechanism-european-electricity-spot-markets#reciteme-launch>

### 3.4 July – August 2022: Power system under real strain

Between mid-June and end-August, electricity prices trended higher, culminating by end-August at levels well above those seen late in 2021 or in the spring of 2022. This increase was driven by a combination of factors:

- Gas prices in Europe rose sharply as flows from Russia were drastically cut (flows on Nord Stream 1 reduced or stopped) and one of the main gas liquefaction plants in the United States was partially shut down because of a fire. Much emphasis was placed during this period on boosting gas inventories. The European Union adopted a regulation late in June requiring that Member States meet a minimum gas storage level before the start of the winter<sup>62</sup> (80% for the winter of 2022/2023 and 90% for the following winters). The quest to meet filling targets drove up demand and this was in turn also reflected in prices. The spot price for gas averaged €150/MWh<sub>PCS</sub> in August of 2022.
- The availability of the French nuclear fleet continued to worsen and reached an all-time low in August.
- Water reserve levels for hydropower generation were very low in France and in Europe in general (see Generation section).
- Coal prices also rose to record highs during the summer. To ensure security of electricity supply in the winter of 2022/2023, European governments began taking measures in the summer to allow increased use of coal-fired plants (reopening of the Saint-Avold plant in France, reactivation of mothballed plants in Germany). At the same time, EU countries approved an embargo on imports of Russian coal early in April, and it came into force in August, putting additional strain on the market.
- Consumption rose during the summer in Europe as heat waves drove up demand for air conditioning. The summer of 2022 was the hottest on record in at least a century in Spain, Italy, Germany and the United Kingdom. In France, it was the hottest summer since 2003<sup>63</sup>.

**Figure 46: Trend in gas storage filling rates per country in 2022 and through 31<sup>st</sup> January 2023**  
(source: GIE AGSI)



<sup>62</sup>. Note that in France, legislation already required that storage be at least 85% filled by 1<sup>st</sup> November.

<sup>63</sup>. 2022, année la plus chaude en France | Météo-France (meteofrance.com)

All of this put considerable strain on the power system during the summer, and spot prices often climbed above the theoretical production costs of gas-fired plants in France. One reason was that France imported from neighbouring countries with gas plants that are older and less efficient. The other reason relates to the optimisation of reserves for electricity generation. Indeed, the plants with reserves that could be tapped for production (hydroelectric dams, nuclear power plants, oil combustion turbines) could choose to save those reserves for periods when supply might be tighter, and when electricity prices would be higher. The prices these actors can ask on the market in the summer months thus depends on the prices they anticipate for the following winter. As mentioned above, in the summer of 2022, it appeared that winter prices would be very high.

The average daily spot price in France thus reached record highs starting on 24 August, climbing above €700/MWh on the 26<sup>th</sup>, 29<sup>th</sup> and 30<sup>th</sup> of August. On average, the spot price was close to €400/MWh in July and €500/MWh in August.

These tensions also affected electricity prices on the forward market, which reached unprecedented highs and were consistently higher in France than in neighbouring countries (see “Overview”).

### 3.5 Sept. – Oct. 2022: Prices drop sharply in a more favourable environment

After a period of unprecedented tension, spot prices on the electricity market dropped sharply in September and October. The average monthly spot price in France plunged from almost €500/MWh in August to under €200/MWh in October, the lowest level observed since October 2021. This notably reflected the downward trend in average gas prices which, by October 2022, had fallen to about €50/MWh<sub>PCS</sub>, comparable to the October 2021 price. Several favourable factors contributed to this reduction in tension on the gas market and power system:

- The gas storage filling rate targets set by the European Union were met well before the 1<sup>st</sup> November deadline, which eased pressure on demand<sup>64</sup>. The decision to keep Germany's last three nuclear reactors in operation through April 2023, to guarantee security of energy supply and save gas, also contributed.
- At the same time, significant LNG deliveries continued. Europe was the main destination of LNG carriers between the end of summer and beginning of autumn<sup>65</sup> thanks to a reduction in LNG imports by Asia, where countries began to rely more on coal as gas prices rose. Against this backdrop, the stoppage of gas flows through Nord Stream 1 for an indefinite period had very little impact on markets.
- Moreover, air temperatures remained unseasonably warm in October and through mid-November, and the resulting reduction in gas and electricity consumption eased the strain on the power system.
- Renewable generation was robust in France during this period. Solar power output was particularly abundant, and wind power generation reached the highest level ever for that time of year.
- Water reserves improved starting in the autumn thanks to increased rainfall and the careful management of reserves during the summer.

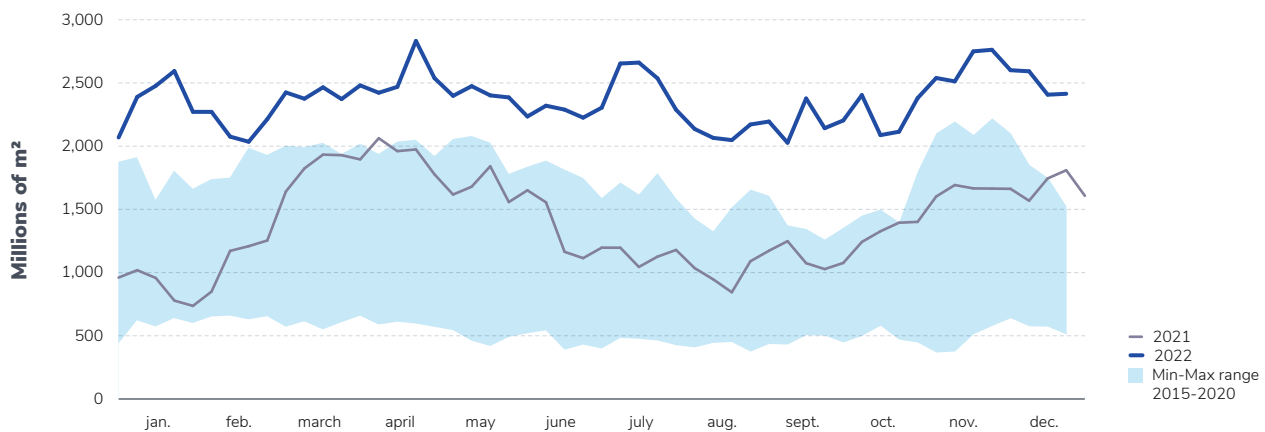
Conversely, forward prices on the electricity market for late 2022 and first quarter of 2023 remained, during this period, above levels that could be explained by economic fundamentals, despite the drop in fuel prices (including on forward markets). Market actors thus appear to have maintained, and even incremented, the risk premiums considered in prior months, even as security of supply assessments were updated to reflect the decreasing likelihood of a particularly unfavourable scenario during the winter.

To limit the effects of high electricity prices on consumers and public finances (for the financing of

64. AGSI (<https://agsi.gie.eu/>) and CRE (<https://www.cre.fr/Actualites/les-stockages-francais-de-gaz-sont-pleins-en-preparation-de-l-hiver>)

65. LNG imports rose by 102% in France and by 84% in Europe (including the United Kingdom) between 2021 and 2022 (source: GRTgaz)

Figure 47: LNG imports by EU Member States (source: Bruegel)



protective measures), emergency measures were adopted early in October by the European Union<sup>66</sup> and the different countries, on the one hand to keep electricity consumption in check, and on the other to cap the revenues of certain electricity producers and redistribute surplus revenues to electricity consumers.

### 3.6 Nov. – Dec. 2022: Gradual return to market fundamentals

Starting mid-October, spot prices in France returned to levels consistent with the variable production costs of thermal power plants in France, which thus often set prices. Prices broke through the high end of this range occasionally when marginal plants (the last plants dispatched, which determine prices) were thermal power plants abroad (if France was importing), or when production in France tapped into reserves that could be useful for the winter (water reserves, nuclear fuel, oil, even gas).

Between November and December, daily spot prices on electricity markets moved in line with gas prices, weather conditions and the pace of nuclear

reactors in France returning to service after being shut down for maintenance.

- Colder weather drove up consumption, though it remained structurally below the levels habitually seen at that time of year (see Consumption section). A cold wave hit Europe between late November and mid-December<sup>67</sup>, with temperatures dropping as low as 6°C below normal in France.
- Gas prices started trending higher again early in November on the back of increased demand for heating and electricity generation.
- The availability of the French nuclear fleet gradually improved, especially from early December, though it remained below the historical average. Average monthly availability rose from 28.5 GW in October to 31.6 GW in November then 39.3 GW in December.
- Wind power output was relatively low during the late November/early December cold spell, but surged in the last two weeks of December.

As a result, spot prices on electricity markets began to trend higher again mid-November and

66. Règlement (UE) 2022/1854 du conseil du 6 octobre 2022 sur une intervention d'urgence pour faire face aux prix élevés de l'énergie

67. A demand peak was recorded (81.8 GW) on Monday 12 December at 7:00pm. However, that was not the highest level observed during the year: the annual peak occurred in January (see Consumption section). On that day, imports to France were significant, and mutual assistance agreements between transmission system operators were activated.

spiked mid-December, during the cold spell, all while remaining below the levels seen in August. Starting mid-December, consumption began to drop as temperatures returned well above seasonal averages and schools closed for the year-end holidays, and wind power generation was robust. All of this pushed electricity prices back down to very low levels, with periods of zero and even negative prices for some time steps. In the last two weeks of the year, spot prices were regularly below the range of variation of production costs for thermal power plants, which were used very little during the period. Similar conditions put downward pressure on prices across most European countries.

Forward prices plummeted starting in November, before bouncing back to levels consistent with market fundamentals. The decline was first seen in forward prices for deliveries at the end of the year (in November, the forward price for delivery in December was halved relative to the August level), then extended to forward prices for deliveries in the first quarter of 2023. Prices in France for deliveries in the first quarter of 2023 decreased by a factor of 7 between end-August and end-December. While the decline in forward prices was linked in part to gas prices dropping from the levels seen in the summer, it was mostly the result of the near elimination of the risk premium associated

with the over-hedging behaviours of market actors and their low degree of confidence in forecasts for when nuclear reactors would be brought back online.

The bottom line is that risk perception evolved during the autumn and early winter, as the availability of the nuclear fleet increased and the structural decline in power consumption seen in previous years was confirmed, making the “worst-case scenarios” market actors had considered early in the autumn much more improbable. The prices observed on forward markets starting late in December thus appear more consistent with the fundamentals, and are now in line with neighbouring countries, though they remain high.

Even after coming down late in 2022, prices remained high enough to continue to put a real strain on public finances and the economy in general. EU countries agreed to a cap on wholesale gas prices in December. Today, the focus is on a more structural reform of the power market, one that would allow for costs to be better aligned with the prices paid by power consumers while ensuring that the short-term market remains efficient and that incentives exist to invest in the new generation capacity that will make decarbonisation possible.



## EXPLAINER

## Why can electricity prices be dependent on gas prices?

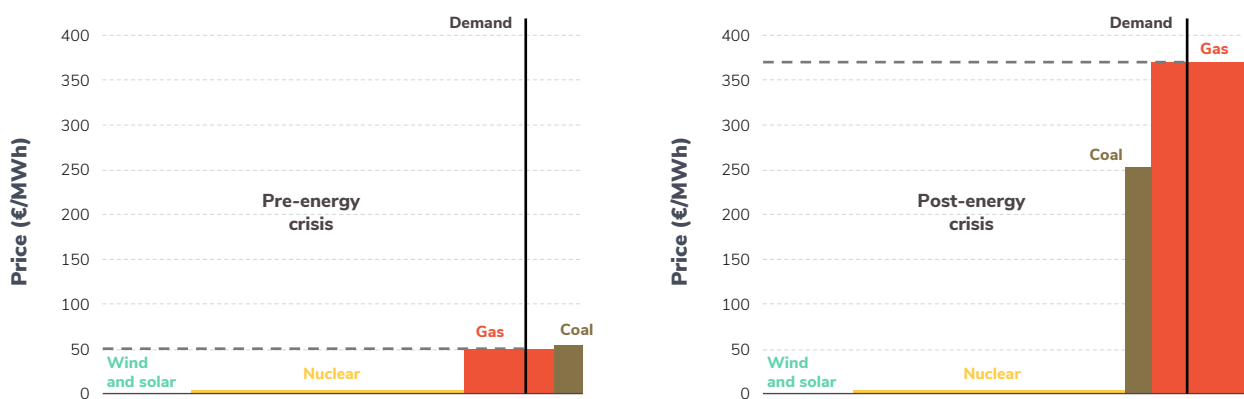
The European power market operates according to the following principle: the electricity price matches the variable production costs of the last plant dispatched to meet power demand<sup>68</sup>. In other words, every hour, the market organises itself as if capacity was “stacked” based on the merit order and dispatched until supply was sufficient to meet demand. The plant at the top of this “stack” (referred to as the “marginal plant”) therefore determines the price of electricity for that hour. This ensures an economically optimal allocation of generation.

At the European scale, since it is usually necessary to dispatch thermal power plants to balance supply and demand, the hourly spot price is generally determined based on the variable production costs

of the corresponding plants. As a result, power prices are correlated to those of fossil fuels such as gas and coal, as well as that of carbon emissions allowances. Therefore, even though fossil-fired thermal generation accounts for a small share of production in France, it still plays a decisive role in the formation of electricity prices there:

- On the one hand, in the current context, gas-fired power plants are typically needed to balance supply and demand, especially when availability of nuclear and hydropower capacity is low;
- On the other hand, because France is interconnected with the rest of the European grid, French prices are also shaped by thermal power generated in other countries and traded on the market.

Figure 48: Illustrative example of the merit order and electricity price formation, before and after the crisis



68. Strictly speaking, this is an approximation since it assumes that there is free competition in the market, that consumption will be paid for at any price, and that plants do not factor technical constraints into their prices, notably start-up costs.



## EXPLAINER

## What the term “electricity price” can refer to (spot, forward...)

In practice, the term “electricity price” encompasses a variety of notions. It is notably essential to distinguish between “wholesale electricity prices” on markets on the one hand, and “retail prices” charged to consumers on the other.

Even the notion of “wholesale prices” is multiple. It may refer either to the spot price, which is the price charged for a megawatt-hour of electricity for a given hour, deliverable the next day (set according to the merit order principle illustrated above), or the forward price, meaning the price for delivery on a more distant time horizon and for a period ranging between a week and a year.

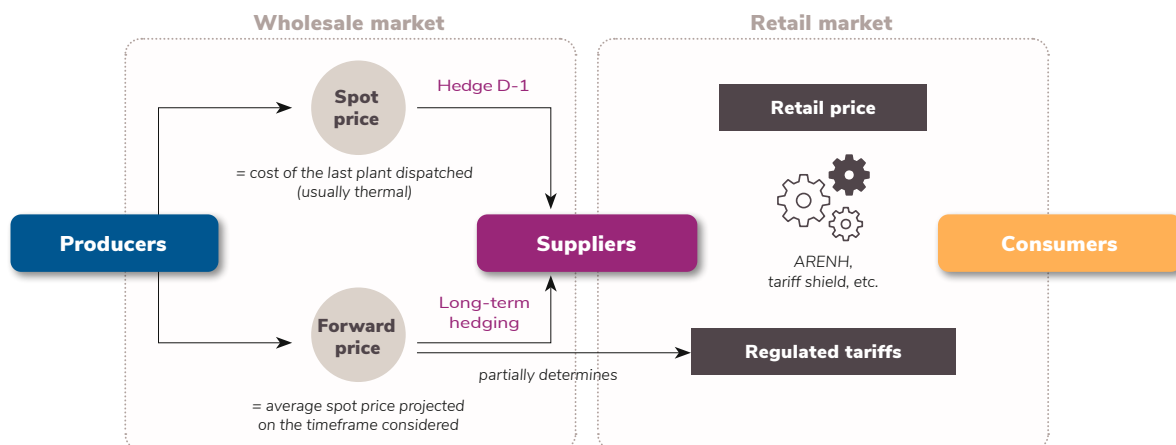
Forward markets allow actors to hedge the “price risk” on the spot market. They notably provide an opportunity for producers to set their margins and for suppliers to set a price for their customers without being exposed to the hourly volatility of the spot market. Suppliers and large consumers thus secure a considerable portion of their consumption on forward markets, several months or even several years ahead of time, and only secure

the residual share on the spot market for next-day delivery.

In principle, the “forward price” reflects the average spot price market actors are anticipating over the entire delivery period considered. Forward prices have a direct impact on the price consumers pay for power, since they (i) are factored into the construction of regulated tariffs, and (ii) are used for hedging purposes by customers that no longer have access to these regulated tariffs, such as industrial users. The “retail price” that appears on a consumer’s electric bill reflects more than the forward price: in addition to power procurement costs, it also includes “off-market” regulation mechanisms such as ARENH as well as power grid costs and taxes.

On physical short-term markets (the spot market, with next-day delivery, but also intraday markets), weather conditions play a significant role. On forward markets, involving deliveries farther in the future, prices are very dependent on projected trends in gas prices and the supply-demand balance over the medium term.

Figure 49: Operations of wholesale and retail power markets



## 4. Electricity exchanges

### 4.1 Introduction: the power system, a European subject

Today, the power systems of European countries are broadly interconnected. Most of continental Europe is part of the “Synchronous Grid of Continental Europe”, which operates at all times at the same frequency of 50 Hz. In March 2022, the synchronous grid was extended in an emergency to those of Ukraine and Moldova to support the stability of the power grids in those regions, by accelerating procedures which were already under way.

**Increasing interconnection between regions has long been a priority of the European Union's energy policy.** First mentioned in 1955<sup>69</sup>, it is considered a way to reduce the cost of electricity. Indeed, interconnecting national power grids is a prerequisite to creating the European electricity market. Interconnections make it possible to take advantage of the complementarity of the energy mixes of different countries, in such a way as to benefit the European community in three ways: it strengthens security of electricity supply and the operational safety of interconnected systems; it reduces production costs at the scale of the continent by bolstering competition; and it allows for the integration of more low-carbon energy.

By trading electricity, European countries pool resources to guarantee the security of supply and ensure that, at all times, power demand in Europe is met with the least costly (and least carbon-emitting) capacity available. Such pooling of capacity is particularly beneficial in that it capitalises on differences between consumption profiles in different countries. For instance, demand does not peak at the same time of day, or in the same season, in all countries (peaks occur on summer afternoons in Italy, on winter evenings in France, and on winter mornings in Scandinavian countries). To a lesser degree, pooling of capacity makes it possible to

take advantage of the geographic spread of variable renewable generation.

**The European electricity market helps minimise the cost of power system operation at the European scale.** However, the very high price levels seen in 2022 (see *Prices* section), which put a real strain on consumers, public finances, and the economy in general, gave rise to a debate in Europe about this very subject, and the current thinking is that structural reforms are in order. The goal would be to better align costs with the prices paid by electricity consumers, while ensuring that the market remains efficient in the short term and that incentives exist to encourage investments in the new electricity generation capacity that will be required for decarbonisation.

The strengthening of interconnection capacity also furthers the European Union's political project. EU Regulation 2018/1999 of 11 December 2018 on the governance of the Energy Union and Climate Action requires that the energy-climate plans of each Member State prioritise investments in interconnections so that the capacity of cross-border electricity connections reaches at least 15% of domestic generation capacity by 2030, subject to cost-benefit analyses being positive for each investment and to certain other conditions, notably related to environmental integration. As regards the regulation of trans-European energy grids, the European Union introduced the concept of projects of common interest. The interconnection projects that earn this label become eligible, if they meet additional conditions, for EU financial support through the Connecting Europe Facility.

**Today the operation of the power system at the European scale is a reality, and it proved essential when the system was under strain during the autumn and winter of 2022/2023.** For the past ten years, the strengthening of interconnections

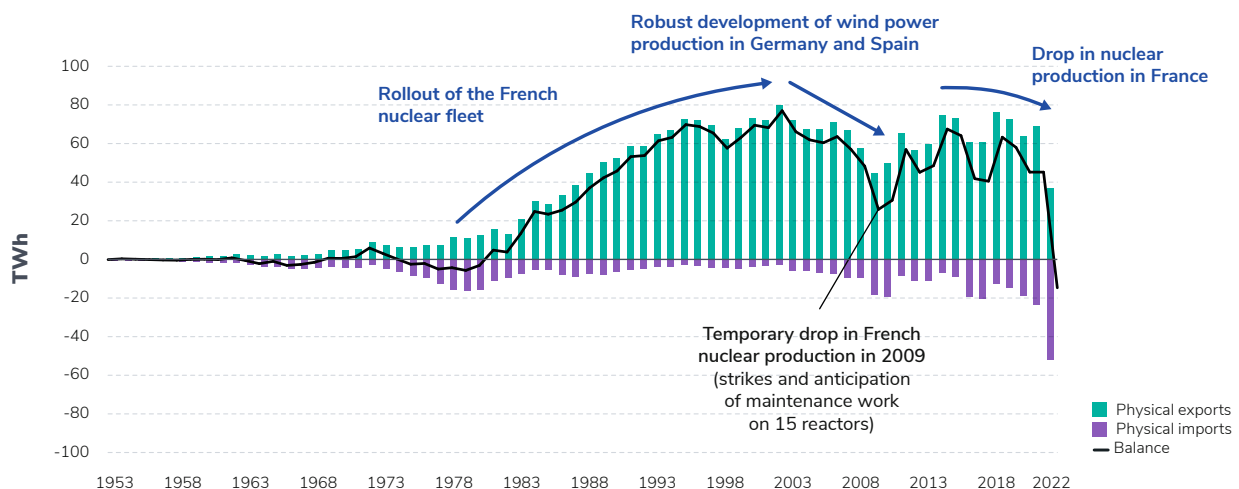
<sup>69</sup>. The Messina Resolution (1955) mentions that “all measures should be taken to develop the exchange of gas and electric current in order to raise the profitability of investments and reduce the cost of supplies.”

between countries, and the development of variable renewable energy sources, have led to a sharp increase in cross-border trading.

Located at the intersection of several “electric peninsulas” (Iberia, Italy, Great Britain) and boasting a high level of installed generation capacity, France participates fully in European power exchanges. Because domestic consumption is temperature-sensitive and its generation fleet has no margin relative to the national security of supply criterion, France becomes a net importer when supply is tight. That being said, since power generated

in France (nuclear, hydropower and other renewables) is more competitive than in neighbouring countries, France becomes a net exporter again once tension eases. France's interconnection with other European countries thus allows it to guarantee security of supply domestically and also to find end-markets for its low-carbon production, thereby helping to decarbonise the European mix. **In past years, France has mostly been a net exporter to neighbouring countries, but significant supply tension throughout 2022 (see Generation section) caused the situation to reverse, with France ending the year as a net importer.**

Figure 50: Electricity trading between France and its neighbours, 1953-2022



## 4.2 In 2022, France was a net importer of electricity for the first time in 40 years

During the past year, French generation capacity was under considerable strain (see Generation section), making it necessary to rely heavily on imports, which affected France's traditional position as a net exporter. **Over 2022 as a whole, France imported more electricity than it exported, something which had not happened since 1980, i.e. before the large-scale development of its nuclear fleet.**

Low availability of nuclear capacity was the main cause of this reversal. **During certain periods, high renewable output temporarily offset the drop in nuclear generation, allowing France to momentarily become a net exporter** (examples include the month of February and the last two weeks of December), albeit in proportions that did not suffice to restore the yearly balance.

This reversal, historic for France, is in accordance with the normal operating principles of European electricity markets, even when prices rise across the board: in Western Europe, electricity generally flowed in the direction of countries where prices were highest due to tight supply. Interconnections notably helped France import significant quantities

of electricity to balance supply and demand, while continuing to export during periods when tension eased, notably when renewable output was robust or when consumption decreased. Intended to promote the economic optimisation of production capacity across Europe, interconnections also allowed the French power system to take advantage of cheaper electricity in other countries when it was available.

In the recent past, France has largely been a net exporter during the summer, but its positions in winter are more mixed. Given the high degree of temperature-sensitivity of consumption in France (see Consumption section), the supply-demand balance is tighter in winter, which limits the production margins available for exports, and may at times force the country to import large volumes of electricity. This is also the case when nuclear power generation is nominal. Conversely, during the summer months and when weather conditions are normal, France tends to continuously export large quantities of electricity, this being when its annual net export balance is "constructed". **In 2022, it was mostly during the summer that the exchange balance deepened.** During the winter months (early and late 2022), efforts to maximise the availability of the nuclear

Figure 51: Electricity trade balance between France and its neighbours in 2022, by month

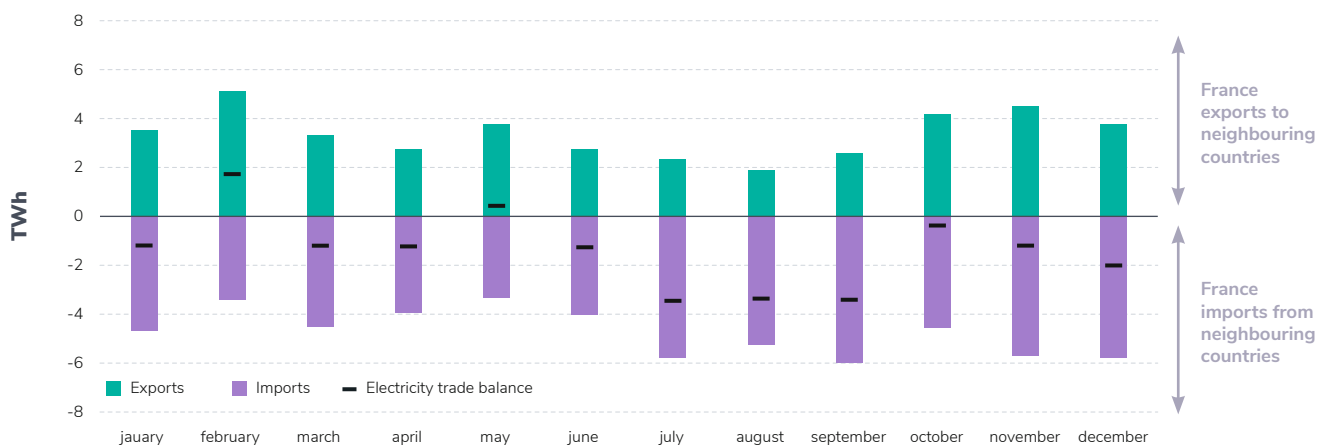
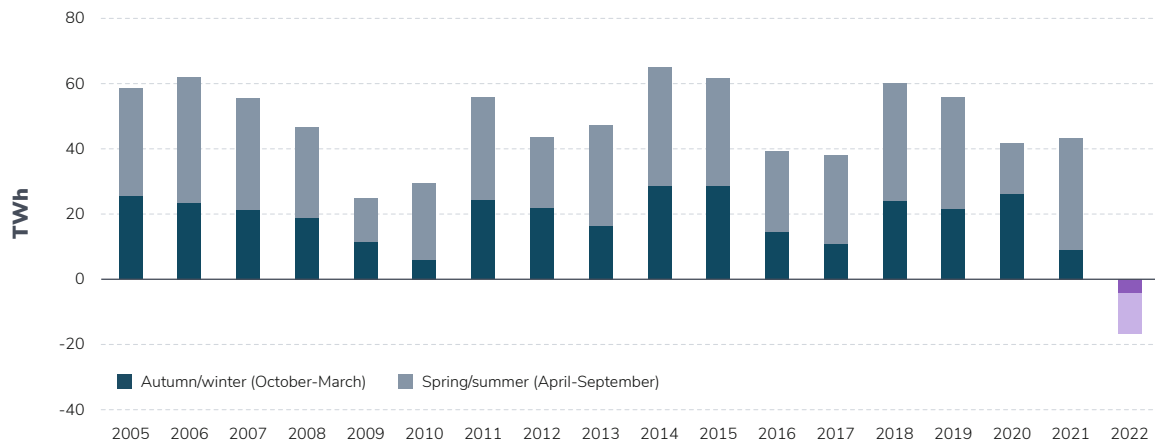


Figure 52: Electricity trade balance between France and its neighbours, by season



fleet limited the departure from the balances of previous winters, during which France already often had to import electricity<sup>70</sup>.

France's net import balance in 2022 was 16.7 TWh, or just under 4% of total consumption<sup>71</sup>. **The months of July, August and September alone accounted for 60% of this negative balance, or 10 TWh.**

An analysis that looks at net volumes on an annual or even a monthly basis masks one essential reality of how the French and European power systems operate: electricity exchanges, like many other power system metrics, varies widely across time (depending on the time of year, the week or even the day) and space (depending on the border considered). These variations are driven more by an objective of minimising production costs at the

scale of the interconnected European system (the direction of flows depends on price gaps) than by security of supply, though the two are linked.

**The number of time steps during which France relied on imports from neighbouring countries to meet domestic demand rose considerably in 2022.** It is nonetheless important to note that the periods during which France imports electricity may include situations where those imports are essential to security of supply (i.e. when there is no margin left to ramp up generation or demand response in France) but also ones where power is imported to meet demand without firing up additional and very costly capacity domestically. **France relied on imports strictly to ensure security of supply less than 10% of the time in 2022, even though it was a net importer almost 70% of the time.**

<sup>70</sup>. It should be noted, however, that the present analysis covers the calendar year. The early part of the 2021/2022 winter is considered in the data for 2021 while the latter part of the 2022/2023 winter is not included.

<sup>71</sup>. For comparison purposes, this is close to the average annual output of the Belleville nuclear power plant (2 x 1,310 MW, P'4 series)

### 4.3 Electricity trade balances varied widely from one border to the next

In addition to variations observed over the course of the year, France's electricity trade balances also varied from one border to the next. Three types of borders can be identified:

- Those where France is a major importer: Germany and Belgium<sup>72</sup>;
- Those where France is a major exporter: Italy and Switzerland;
- Those where trading is more balanced or mixed: Spain and Great Britain.

An analysis of the breakdown by border can also reveal the progress made with electricity mix decarbonisation in recent years: production in some neighbouring countries is increasingly competitive, increasingly often. This is notably the case of systems that include a growing percentage of renewable energy sources, such as Spain and Great Britain.

#### France – Spain

On its border with Spain, France is usually a major net exporter in the spring and summer. During the winter, trading tends to be more balanced and varies with weather conditions. Spain notably has substantial wind capacity, with nearly 30 GW installed, which allows it to export its surplus production during periods of strong wind in winter. Additionally, power demand is high in Spain in the

summer, notably because of widespread use of air conditioning, contrary to France, where demand peaks in the winter.

In the first half of 2022, trading with Spain was balanced and varied widely with weather conditions, as it did in previous years. France showed a small net import position for the period, except in February, notably because of strong wind output in France during part of the month and decent nuclear plant availability.

Conversely, in the second half of the year, trading between France and Spain was determined chiefly by the capping of the price of gas used for power generation enacted by the Spanish and Portuguese governments<sup>73</sup> to limit the surge in electricity prices across Europe. Starting in June, thermal power generated in the Iberian Peninsula at lower cost became available, resulting in such a large spread between spot prices in France and Spain that the interconnections were heavily saturated in the direction of imports to France. During the last six months of the year, France only exported to Spain during a few days in October, amid particularly mild temperatures for the season.

France ended the year with a net import balance of 9.1 TWh, about 85% of which was accumulated in the second half, after Spain implemented its cap on the price of gas used for power production.

<sup>72</sup>. At this border, trading is organised at the scale of a group of countries called the Central Western Europe (CWE) region, which was renamed the Core region on 9 June 2022. This organisation means that it is not possible to isolate trading with individual neighbours in the CWE region (resp. Core), Belgium and Germany: exchanges are referred to as trades with the CWE region (resp. Core) without distinction.

<sup>73</sup>. This mechanism, which took effect mid-June 2022 in Spain and Portugal, involves capping the price of natural gas used to generate electricity. The difference between that price and the real gas price is covered by a public subsidy, and thus by the national budget. Insofar as the marginal plant in Spain is usually a gas-fired facility, in practice, this also limits electricity prices.

Figure 53: Electricity trade balance (top) between France and Spain and Average monthly gap between spot prices in France and Spain (bottom) in 2022, by month



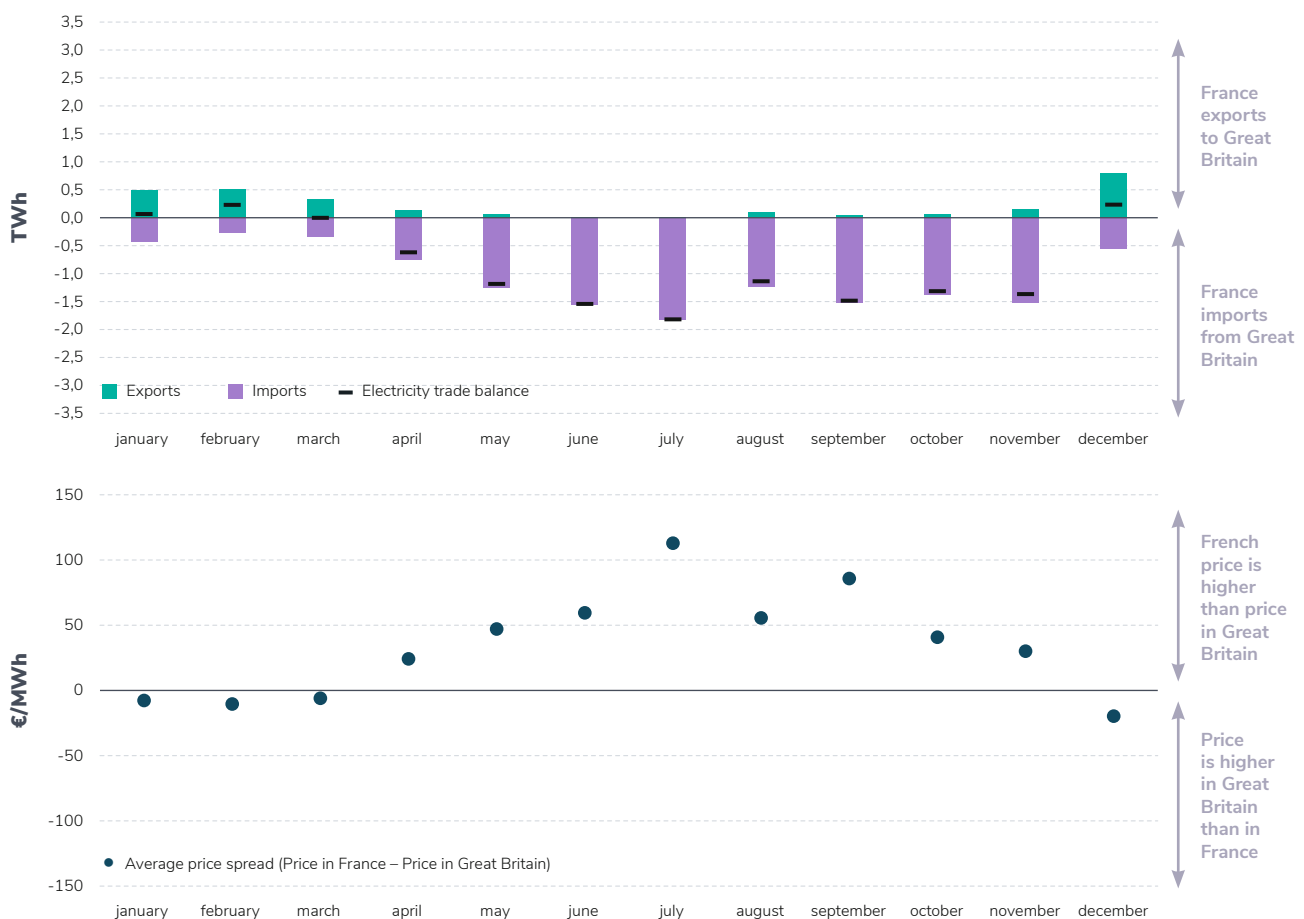
### France – Great Britain

France is usually a major exporter to Great Britain all year round. In 2022, however, it was a net importer.

Its yearly net import balance with Great Britain was around 10 TWh, nearly half of which was accumulated during the three months during which nuclear capacity availability was at its lowest (July, August, September).

In recent years, like in France, the British power system's margins have narrowed. Therefore, even though renewable generation can be quite high at times, periods of tight supply occur regularly in winter. In 2022, this was the case early and late in the year, when France exported to Great Britain.

**Figure 54: Electricity trade balance (top) between France and Great Britain and Average monthly gap between spot prices in France and Great Britain (bottom) in 2022, by month**



### France – CORE

France is usually a major net importer from the Central Western Europe/Core region<sup>74</sup> (represented by the borders with Belgium and Germany) in the winter, but a major net exporter in the summer. Over the past ten years, the annual electricity trade balance with the CWE region has fluctuated between +10 TWh and -10 TWh. Though trading with Germany does not account for 100% of exchanges with this region, the situation does help

illustrate contrasting trends in the two countries, reflecting different generation capacity structures, residential heating equipment, etc.

In 2022, because generation dropped in France during the summer, nearly all trading at the border involved imports. France was in fact a net importer for every month of the year, and for 51 out of 52 weeks. Its total net import balance for the year was 27 TWh, making this by far the

**Figure 55: Electricity trade balance (top) between France and Central Western Europe/CORE region countries (top) in 2022, by month, and Average monthly gap between spot prices in France and Germany and France and Belgium (bottom) in 2022, by month**



<sup>74</sup> The Central Western Europe region corresponds to the region for which the capacity calculation includes France, Germany, Belgium and the Netherlands. It has been operational since 2015. On 9 June 2022, this region was renamed the CORE region and expanded to include Austria, Slovenia, Poland, the Czech Republic, Slovakia, Croatia, Hungary and Romania.

most important border in absolute terms based on exchange volumes.

The main effect of expanding the Central Western Europe capacity calculation region to include the CORE countries, all other things being equal<sup>75</sup>, is that it allows a better optimisation of trading capacity

between France and the region. Consequently, instantaneous electricity imports climbed to new records at this border in 2022, with a peak of almost 10 GW recorded early in December, when supply pressure was at its most intense in France. In other words, the CORE region made a very significant contribution to France's security of supply.

<sup>75</sup>. Grid outages, production schedules, etc.

### France – Italy

The Italian border is the only one at which France exports almost continually, and this has been the case since the 1980s. Indeed, Italy has been heavily reliant on imports to meet electricity demand for decades, and imports routinely account for more than 10% of the country's demand. Moreover, thermal power plants make up a large share of Italy's generation capacity (65.1% in 2021<sup>76</sup>), particularly gas-fired plants, which is why production costs are often higher than in France. This remains true

when France is firing up its own thermal power plants, since the French plants are newer and more efficient.

Given these structural factors, the Franco-Italian border was the only one where the situation changed little in 2022: France exported about 18 TWh of electricity to Italy. It is nonetheless interesting to note that France did import from Italy for a few days during the severe cold spell early of early December<sup>77</sup>.

**Figure 56: Electricity trade balance (top) between France and Italy in 2022, by month, and Average monthly gap between spot prices in France and Italy (bottom) in 2022, by month**



<sup>76</sup> Terna, "Dati statistici sull'energia elettrica in Italia 2021".

<sup>77</sup> Which confirms the benefits of trading when it comes to security of supply at the European level, and would be an interesting example to use in a study of "dependence" (see below).

### France – Switzerland

Exchanges with Switzerland are more complex. First, transmission capacity is asymmetrical: about 3 GW for exports from France to Switzerland versus around 1 GW in the opposite direction. This means that, broadly speaking, if market conditions were such that it would make sense to export to Switzerland half the time and to import the rest of the time, import and export volumes would not match at the end of the year. Then, Switzerland often acts as a “transit country”, meaning that when it imports from France, it is usually exporting to Italy at the same time, since it typically generates

enough power to meet its own needs. For these two reasons, interpreting trade balances based on economic considerations or the need to balance supply and demand is less straightforward at this border than at others.

In terms of net total, France is usually a net exporter to Switzerland, though the balance has been tending to shrink since the mid-2010s. From this standpoint, 2022 was not very different: France was a net exporter, with a net export balance of 12 TWh (since 2015, the yearly net export balances have ranged between 10 and 16 TWh).

**Figure 57: Electricity trade balance (top) between France and Switzerland in 2022, by month, and Average monthly gaps between spot prices in France and Switzerland (bottom) in 2022, by month**



#### 4.4 France's energy supply remains much more dependent on imports of fossil fuels than on imports of electricity

Power trading between European countries allows generation resources to be pooled and the operations of the power system to be optimised by generating electricity from the least carbon-emitting, least costly source.

Such pooling of capacity makes it possible to capitalise not only on differences between consumption profiles in different countries but also, to a certain degree, the geographic spread of variable renewable generation, thus driving down electricity production costs at the European level. It also helps prevent the addition of excess capacity while bolstering security of supply for national power systems.

France was a net importer in 2022 because of an atypical situation, characterised by periods of tight supply notably in summer, when generation capacity was subject to the most constraints.

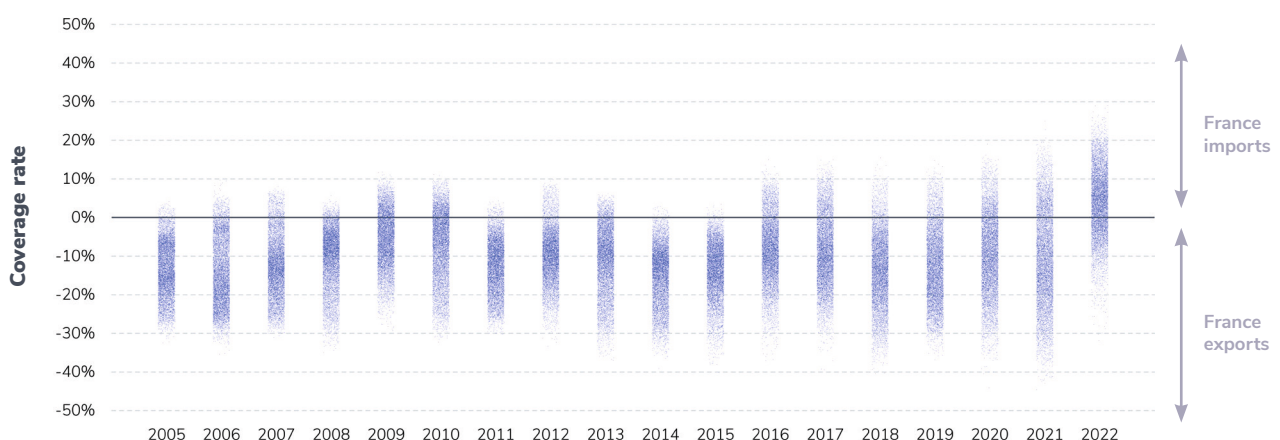
The periods during which France was a net importer of electricity (21% of the time in 2021

and around 70% of the time in 2022) included situations where imports were needed to guarantee security of supply, and situations where imports made it possible to meet demand without dispatching additional and very costly generation capacity in France. In the end, **France relied on imports strictly to guarantee security of supply less than 10% of the time in 2022, even though it was a net importer nearly 70% of the time.**

Every year, France is a net importer over a non-negligible number of time steps, with the number varying from one year to the next (depending on weather conditions in France and neighbouring countries, availability of the nuclear fleet and hydropower output, etc.).

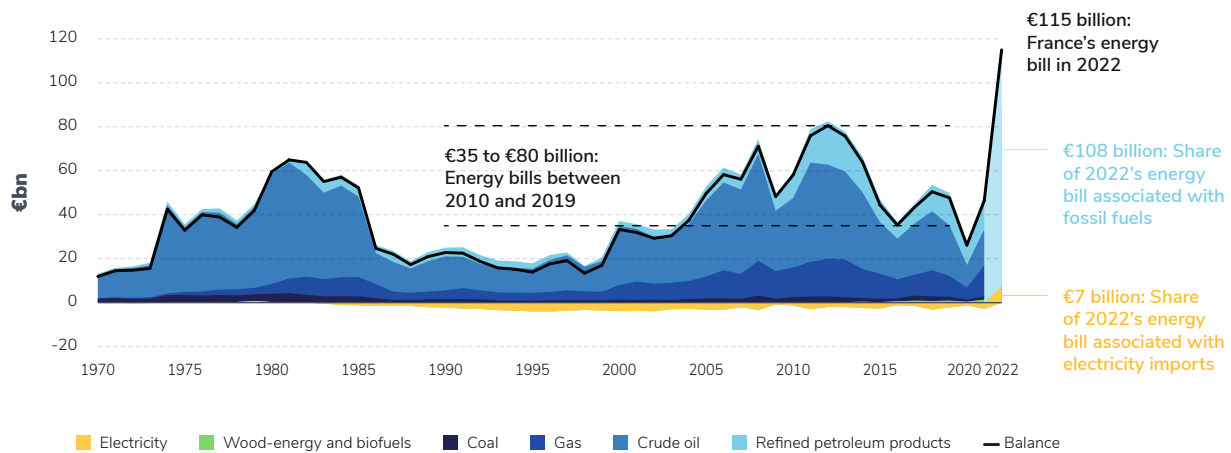
Lastly, in terms of energy, it is essential to remember that as of today, supply in France<sup>78</sup> is more than 60% dependent on fossil fuels, mostly imported from the Middle East, North Africa, Russia (despite the drop in flows in 2022) and a few European countries (Norway, the Netherlands). Moreover, from an economic standpoint, fossil fuel imports have a much bigger impact on France's energy bill

**Figure 58: Distribution of the rate of coverage of gross consumption in France with imports during a year, for several recent years (one point = one hour out of the year)**



<sup>78</sup>. In final energy terms. (source: Ministry of Ecological Transition, Data and Statistical Studies Department).

Figure 59: France's annual energy bill between 1970 and 2021 (data from SDES Energy Reports) and in 2022 (data from French Customs and RTE), constant 2022 euros



than electricity exports did in past years, and their weighting will remain an order of magnitude higher than that of electricity imports in 2022. Indeed, the French Treasury Department estimates that the national energy bill may have reached €48 billion in the first half of 2022 and could be as high as

€115 billion for the full year<sup>79</sup>. This is due in large part to the increase in fuel prices. An initial analysis by RTE suggests that the increase in electricity imports will have an effect of around €7 billion on France's energy bill (compared with just under €3 billion of profits in 2021).

<sup>79</sup>. La facture énergétique française dépassera les 100 milliards d'euros en 2022 – EURACTIV.fr

## 5. Emissions

### 5.1 Introduction

France's electricity mix, largely dominated by nuclear and renewables, is among the least carbon emitting in Europe. As such, though per capita power consumption is relatively high compared with neighbouring countries<sup>80</sup>, emissions from electricity generation only represent about 5% of France's territorial emissions<sup>81</sup> compared with 19% for the European Union<sup>82</sup>. Moreover, because it usually a net exporter, France's neighbours also benefit from the low-carbon electricity generated within its borders.

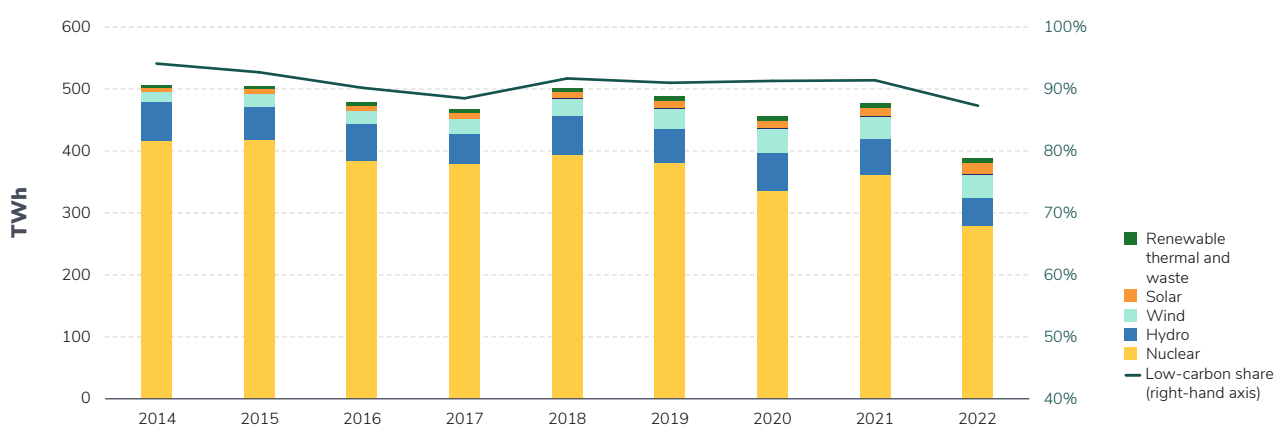
In 2022, the reduced availability of domestic generation capacity caused France to go from being a net exporter to a net importer, which had an impact on greenhouse gas emissions of the power system. This impact can be analysed within different frameworks:

1. In terms of domestic generation: direct emissions from electricity production in France.
2. In terms of French power consumption: emissions linked to electricity produced and consumed in France (i.e., not counting exports), plus emissions linked to electricity imported to meet demand in France.
3. In terms of emissions avoided by neighbouring countries thanks to exports from France: France's very low-carbon mix means that exports to neighbouring countries allow those countries to avoid dispatching more carbon-intensive generation capacity.

### 5.2 Emissions from electricity generation increased in 2022 but remain below the levels seen in 2016 and 2017

In terms of domestic generation (framework 1. above), the constraints affecting nuclear and hydropower production led to a drop in the volume of low-carbon production, which was only partially offset by the rise in solar and wind power

Figure 60: Production of low-carbon electricity in France



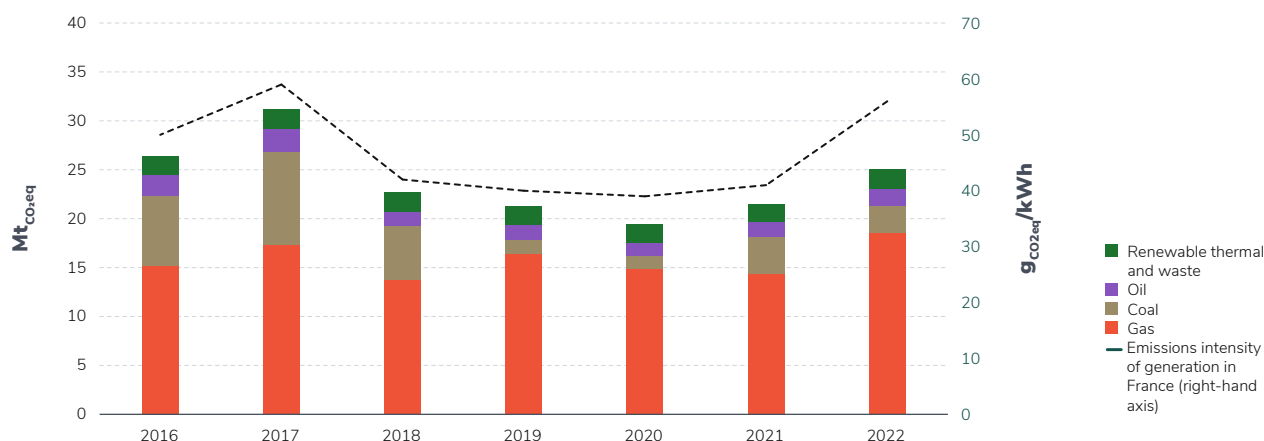
Electricity generated from waste is considered 50% renewable; 70% of consumption for pumping at pumped storage stations is deducted from hydropower generation in accordance with EU Directive 2009/28/EC

80. Notably because of the widespread use of electric heating. In 2021, per capita consumption in France was close to 7,200 kWh, compared with 6,000 kWh in Germany, 5,500 kWh in the European Union, and less than 5,000 kWh in Spain and Italy.

81. Territorial emissions in France reached 418 Mt<sub>CO2eq</sub> in 2021 (source: CITEPA).

82. Territorial emissions in the European Union reached 3,735 Mt<sub>CO2eq</sub> in 2021 (source: European Environmental Agency). Emissions due to electricity generation reached 210 Mt<sub>CO2eq</sub> (source: Ember Climate).

Figure 61: Greenhouse gas emissions linked to electricity generation in France



output. Despite this drop, the electricity generated in France in 2022 was still **87% low-carbon**, down from around 91% over the 2014-2021 period.

Increased use of thermal power plants drove **emissions from electricity generation up, which reached 25 Mt<sub>CO2eq</sub>** (versus 21.5 Mt<sub>CO2eq</sub> in 2021). **Emissions remained below the levels seen in 2016 and 2017**, during which there was more coal-fired generation in France than in 2022. Indeed, it was primarily gas-fired plants that were dispatched to make up for lower output from low-carbon sources (hydropower and nuclear). Conversely, coal-fired generation decreased from previous years. Overall, emissions remained much lower in France than in comparable countries. For instance, in 2022, emissions from electricity generation in Germany were about ten times higher than in France.

France's carbon emissions from electricity generation are among the lowest in Europe (third lowest behind Sweden and Finland). The power used in France is largely low-carbon, even factoring in

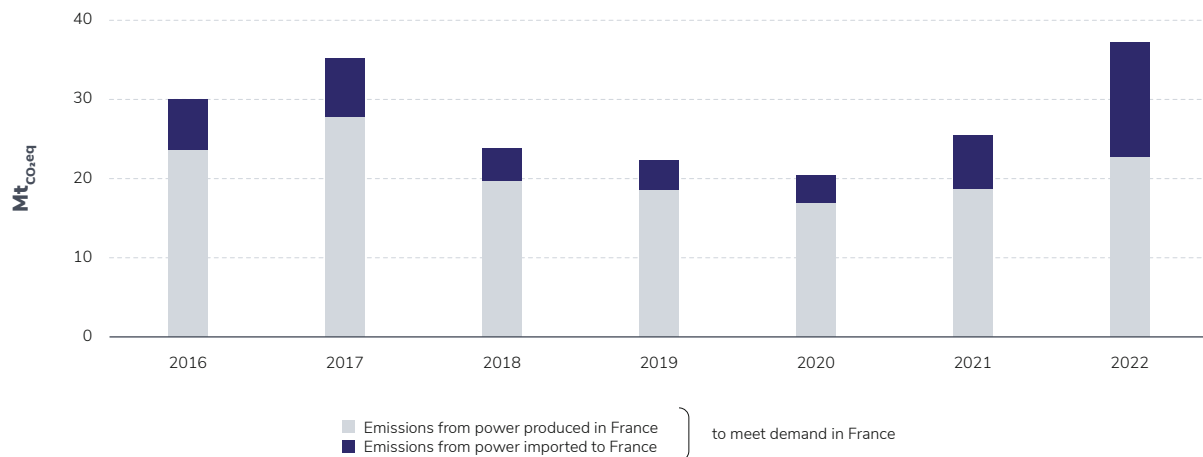
imports, which were higher in volume terms in 2022. These imports were from countries where electricity generation emits more CO<sub>2</sub>eq than France, though they are gradually decarbonising their mixes by incorporating more renewable energy sources.

### 5.3 Even taking imports into account, the electricity consumed in France is among the most decarbonised in Europe

In 2022, France was a net importer of electricity, which is why it is necessary to also analyse the **emissions associated with the electricity consumed in France** (framework 2. above) factoring in all the generation resources used in France and abroad to meet that demand. Emissions associated with electricity generated in France and exported to meet demand in neighbouring countries is not included in the calculation. The analysis takes into account variations in the quantities imported (and exported) to and from neighbouring countries and the generation mix in those countries at all times<sup>83</sup>.

<sup>83</sup>. A simplification is made for this calculation, which is to consider that electricity flows go from France to neighbouring countries or vice versa, without extending the tracing of flows to the countries bordering those neighbours, and so on. The imprecision caused by this simplification is unlikely to affect the orders of magnitude shown.

Figure 62: Greenhouse gas emissions (direct) associated with electricity consumed in France



Imports, which reflect the generation mixes in neighbouring countries, are generally more carbon-intensive than power produced in France, which is very low-carbon. Therefore, total emissions associated with the electricity consumed in France, within this scope, are higher than those associated with electricity generated in France.

It should be noted, however, that **the electricity mixes of France's neighbours have been steadily decarbonising for several years, integrating larger shares of renewable energy sources to varying degrees.** The carbon content of the mixes in neighbouring countries is thus much lower than the emissions content of power produced by gas-fired plants and, a fortiori, by coal-fired plants.

Figure 63: Average emissions intensity of the French power system based on different reporting frameworks and comparison with that of gas-fired plants

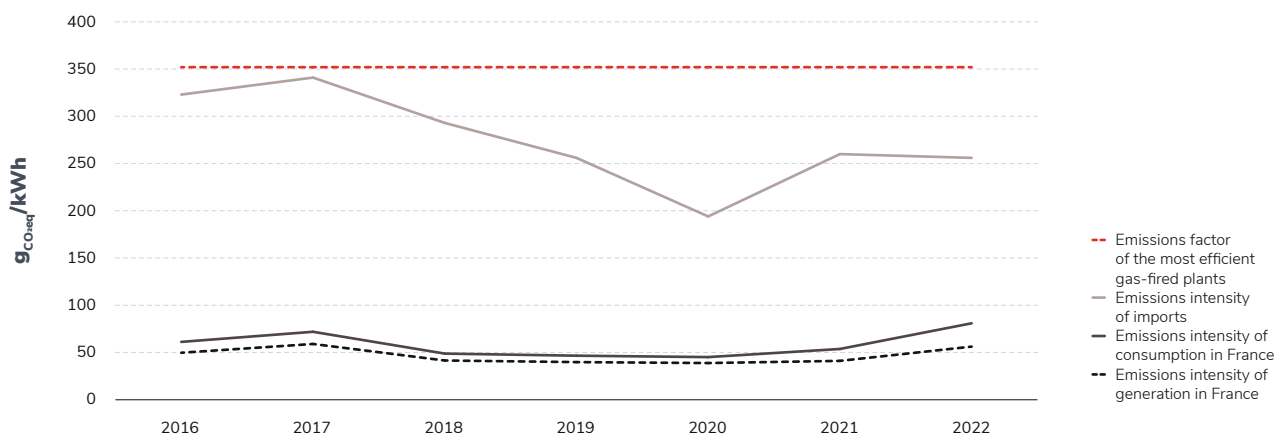
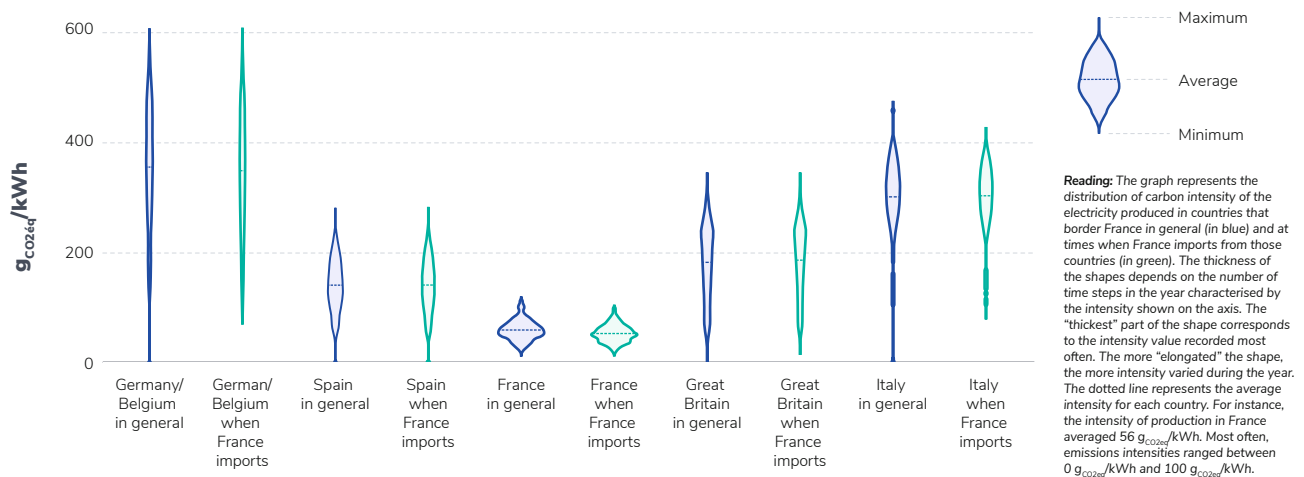


Figure 64: Comparison of the distribution of emissions intensities of neighbouring countries in general, and when France imports at these borders



As a result, even taking into account the impact of electricity exchanges in 2022 (i.e. the sharp increase in imports), emissions associated with the electricity consumed in France were of the same order of magnitude as in recent years, for instance 2016 and 2017.

In volume terms, emissions associated with imports are primarily linked to exchanges at the German and Belgian borders<sup>84</sup>, reflecting their predominance in energy imports to France, and secondarily linked to the higher carbon intensity of the German mix.

84. Trading with the CORE region which includes the following countries in addition to France: Germany, Austria, Belgium, Croatia, Hungary, Luxembourg, Netherlands, Poland, Czech Republic, Romania, Slovakia and Slovenia.

## 5.4 France's neighbours benefited less from exports of its low-carbon electricity

France usually exports more electricity than it imports, allowing its neighbours to benefit from imports of low-carbon French production. The

sharp decline in export volumes in 2022, making France a net importer for the year, also had repercussions on the greenhouse gas emissions of neighbouring countries needed to meet domestic demand.

Figure 65: Greenhouse gas emissions avoided in other countries thanks to electricity generated in France and exported

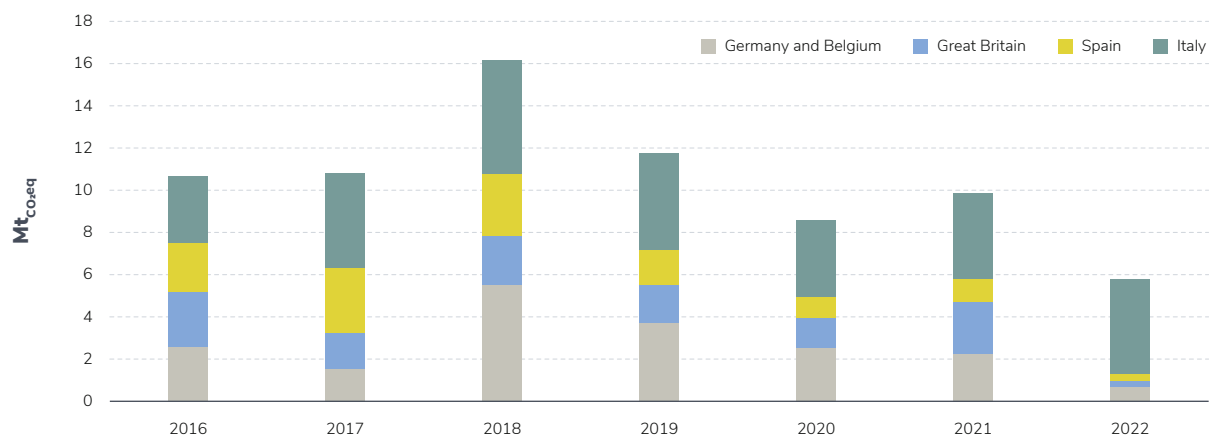
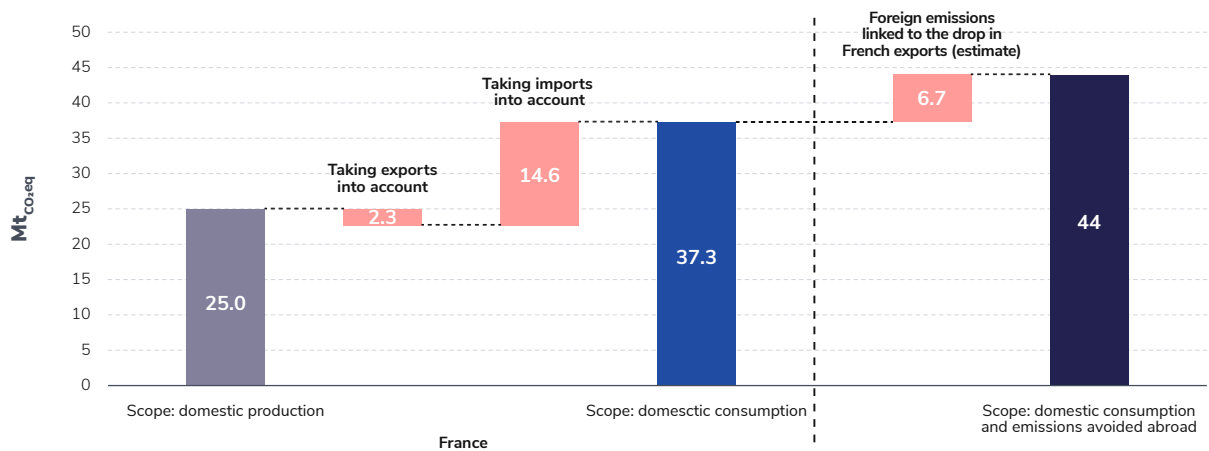


Figure 66: Comparison of emissions associated with electricity generation in France, emissions associated with consumption (taking trading into account) and emissions avoided in other countries<sup>85</sup>

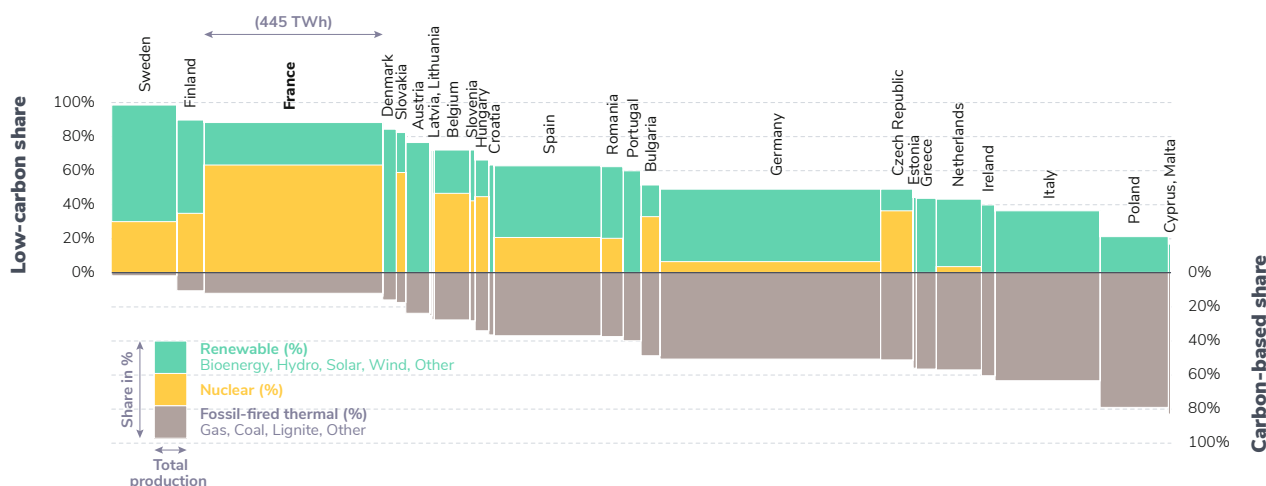


85. The rise in emissions in other countries linked to the decrease in exports from France is estimated by comparing the emissions avoided thanks to French exports in 2022 with the average emissions avoided thanks to French exports each year between 2016 and 2019.

Indeed, the drop in exports of low-carbon electricity from France made it necessary to make up the difference with power from neighbouring countries the mixes of which often emit more greenhouse gases. It is possible to estimate the emissions avoided in other countries by considering, at each border and at each point in time, the volume of electricity exported

by France and the emissions intensity of the generation mixes of the two countries for the time step considered. Based on this approach, in 2022, the emissions avoided in other countries decreased by about 7 Mt<sub>CO2eq</sub> relative to 2021, but remained high in Italy, as France remained a net exporter to that country during the year.

**Figure 67: Electricity generated in the European Union in 2022 and breakdown between carbon-based and carbon-free production (data: Ember)**



## 6. Electrification of end-uses

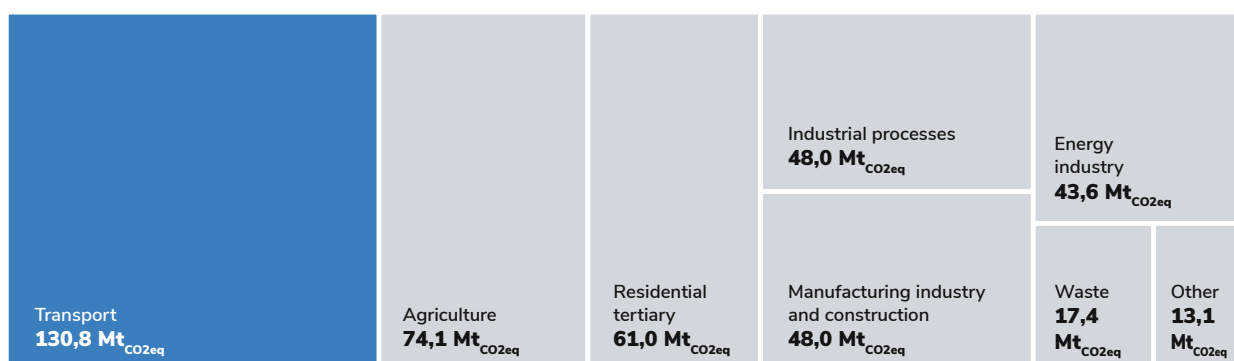
Under all scenarios in which France and Europe reach carbon neutrality in 2050, decarbonising the economy requires significant electrification of energy end-uses, especially in the sectors that are the largest emitters of greenhouse gases. Electrification can be direct or indirect, notably via the use of electrolysis to produce zero-carbon fuels. The implications for the power system will be significant in terms of consumption volumes, which will increase under all the trajectories analysed by RTE<sup>86</sup>, and in terms of load management. Between 2019 and 2020, RTE published three in-depth reports analysing the challenges that the electrification of end-uses will pose for the power system by 2035: one focused on electric mobility<sup>87</sup>, one on hydrogen production<sup>88</sup> and one on building heating<sup>89</sup>.

### 6.1 Electrification of transport

Transport currently accounts for 30% of France's annual greenhouse gas emissions, with ground transport alone making up 29%. This is one of the only sectors in which emissions have increased since 1990 (+10%)<sup>90</sup>. For this reason, the electrification of the vehicle fleet, and the expansion of low-carbon fuel production (including hydrogen produced with electrolysis), will be key to decarbonising the economy, and their development can be expected to drive up power consumption considerably<sup>91</sup>.

The massive development of electric mobility in the near future now appears certain, and a positive trend has taken hold in recent years. Electrification of the French vehicle fleet continued in 2022, notably thanks to the government keeping incentive schemes in place (ecological bonus, “prime à la conversion” bonus) and expanded line-ups. All-electric

Figure 68: Territorial greenhouse gas emissions, France 2019, by sector, in Mt<sub>CO2eq</sub>  
(source: Ministry of the Ecological Transition, “Key climate figures 2019”)



<sup>86</sup>. See “Energy Futures 2050”, Chapter 3, “Consumption”, 2022, RTE.

<sup>87</sup>. See “Integration of Electric Vehicles into the Power System in France”, 2019, RTE.

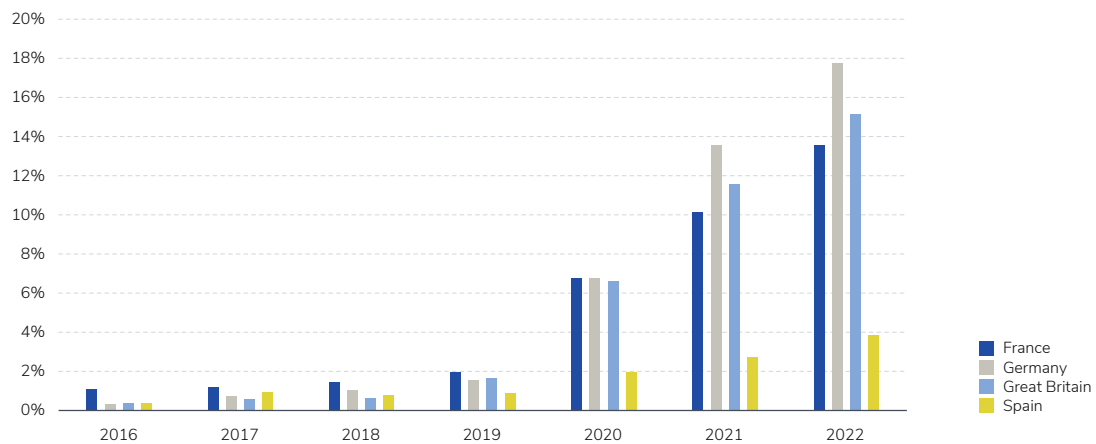
<sup>88</sup>. See “The Transition to Low-Carbon Hydrogen in France”, 2020, RTE.

<sup>89</sup>. See “Reduction of CO<sub>2</sub> Emissions, Impact on the Power System: Contribution of Heating in Buildings by 2035”, 2020, RTE, ADEME.

<sup>90</sup>. Citepa, Secten report, 2022

<sup>91</sup>. See “Energy Futures 2050”, Chapter 3, “Consumption”, 2022, RTE.

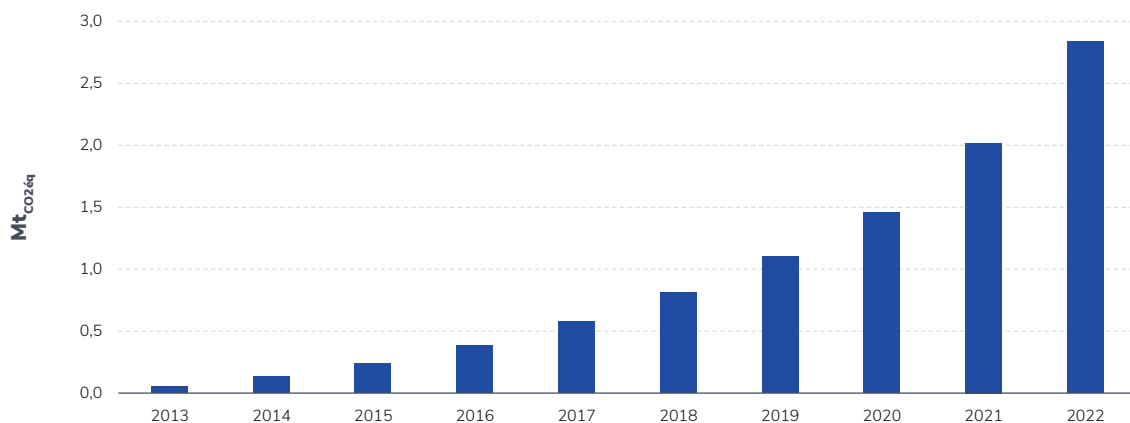
Figure 69: Market share of all-electric vehicles in select European countries, 2019-2022 (source: Argus)



and plug-in hybrid electric vehicles made up 18.5% of the market in 2022 (up from 15% in 2021), accounting for some 346,000 sales out of total light vehicle sales of close to 1.9 million (passenger and light utility vehicles)<sup>92</sup>. New vehicle registrations thus rose by 10% year-on-year in 2022, and by a factor of 5 relative to 2019. **All-electric passenger vehicles boasted a market share of 14%, or 207,000 out of a total of 1.5 million sales.**

Electric mobility is also gathering momentum in other European countries, and at a similar pace. The market share of all-electric vehicles is higher in Germany than in France, climbing above 30% in 2022, and comparable in the United Kingdom (slightly above 20%). In Spain, the market share of all-electric vehicles is much lower, still hovering below 5%.

Figure 70: Emissions avoided thanks to the electrification of the all-electric light vehicle fleet in France since 2013 (cumulative) (calculations: RTE)



92. AVERE data.

Electric mobility adoption in France has already made it possible to avoid a non-negligible quantity of emissions, given that electric vehicles still only account for a small share of the fleet (less than 1%). **Some 2.8 Mt<sub>CO2eq</sub> have been avoided since 2013 thanks to the electrification of light vehicles (all-electric), with half of that total avoided in the past two years.** Volumes are estimated by looking at emissions over the lifecycle of the vehicles, notably those associated with battery manufacturing, and comparing them with the lifecycle emissions of equivalent internal combustion engine (petrol) vehicles.

### Possible levers for improving environmental performances

The estimates above are calculated assuming that batteries are made in Asia. One possible way to improve the lifecycle environmental performance of electric vehicles in terms of greenhouse gas emissions could be to produce the batteries in countries where energy mixes, and particularly

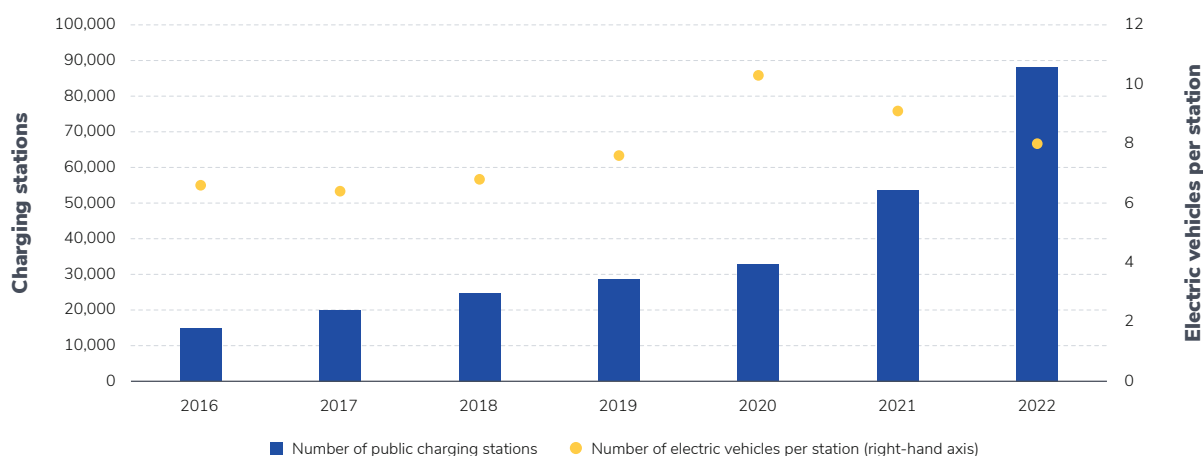
electricity mixes, are lower in carbon. For instance, an estimate in which batteries are manufactured in France would increase CO<sub>2</sub>eq emissions avoided since 2013 by 25%, to 3.5 Mt<sub>CO2eq</sub><sup>93</sup>.

### The development of charging infrastructure

A large-scale rollout of public charging stations is needed to foster electric mobility adoption by users. In 2014, the European Commission recommended a ratio of at least one public charging point for every ten vehicles<sup>94</sup>. This recommendation is an acceptable marker to estimate whether the electric vehicles on the road are adequately supported by the infrastructure they require<sup>95</sup>. The chart below shows the evolution of the cumulative number of public charging points in France in recent years, as well as the ratio of vehicles to stations.

Overall, the development of public charging infrastructure is tracking that of electric vehicles. In 2022, there was one public charging point

Figure 71: Development of public charging infrastructure, 2016-2022 (source: Avere-France)



93. Data on lifecycle emissions are drawn from the environmental analysis in the Energy Futures 2050 report, for 2021 and prior years. Data on new vehicle registrations are from the Ministry for the Ecological Transition, or from AVERE for month-by-month registrations in 2022.

94. Directive (EU) 2014/94 on the deployment of alternative fuels infrastructure.

95. Another important factor that is more difficult to measure is the geographic distribution of these stations. One indicator that is currently being discussed for the draft regulation on alternative fuels, part of the Fit-for-55 package, is to require one charging point every 60 km.

available for every eight electric vehicles on the road – a ratio that exceeds the Commission's target<sup>96</sup>. While the number of public charging points continues to grow, it will also be necessary to adequately develop a private network of charging points, notably on company premises and in multi-family residential housing.

## 6.2 Electrification of end-uses in buildings

Residential and commercial buildings account for about 13% of France's territorial emissions, not counting the emissions due to the production of electricity consumed in those buildings.

Energy consumption in buildings is in large part driven by heating and, to a lesser extent, by domestic hot water, air conditioning in summer, and cooking. This explains why the decarbonisation strategies put forward by public authorities for this sector rest on three main pillars:

- Improving the energy performance of buildings by applying stricter standards to new construction and the renovation of existing buildings;
- Improving the efficiency of heating by adopting efficient solutions such as heat pumps;

- Replacing heating systems running on gas or oil with low-carbon systems, such as efficient electric heating equipment, or other solutions involving district heating or bioenergy.

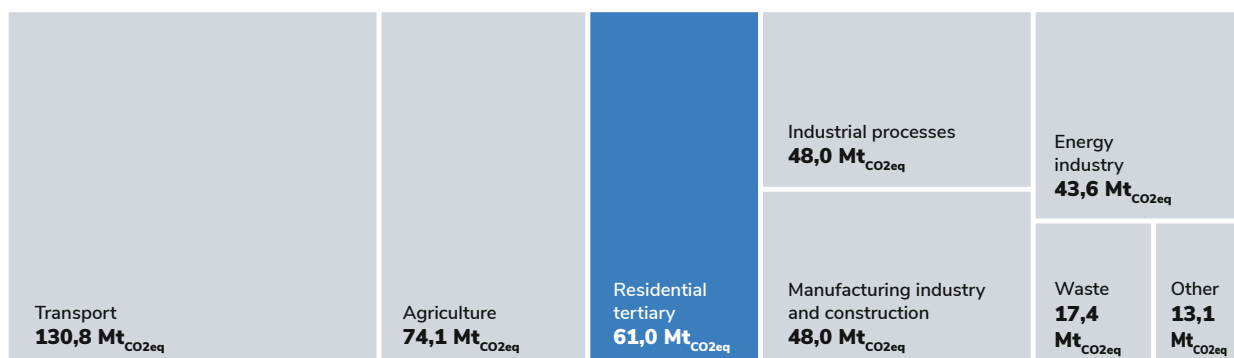
### Heating systems

The gradual replacement of fossil fuel heating equipment, combined with the transition to more efficient solutions, is reflected in the changing breakdown of types of heating equipment installed in new residential units. It is important to note that there is considerable inertia in the stock of existing systems, as their long lifespan slows the adoption of newer ones.

Looking at all types of housing together, one can observe a rise in the market share of heat pumps in the 2010s, with those systems installed in just under a third of new residential units in 2021. The share of **electric** heating decreased early in the decade as the number of electric radiators shrank, before rebounding back to 40% today.

These figures mask significant disparities between the different types of housing. Heat pumps' market share in new single-family homes is much higher, reaching 60% in 2021, and has been rising steadily

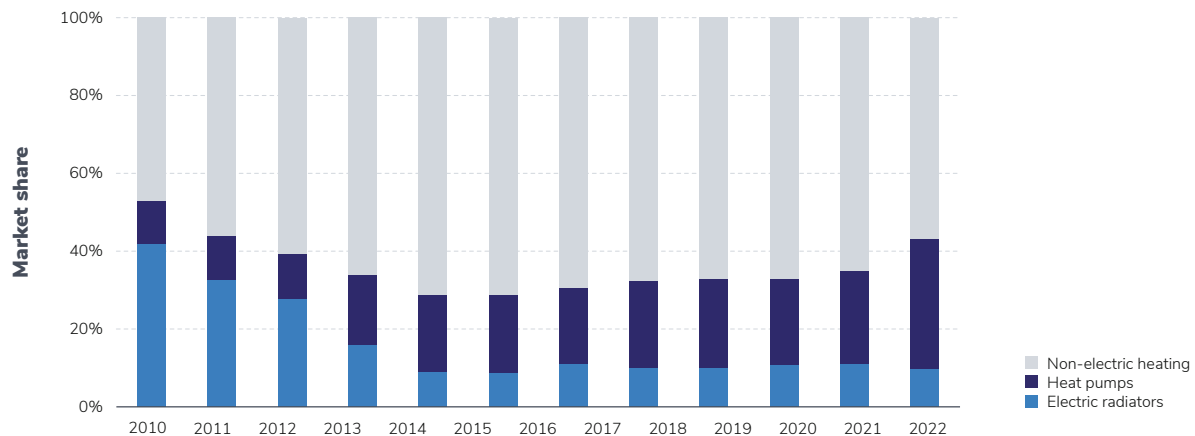
Figure 72: Territorial greenhouse gas emissions, France 2019, by sector, in Mt<sub>CO2eq</sub>  
(source: Ministry of the Ecological Transition, "Key climate figures 2019")



96. With the exception of 2020, where one can assume that the pace of installations stalled temporarily due to the health crisis.

Market share, Non-electric heating, Heat pumps, Electric radiators

Figure 73: Market shares of different types of heating solutions in new residential buildings in France (source: Bati-étude)



since 2010. In multifamily housing, heat pumps, and electric heating in general, are less common (market shares of 13 and 23%, respectively), though a slow upward trend has been visible since the late 2010s. Most non-electric systems run on gas. In multifamily housing, district heating also has non-negligible market share (about 10%), as does wood heating in single-family homes (between 10 and 15%).

### Thermal renovation of buildings

The other main driver of decarbonisation in the sector will be the thermal renovation of buildings. The stakes are high for the economy, the energy market and the climate, since existing housing stock includes 5.2 million so-called “energy sieves” (*passoires énergétiques*)<sup>97</sup> (class F and G buildings based on energy performance diagnostics) that consume large quantities of energy for heating, which has major repercussions for the budgets of occupants as well as for greenhouse gas emissions.

The government is marshalling very significant resources<sup>98</sup> to meet the target set out in the last Multiannual Energy Plan: complete about 380,000 renovations a year between 2015 and 2030<sup>99</sup>, thanks to incentive schemes for individuals and local authorities. Funds mobilised for this purpose exceeded €3 billion in 2022<sup>100</sup>. Though the thermal renovation programme got off to a slow start, it has accelerated sharply in the past two years, with close to 700,000 units renovated in 2021 and as many in 2022, well ahead of the Multiannual Energy Plan target and more than the cumulative total for the entire 2012-2020 period. However, the target set in the Multiannual Energy Plan is an average per year between 2015 and 2030, and the delays accumulated early in the period have only been partially made up in the last two years. As a result, meeting the target will require completing about 500,000 renovations a year between now and 2030.

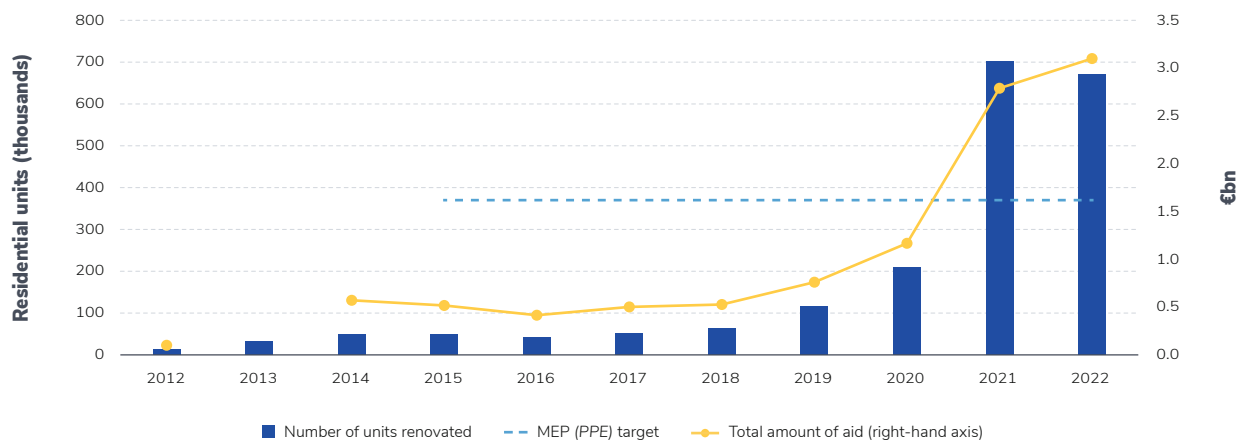
97. Le parc de logements par classe de performance énergétique au 1<sup>er</sup> janvier 2022/Données et études statistiques (developpement-durable.gouv.fr)

98. These resources, administered by France's National Housing Agency (Agence nationale pour l'habitat), come, among other sources, from the EU's Emissions Trading Scheme (ETS) – 100% of the funds returned to France are directed toward thermal renovation – and from France's post-Covid Recovery plan.

99. This target will need to be re-evaluated in the next Multiannual Energy Plan/National Energy-Climate Strategy.

100. This increase must be seen in the light of the rise in the price of carbon allowances, which has a direct impact on the budgets available to be allocated to the thermal renovation of buildings.

Figure 74: Trend in the number of thermal renovations completed in France and the amount of thermal renovation incentives distributed by France's National Housing Agency, 2012-2022 (source: Agence nationale de l'habitat)



### 6.3 Electrification of industry

In the last quarter of the 20<sup>th</sup> century, the French economy was impacted by deindustrialisation, as evidenced by the decline in industry's share of French GDP. This movement was driven by the economy's shift toward services, which is normal in mature economies since, once a certain level of development is achieved, spending on services rises faster than spending on manufactured goods. Another driver, however, was the shutdown of much of heavy industry across the country: even as processes have become more energy efficient in France and around the world, a portion of the energy consumption and related emissions that are necessary to meet demand for industrial products in France was simply relocated to other countries.

Some energy-intensive, high-emissions industries continue to operate in France today, for instance oil refining, steelmaking, and chemicals. These industrial complexes are concentrated in a few economic zones, particularly the Hauts-de-France region, Normandy, the Rhône Valley, and the Bouches-du-Rhône department. As of today, these industries

account for about a fifth of territorial emissions in France<sup>101</sup>.

Decarbonising industrial activities will require targeting both the ones that already exist in France and the ones that reindustrialisation could introduce. Indeed, since France's electricity mix is already very low-carbon, the country has a relative advantage (from an economic and climate standpoint) in terms of electricity generation<sup>102</sup>, and this creates a window of opportunity for investments in the industrial apparatus over the coming years.

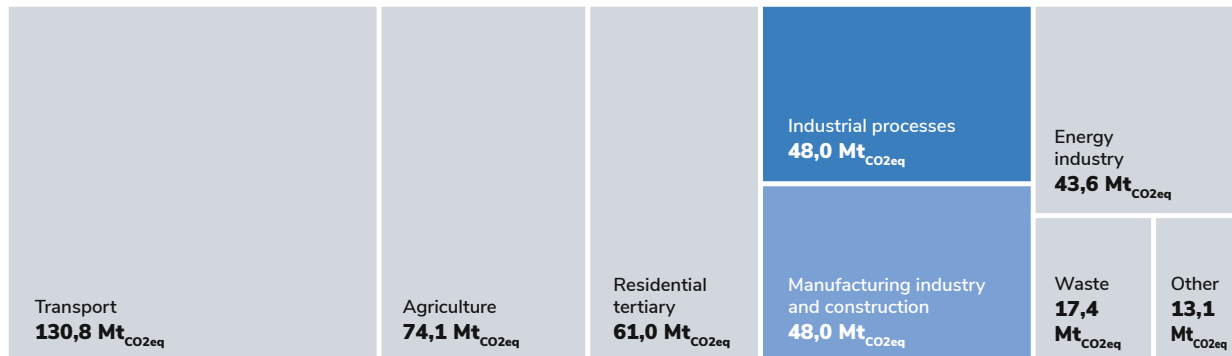
Direct electrification is an option for some industrial processes, but is more difficult for others, such as steelmaking. Another potential way to decarbonise these processes is to use low-carbon hydrogen. The production of this hydrogen with electrolyzers would pose other challenges to the power system over the coming decades.

An analysis of the share of electricity in final energy consumption in industry since the 1970s shows an upward trend between 1970 and 2005 followed

<sup>101</sup>. 2019 figures, Ministry of the Ecological Transition

<sup>102</sup>. This advantage will nonetheless gradually fade as other countries decarbonise their electricity mixes.

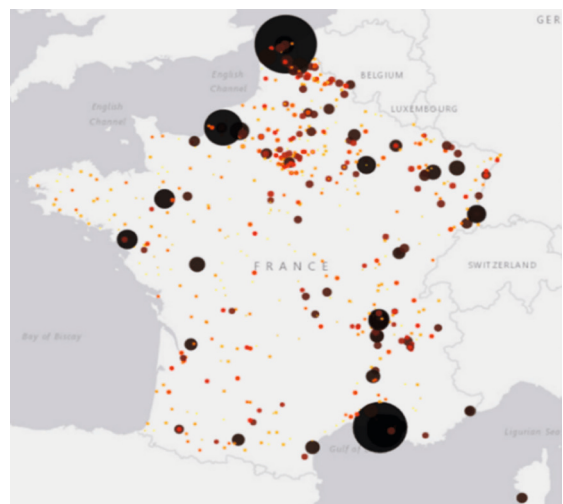
Figure 75: Territorial greenhouse gas emissions, France 2019, by sector, in Mt<sub>CO2eq</sub> (source: Ministry of the Ecological Transition, “Key climate figures 2019”)



by a period of relative stability. The rise was chiefly attributable to a change in the nature and structure of French industry. The relative stagnation seen since the 2000s may be the result of several opposite effects, notably electrification, the development of energy efficiency, and ongoing structural changes in production.

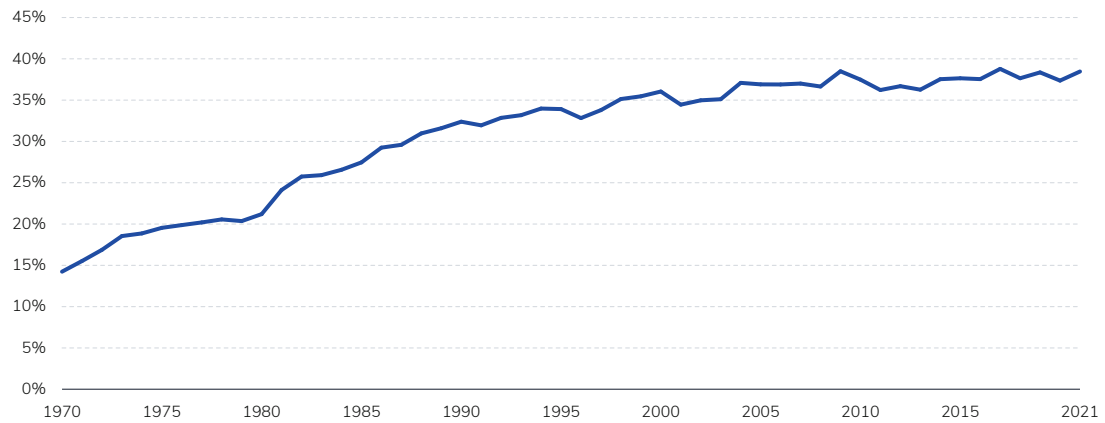
Against this backdrop, and with Europe in the throes of an energy crisis, legislative action taken in 2022 included the adoption of a law to accelerate administrative review procedures for projects that support the energy transition<sup>103</sup>, including some that specifically target priority areas for decarbonising industry.

Figure 76: Map of greenhouse gas-emitting industries across France (data: Ministry of the Ecological Transition, French registry of pollutant emissions. Calculations and map: RTE)



<sup>103</sup>. Draft law on the acceleration of the use of renewable energies, officially adopted on 7 February 2023.

Figure 77 : Share of electricity in final energy consumption by industry, excluding heat sold, excluding raw material usage, 1970-2021  
(source: Ministry of the Ecological Transition, SDES)



## 7. Flexibility and balancing

### 7.1 Flexible resources help guarantee that supply and demand are balanced

Today, it remains difficult to store electricity on a large scale, though some stations can store potential energy, such as pumped storage stations, and progress has been made with batteries. As a result, if supply and demand are to match at all times, flexible resources are needed to **counterbalance the variability of consumption and production, and to respond to hazards in real time**. The development of variable renewable energy sources is **further increasing the need for flexibility on the system**, and these needs will change considerably over the medium and long terms<sup>104</sup>.

Flexible resources are capacity that can be dispatched to balance electricity supply and demand, either on the generation side (upward or downward modulation of production) or on the demand side (on-demand reduction) or through storage. When situated in foreign countries, flexible resources can help balance the system via cross-border trading.

Each flexible resource has specific technical and economic characteristics that allow it to respond to different flexibility needs. Indeed, in a broad sense, flexibility can mean modifying a consumption profile over the medium-long term to better integrate variable renewable energy sources (for instance, via peak/off-peak mechanisms), or managing generation and demand risks in close to real time. A variety of market mechanisms exist to organise

the contributions of the different actors that provide flexibility to the system.

Capacity that can be activated to manage balancing in real time constitutes the system's "operational reserves". The quantities required for each timeframe (a few seconds, a few minutes, a few tens of minutes) are determined based on the situations the power system is considered likely to face. This capacity is thus held in reserve and not used to meet demand if consumption is in line with forecasts. Rather, it is only used if short-term hazards arise. As of today, these reserves, calculated to address the risk of a sudden outage of major generation facilities and demand forecasting errors, represent about 3 GW in total. All dispatchable generation capacity connected to the public transmission grid is required to be made available through the balancing mechanism (tertiary reserve or mFRR and RR<sup>105</sup>) and thus contribute to power system balancing if the need arises.

Other resources (non-dispatchable generation, demand-side flexibility, storage, etc.) can be offered voluntarily on the various market mechanisms. Though the modulation capacity they provide is limited relative to conventional generation for now, their volumes are increasing.

This chapter presents the different types of resources that contribute to power system flexibility and the market mechanisms through which they do so.

<sup>104</sup>. See, in particular, chapter 7 (Security of Supply) of RTE's "Energy Futures 2050" report.

<sup>105</sup>. mFRR = manual frequency restoration reserve and RR = replacement reserve. The English terms are used throughout Europe.

## 7.2 Pumped storage plants

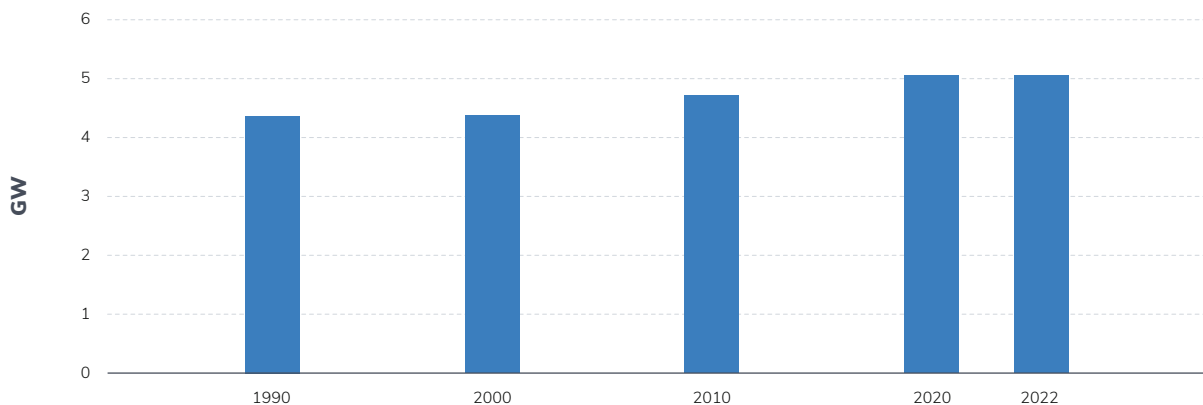
Pumped hydro storage plants, “stations de transfert d’énergie par pompage (STEP)” in French, are currently the only large-scale storage system in operation in France with storage capabilities over several hours (up to a few tens of hours). These plants are typically used to provide flexibility at the intraday scale or within a one-week timeframe.

For instance, pumped storage plants can store energy at night, taking advantage of nuclear power generation when demand is low, and return it to

the grid during the day, or if wind power generation is robust over the weekend, it can be stored then delivered it to the grid the following days.

**Installed capacity currently stands at about 5 GW** in France and has not changed much in recent years. However, some opportunities exist to develop new stations in France. The Multiannual Energy Plan (PPE) foresees the possibility of bringing 1.5 GW of new pumped storage station capacity into service between 2030 and 2035.

Figure 78: Installed pumped storage station capacity in France



### 7.3 Battery storage

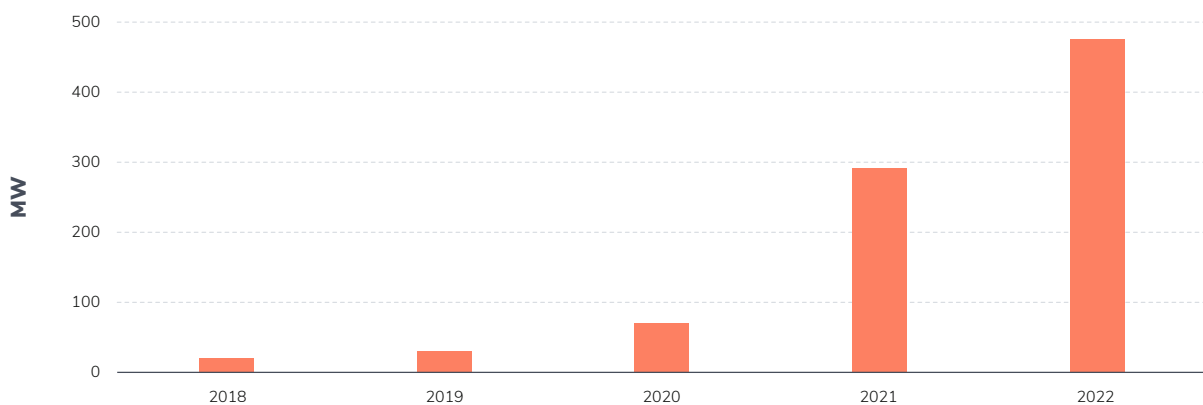
Batteries can be used to address flexibility needs on timescales ranging from a few seconds to a few hours, meaning they can notably participate in primary frequency control, which requires very fast response times (a few seconds).

Frequency is an important indicator of the balance of the power system. If production exceeds consumption, the frequency tends to increase,

and it drops when demand exceeds supply. Since electricity demand and electricity production are constantly changing, frequency also continuously varies. Under normal circumstances, the tolerance range is 0.05 Hz above or below the nominal frequency of 50 Hz.

**Installed battery capacity continued to rise in 2022, approaching 500 MW.**

Figure 79: Installed battery storage capacity in France



## 7.4 Demand response

Modulating demand, by increasing or reducing it, can contribute to power system flexibility at several levels and over different timescales. One type of modulation is **demand response**, which is defined in article L 271-1 of the French Energy Code. It involves a demand response operator or electricity supplier sending a one-time request to one or more final consumers to **temporarily reduce the electricity effectively consumed** from the public transmission or distribution grid at one or more consumption sites, **relative to a consumption schedule or consumption estimate**.

Market players can use demand response to optimise their own portfolios or to sell energy directly to other users or to RTE. There are two main categories of demand response that contribute to the supply-demand balance:

- Industrial demand response, when consumption is reduced at one or more industrial sites (either by shutting down processes or by switching over to self-consumption). This type of demand response can be proposed either directly by the industrial user or through an aggregator or supplier.
- Distributed demand response, or the aggregation through an aggregator or supplier of individual demand response actions involving smaller volumes, all carried out at the same time by retail or professional customers.

Market players (individuals or aggregators) can be remunerated for their demand response actions via several market mechanisms. Options include making their capacity available to the French capacity mechanism or participating in various tenders (for demand response capacity, for the mFRR, or for system services). They can also sell through the NEBEF mechanism, the balancing mechanism, or by participating in frequency ancillary services (system services).

**The NEBEF mechanism (Demand Response Block Exchange Notification) allows market actors to be remunerated for demand response through the energy market**, where a reduction in consumption is treated the same as the production of an equivalent quantity of electricity by conventional generation resources. Given the amount of strain on the electricity market in 2022, with the price increases discussed in the corresponding chapter, the volume of demand response capacity offered on the market rose sharply in 2022.

Figure 80: Volume of demand response offers activated on the balancing mechanism between 2010 and 2022, in GWh

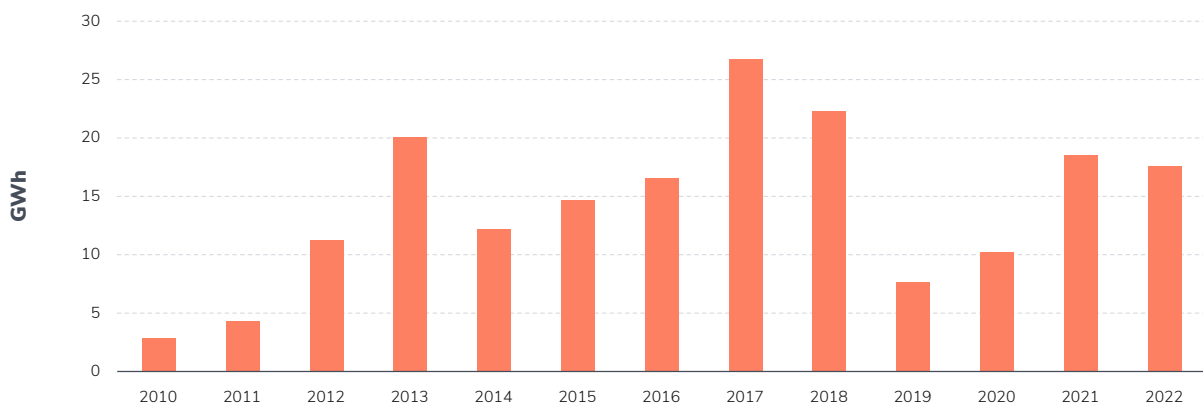
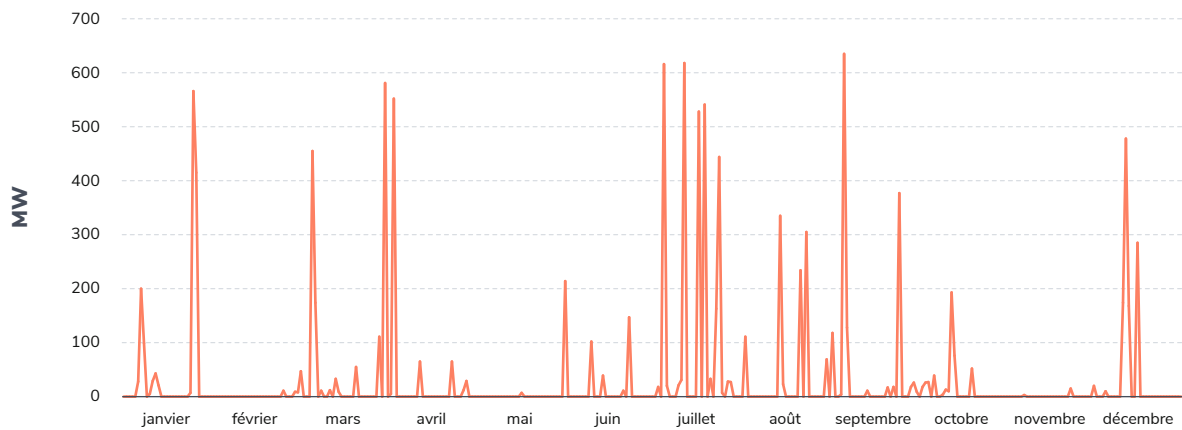


Figure 81: Maximum daily volumes activated on the balancing mechanism in 2022



Moreover, market actors participating in the balancing mechanism can offer upward or downward modulation, and their offers can be activated at RTE's request if such adjustments are required for power system balancing.

**Total demand response volumes activated on the balancing mechanism declined slightly year-on-year in 2022 (17.6 GWh). Activations were spread out across the year, with spikes during the summer when the power system was particularly strained.**

## 7.5 Balancing mechanism

The balancing mechanism allows RTE to manage imbalances between demand and supply in real time, if necessary by modulating generation or demand volumes, or trading with neighbouring countries.

It does this by activating “upward” or “downward” rebalancing offers submitted by actors participating in the mechanism:

- “Upward rebalancing” is necessary when power demand outpaces generation. It can lead to ramped up production, a reduction in demand by a consumer, or additional imports.
- “Downward rebalancing” is needed when electricity generation exceeds demand.

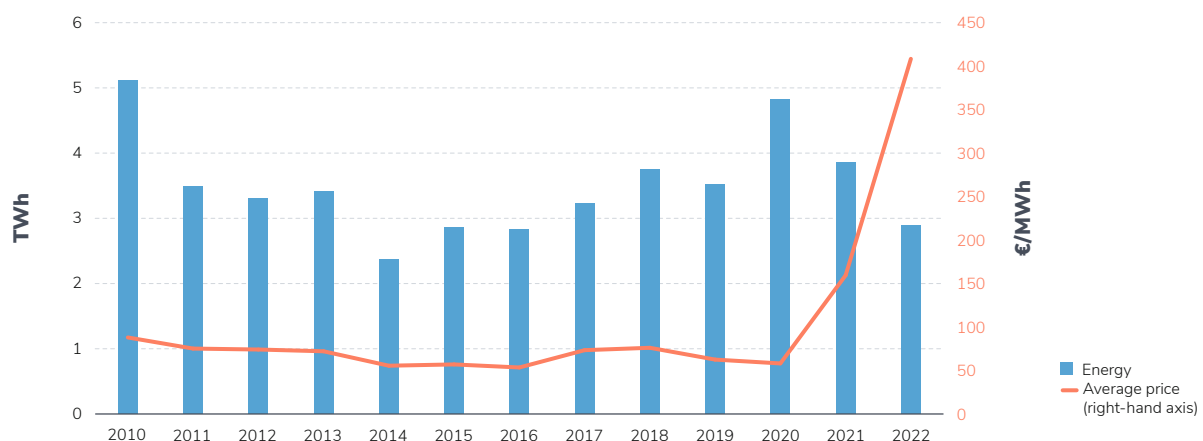
As of today, all dispatchable generation capacity connected to the public transmission system is required to offer available capacity through the balancing mechanism (tertiary reserve or mFRR or RR<sup>106</sup>). Other types of capacity (non-dispatchable generation, demand flexibility, storage, etc.) can participate on a voluntary basis.

When RTE identifies a situation of tight supply, when the balancing capacities available might prove insufficient to ensure balancing, it generates “messages concerning lack of bids” to identify additional bids that could be activated if needed.

Bids are activated based on the merit order and settled at the bid price, except if a bid is activated via the TERRE (Trans-European Replacement Reserve Exchange) platform, in which case it is settled at the marginal price.

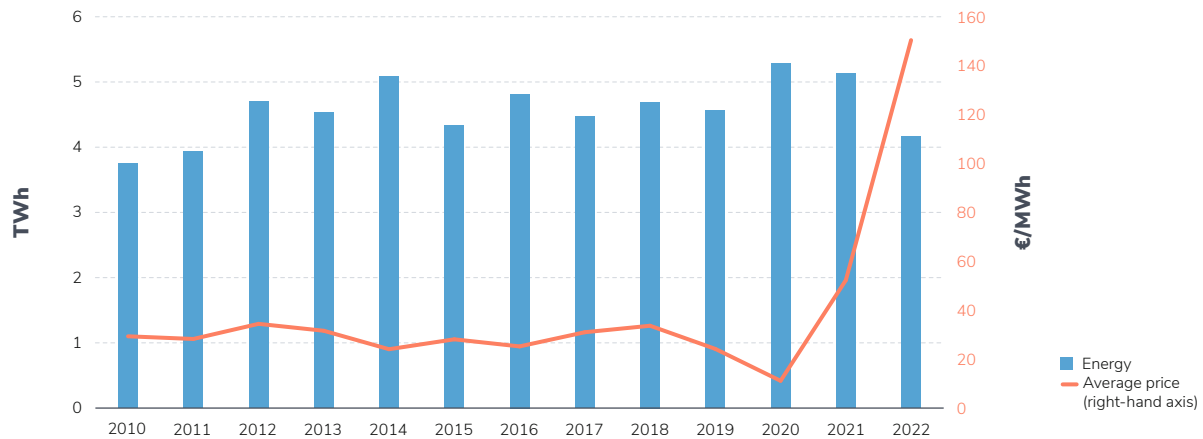
In 2022, the volume of upward and downward rebalancing to balance the power system contracted by nearly 2 TWh relative to 2021. Upward rebalancing volumes fell to the lowest level on record since 2016, while downward rebalancing volumes dropped to the lowest level since 2011. Due to the rise in prices on the spot market, the average rebalancing cost was higher than in 2021 (€408.4/MWh for upward rebalancing, €150.4/MWh for downward rebalancing), when costs had already been above historical averages.

Figure 82: Energy volumes activated on the balancing mechanism and average price paid to activate upward rebalancing during the year



106. mFRR = manual frequency restoration reserve, RR = replacement reserve. The English terms are used throughout Europe.

Figure 83: Energy volumes activated on the balancing mechanism and average price paid to activate downward rebalancing during the year

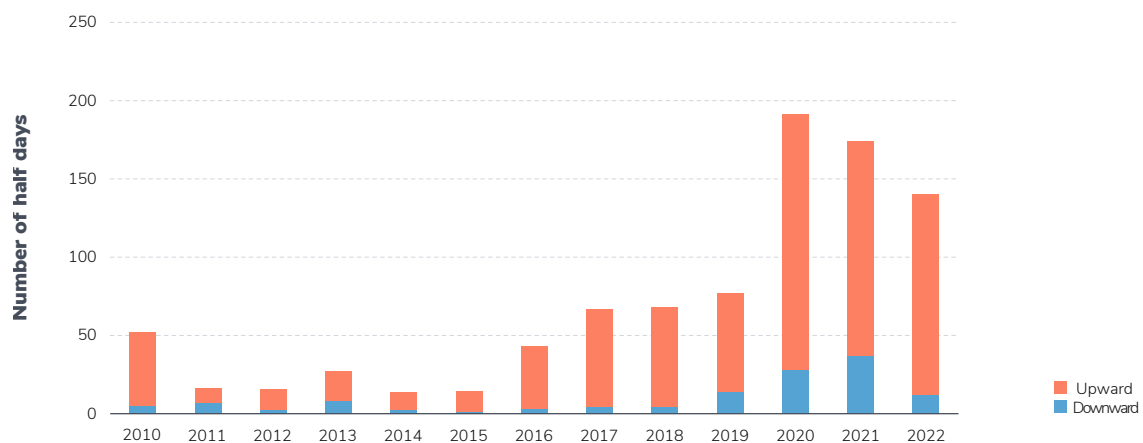


**The number of tight situations on the balancing mechanism declined slightly in 2022 from previous years, but remained higher than the years before the health crisis.**

This reflected the tension on the French power system in 2022, as discussed in detail notably in the

“Generation” and “Prices” sections of this report. Tensions were notably present in the third quarter, when nuclear and hydropower generation were at their lowest. As a result, the number of half-days for which messages were generated to signal a lack of upward bids rose by a factor of 30 from 2021.

Figure 84: Number of half-days for which a message was issued to signal insufficient offers on the balancing mechanism



## 8. The transmission network

### 8.1 Evolution of the network

France's electricity transmission system, operated by RTE, includes 105,817 km of high-voltage lines operating at voltages of between 63 kV and 400 kV. It is the largest transmission grid in Europe.

This grid is constantly evolving, with:

- The creation of new overhead and underground lines;
- The renewal of lines (replacement of conductors);
- The undergrounding of overhead lines;
- The decommissioning of lines.

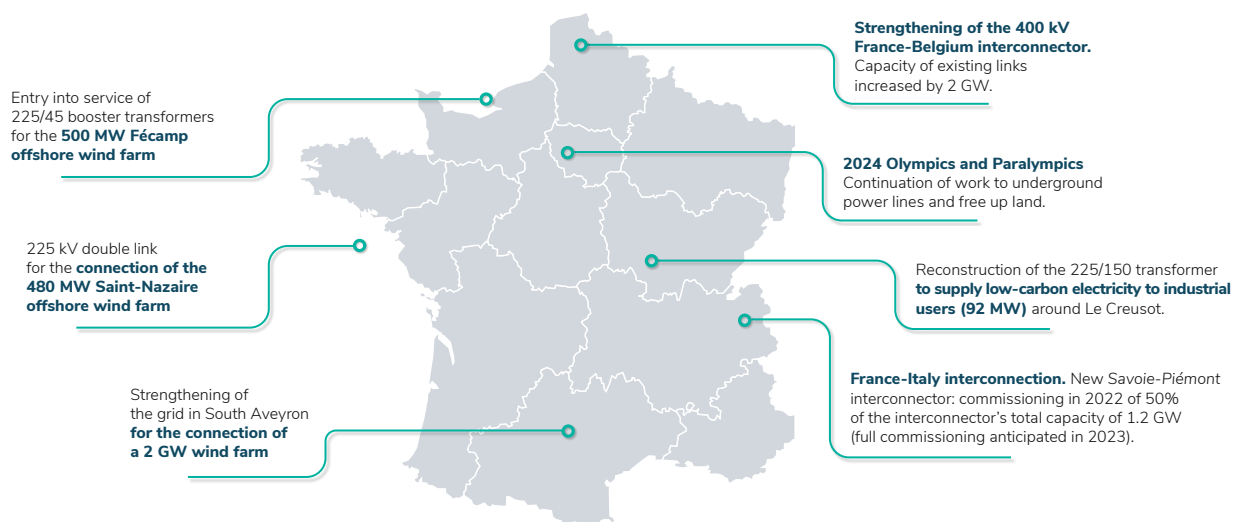
At the end of 2022, the total length of overhead lines stood at 98,762 km, down very slightly (-0.4%) from a year earlier, in accordance with the commitments RTE made as part of its public service contract with the French State. Conversely, the total length of underground lines continued to increase, ending the year at 7,055 km (+3.4% from 2021).

In 2022, 226 km of new lines were added to the transmission grid:

- 96% through the creation of new underground lines or the undergrounding of existing overhead lines;
- 96% operating at voltages of 225 kV and 63 kV.

The key changes affecting the transmission grid in 2022 were the connection of the Saint-Nazaire offshore wind farm, the continuation of work to connect the Fécamp offshore wind farm (see *Offshore Networks* section), the expansion of interconnection capacity with neighbouring countries (see section on *Interconnections*) and the adaptation of the grid to accommodate increasing quantities of renewable generation and the undergrounding of lines around Paris to free up space ahead of the 2024 Olympics.

Figure 85: Main changes to the transmission system in 2022



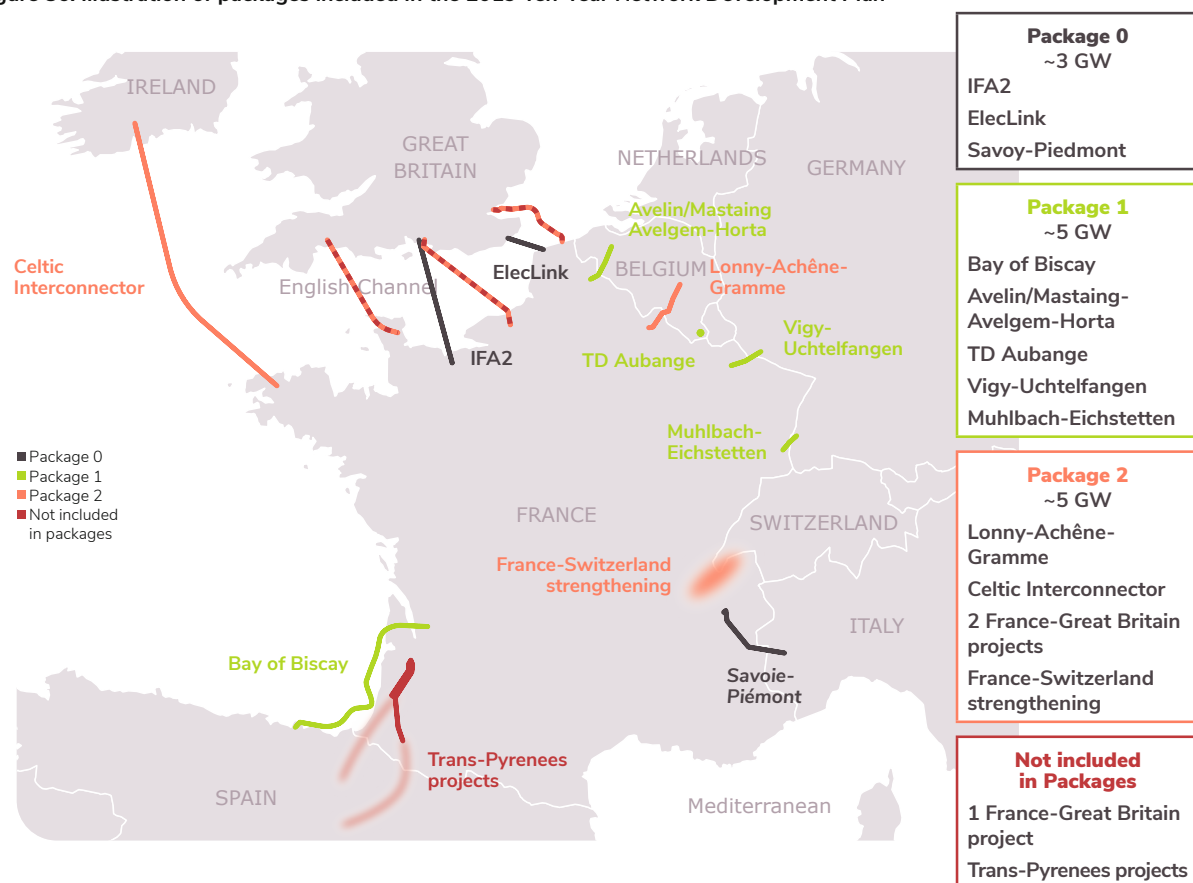
## 8.2 The energy transition will require doubling interconnection capacity by 2035

Expanding electrical interconnections has long been a pillar of European Union energy policy. By making it possible to take advantage of complementary energy situations in different countries, interconnections are essential to integrating renewable energies, and a core component of the energy transition. France's national energy roadmap factors in a significant expansion of interconnections, as reflected in the draft Multiannual Energy Plan by projects to strengthen interconnections at all borders. The Ten-Year Network Development Plan published by RTE in 2019 assumes that France's interconnection capacity will double between 2019 and 2035, from about 15 GW to close to 30 GW.

Interconnection projects have been classified into three coherent packages to be carried out sequentially. Some projects have been completed since 2019, and others are underway:

- “Package 0” includes two new interconnections with the United Kingdom (IFA2 and ElecLink), now in service, with capacity of 2 GW and 1 GW respectively, as well as a new interconnector with Italy, the Savoie-Piémont project, which went live in November 2022 at 50% of its total capacity of 1.2 GW;
- “Package 1” covers all interconnections considered “without regret”, meaning their justification has been proven under all future energy mix scenarios. It includes the strengthening of interconnections with Belgium. Completed late in 2022, that project made it possible to equip the existing line (Avelin-Avelgem) with

Figure 86: Illustration of packages included in the 2019 Ten-Year Network Development Plan



new cables, boosting its capacity by 2 GW. The link was returned to service in November 2022. This package also calls for strengthening trading capacity with Spain via the Bay of Biscay line and boosting exchange capacity with Germany.

- “Package 2” groups together other interconnection projects that are “subject to conditions”, whether political, economic or technical in nature. One example is the Celtic Interconnector project, which involves creating a subsea line over 575 km to connect France and Ireland with a target capacity of 700 MW.

### Projects underway

#### SAVOIE-PIÉMONT

The Savoie-Piémont interconnection **became partially operational in November 2022, with 600 MW coming online**. The second 600 MW cable is expected to go live in 2023, bringing total capacity to 1,200 MW and further boosting electricity trading capacity between France and Italy. This direct-current underground interconnector, covering a distance of 95 km on the French side, melds with existing road infrastructure. It runs across 66 km of motorway, 18 km of by-roads, six viaducts, three tunnels and one underground conduit, while also running through the Fréjus road tunnel over 6.5 km. In France, this is the first time that an underground interconnector has been combined with a motorway to minimise use of space.

#### BAY OF BISCAY

This project involves creating a new interconnection between France and Spain. Scheduled to be brought into service in 2028 (with a partial start in 2027), it will boost electricity trading capacity between the two countries to around 5,000 MW. Almost 400 km long, and buried underground or in the seabed, it will connect the substation in Cubnezais (near Bordeaux) to the one in Gatika (near Bilbao) and will be the first mostly subsea interconnection between France and Spain.

Administrative authorisations began to be reviewed on both sides of the border in December of 2021. In France, a public inquiry was conducted between October and December 2022. Administrative authorisations, which must be secured before procurement and construction can begin, are expected to be obtained in 2023 with partial commissioning of the interconnection scheduled for 2027.

#### CELTIC INTERCONNECTOR

The Celtic Interconnector project involves creating a HVDC line spanning about 575 km (of which approximately 500 km subsea) to allow direct electricity trading between France and Ireland. With a capacity of 700 MW, the cable will link the northern coast of Brittany to the southern coast of Ireland by 2027.

In August 2022, the project was the subject of a “declaration of public utility”. It subsequently received all required authorisations for construction to start. Work will begin in 2023 and the interconnector is expected to go into service early in 2027.

### 8.3 Offshore networks

If it is to phase out fossil fuels and reach carbon neutrality by 2050, France will need to considerably ramp up its production of carbon-free electricity, including offshore wind power. **The 2022 offshore wind pact between the French State and the wind power industry set a target of developing some 50 offshore wind farms by 2050, raising installed capacity to 18 GW by 2030 then to 40 GW by 2050.**

RTE, as the transmission system operator, is tasked with connecting new offshore wind farms to the grid. This mission includes **15 projects that are underway and one that was completed in 2022:**

- **The Saint-Nazaire wind farm was connected to the grid in 2022, making 480 MW of capacity available.**
- Work continues to connect the three other fixed-turbines wind farms—Saint-Brieuc, Fécamp and Courseulles-sur-Mer—with combined capacity of 1.4 GW.
- Three pilot projects involving floating wind turbine technology also continue to move forward (Faraman, Leucate and Gruissan), representing capacity of 84 MW.
- Three other projects are in the development phase (meaning they are waiting for the government to select a bidder to develop the farm and start the construction): Dieppe-Le-Tréport, Yeu-Noirmoutier and Dunkirk, for capacity of 1.6 GW.
- Six projects are currently being scoped before the State awards a contract: Centre Manche 1 and 2 (2.5 GW), Bretagne Sud (750 MW), SUD-ATLANTIQUE (1 GW + 1 GW max), SUD-PACA (250 MW + 500 MW), OCCITANIE (250 MW + 500 MW),

Méditerranée (2 farms representing 1.5 GW) and Sud Atlantique (2 GW).

RTE is active in every phase of these projects: scoping, development, execution, operation and maintenance.

Figure 87: Map of offshore wind farm connection projects



## 8.4 Evolution of the “S3REnR” regional schemes

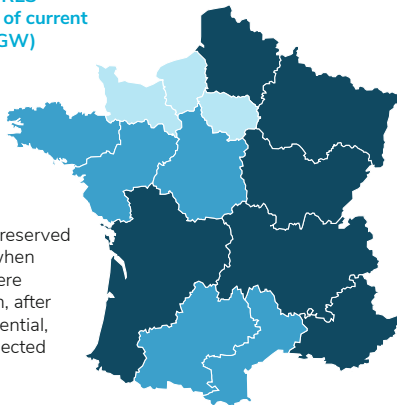
Figure 88: Trend in S3REnR schemes

### Capacity reserved for RES within the framework of current S3REnR projects (en GW)

#### Capacity of S3REnR projects underway

- Less than 1 GW
- 1 to 3 GW
- More than 3 GW

Total capacity (in GW) reserved for RES as estimated when the current S3REnR were published by the region, after evaluating the RES potential, and which will be connected to the RTE grid.

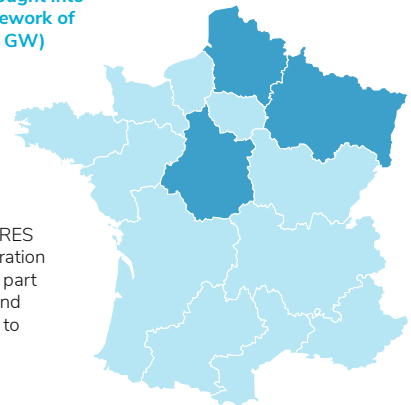


### Capacity of projects brought into service within the framework of the current S3REnR (in GW)

#### Capacity of projects brought into service

- Less than 1 GW
- 1 to 3 GW
- More than 3 GW

Capacity (in GW) of the RES production plants in operation (brought into service) as part of the current S3REnR and which will be connected to the RTE grid.

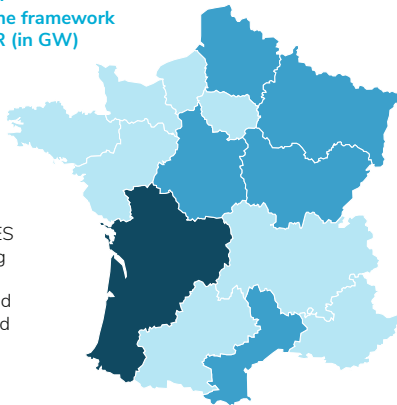


### Capacity of projects in development within the framework of the current S3REnR (in GW)

#### Capacity of projects underway

- Less than 1 GW
- 1 to 3 GW
- More than 3 GW

Capacity (in GW) of RES production plants being developed as part of the current S3REnR and which will be connected to the RTE grid.

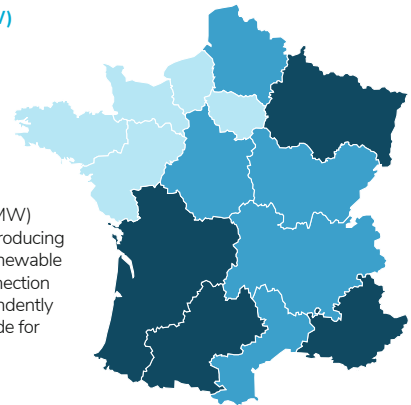


### Discounted unit share of producers (in €/MW)

#### Producers' shares

- Less than €20k/MW
- Between €20k and €70k/MW
- More than €70k/MW

Financial contribution (€/MW) due from each operator producing more than 250 MW of renewable electricity requesting connection to the power grid, independently of actual investments made for that connection.

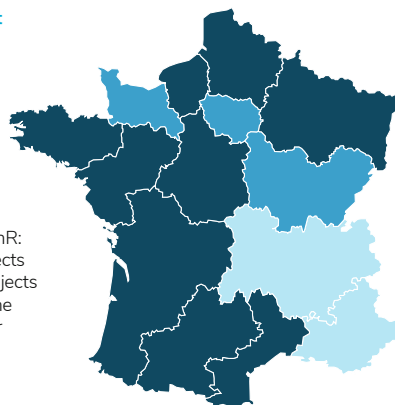


### Completion rate of current S3REnR (in %)

#### Completion rate

- Less than 30%
- 30 to 50%
- More than 50%

Completion rate (in %) for projects in current S3REnR: Cumulative capacity of projects brought into service and projects in development relative to the total capacity planned under the current S3REnR.



As part of its climate and energy strategy, and per the recommendations set forth in the Multiannual Energy Plan (PPE), France intends to increase the share of renewable energy sources in its electricity mix over the coming years. The resulting change in how power flows over networks will make it necessary to substantially adapt and expand the grid.

French Law 2010-788 of 12 July 2010, called the *Grenelle 2* law, tasks RTE with supporting the development of renewable energy sources by drafting “**Regional Schemes for the Grid Connection of Renewable Energies**”, shortened in French to S3REnR, designed to facilitate the integration of

renewable energy sources into the power system while ensuring that system safety is maintained and that costs are kept in check.

These S3REnR schemes lead to:

- Visibility on the grid's capacity to accommodate renewable energy generation by 2030.
- Increased capacity for accommodating renewable sources by optimising the necessary grid investments, notably by strengthening infrastructure.
- Cost pooling between several facilities to favour the development of renewable energy resources in areas where costs would be too steep for a single facility.

## Glossary

| Key word                                                   | Definition                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ARENH                                                      | The Regulated Access to Legacy Nuclear Power mechanism ( <i>accès régulé à l'électricité nucléaire historique</i> ) grants to retailers the right to purchase part of EDF's production at a set price. The price and volumes are set by the regulator (CRE).                                                                                                                                                                                                                                                       |
| Adjusted (for weather and/or calendar effects) consumption | The consumption that would have been observed if temperatures had been normal (as defined below "Normal temperatures") and excluding the consumption of 29 February for leap years.                                                                                                                                                                                                                                                                                                                                |
| Ancillary services                                         | Automatic frequency containment reserve.                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| ASN                                                        | The Nuclear Safety Authority ( <i>Autorité de sûreté nucléaire</i> ) is the public entity which carries out, on behalf of the French state, the missions of nuclear safety control, radiation protection (workers in the nuclear industry, environment, local communities) and the public's information, "to protect workers, patients, the public and the environment from the risks associated with nuclear activities".                                                                                         |
| Auto-consumption                                           | Consumption, by a consumer, of all or part of the electricity generated by their own production installation. Closely related to the English-language concept of "prosumer".                                                                                                                                                                                                                                                                                                                                       |
| Auto-production                                            | Production, by their own production installation, of all or part of a consumer's electricity consumption. Closely related to the English-language concept of "prosumer".                                                                                                                                                                                                                                                                                                                                           |
| Balance responsibility party                               | Balance responsibility parties are participants in the power system (retailers, consumers, traders...) who enter in a contract with RTE which obligates them to ensure that load and injection are equal within their so-called "balancing perimeter". When the sum of all of the parties' balances is not zero, RTE activates the various balancing capacities (adjustment mechanism and ancillary services). The balancing costs are then passed on to the parties which were unbalanced within their perimeter. |
| Balancing mechanism                                        | The mechanism whereby RTE procures dispatchable reserves of supply to balance supply and demand close to real time. RTE can activate production and/or load ramp-up and/or ramp-down offers from participants in the mechanism.                                                                                                                                                                                                                                                                                    |
| Capacity factor                                            | For a given production type, the capacity factor is defined as the ratio between production and installed capacity. In RTE's Electricity report, the monthly and yearly capacity factors correspond to the monthly or yearly average of the half-hourly capacity factors.                                                                                                                                                                                                                                          |
| CO <sub>2eq</sub>                                          | Carbon dioxide equivalent – a comparative emissions measurement index of different greenhouse gases representing their global warming potential. The volume of gas emitted is converted into the equivalent quantity of carbon dioxide needed to reach the same global warming potential.                                                                                                                                                                                                                          |
| Combined-cycle gas turbine plant                           | A technology consisting of the association of a steam turbine and a gas turbine, which results in a better heat rate than conventional gas turbines.                                                                                                                                                                                                                                                                                                                                                               |
| Core                                                       | Capacity calculation and market coupling region. The member countries are: France, Germany, Belgique, the Netherlands, Austria, Slovenia, Poland, the Czech Republic, Slovakia, Croatia, Hungary and Romania.                                                                                                                                                                                                                                                                                                      |
| Coverage rate                                              | The ratio between the output of a given generation type, and demand. In the Electricity review, the monthly and yearly coverage rates correspond to the average of half-hourly coverage rates.                                                                                                                                                                                                                                                                                                                     |
| Demand peak                                                | The hours where electricity demand is highest.                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Dispatchable production unit                               | A production unit which can be started up and/or modulate its output on demand (thermal and nuclear power plants, hydroelectric plants with pumped storage...).                                                                                                                                                                                                                                                                                                                                                    |

| Key word                                              | Definition                                                                                                                                                                                                                                                                                                                                                                                   |
|-------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| EPEX SPOT                                             | One of the power exchange operator among those designated by regulators. Power exchange operators are tasked with the organisation of market coupling, and provide insurance for transactions on the day-ahead and intraday markets. The operators approved for France by the <i>Commission de régulation de l'énergie</i> are EPEX SPOT and Nord Pool.                                      |
| EPR                                                   | The European Pressurized Reactor, or EPR, is a nuclear reactor design of the pressurized water reactor (PWR) type. The EPR is part of the so-called 3rd generation of PWR.                                                                                                                                                                                                                   |
| Forward markets/prices                                | Prices negotiated long ahead of delivery, the date of which can be far away, for periods ranging from a week to a year.                                                                                                                                                                                                                                                                      |
| Fossil-fired thermal/fossil fuels                     | Electricity generation from thermal power plants running on gas, coal or oil.                                                                                                                                                                                                                                                                                                                |
| Geographic spread of variable renewable generation    | Refers to the variations of aggregate production from renewable energy sources due to the fact that they are scattered across vast territories that are susceptible to experience different weather conditions.                                                                                                                                                                              |
| Grand Carénage                                        | An large industrial programme designed to upgrade the safety of existing nuclear plants.                                                                                                                                                                                                                                                                                                     |
| Gross consumption                                     | Countrywide electricity consumption (Corsica included, overseas territories not included), taking into account transmission losses but not the consumption of pumped-storage plants.                                                                                                                                                                                                         |
| High voltage                                          | The electricity transmission network operated by RTE consists of high-voltage (63 000 and 90 000 volts) and extra high voltage (225 000 and 400 000 volts). Those voltage levels allow for lower Joule losses, which allows to transmit electricity over long distances. Distribution networks consists of all the lower voltage levels, which distribute the power to the consumers' meter. |
| Imbalance settlement                                  | Financial transaction whereby RTE passes on the system balancing costs to balance responsibility parties.                                                                                                                                                                                                                                                                                    |
| Imbalances                                            | Difference between injection and load within the perimeter of a balancing entity (balance responsibility party).                                                                                                                                                                                                                                                                             |
| Intraday prices                                       | The prices of electricity transactions for delivery on the same day.                                                                                                                                                                                                                                                                                                                         |
| LNG                                                   | Liquefied natural gas                                                                                                                                                                                                                                                                                                                                                                        |
| Lock hydropower plants                                | Mostly located in lakes downhill from mid-altitude mountains, those plants have a filling duration of 2 to 400 hours. They provide daily or, more rarely, weekly flexibility to the power system (daily demand peak, between business and non-business days...).                                                                                                                             |
| Low-carbon electricity                                | Electricity resulting from the conversion of non-fossil primary energy (renewables, nuclear...).                                                                                                                                                                                                                                                                                             |
| LPEC                                                  | <i>Loi de programmation énergie-climat</i> , French for Energy-climate programming law.                                                                                                                                                                                                                                                                                                      |
| Manual frequency restoration and replacement reserves | Power reserves that help RTE balance the system.                                                                                                                                                                                                                                                                                                                                             |
| MFRR                                                  | Manual frequency restoration reserve                                                                                                                                                                                                                                                                                                                                                         |
| NEBEF                                                 | The French demand-respond products trading mechanism ( <i>Notification d'Échange de Bloc d'Effacement</i> )                                                                                                                                                                                                                                                                                  |
| NEMO                                                  | Nominated Electricity Market Operators                                                                                                                                                                                                                                                                                                                                                       |
| Normal temperatures                                   | Average of past temperature timeseries that are considered representative of the current decade. They are based on Météo France data, and are computed by RTE at the country level thanks to a panel of 32 meteorological stations across France.                                                                                                                                            |

| Key word                               | Definition                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|----------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Other hydro power plants               | The plants in the “other” category are tidal energy plants and pumped-storage plants. Tidal energy plants harvest the energy from the tides in coastal areas where the tidal range (the height difference between high- and low-tide) is large. This range is used to generate electricity by exploiting the height difference between two basins separated by a dam. Pumped-storage plants, operating in pumping-generation cycles between a downhill and an uphill reservoir, thanks to reversible turbines-pumps, are efficient storage assets which contribute to the balance of the power system. When the reservoirs also have natural inflows, the turbine is categorized as “mixed pumped storage”, otherwise as “pure pumped storage”. |
| Physical / commercial exchanges        | Commercial exchanges are the result of a commercial transaction between market participants which are located in different countries (or bidding zones). Physical exchanges account for the actual electricity flows on interconnectors between countries, and can differ from commercial exchanges.                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| PPE                                    | The French Multiannual Energy Plan ( <i>Programmation Pluriannuelle de l'Énergie</i> )                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Renewable thermal and waste            | Electricity generation from thermal power plants running on fuels such as: bioenergy, paper waste, renewable household waste, non-renewable household waste...                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Reservoir hydropower plants            | Located downhill from mid- and high-altitude mountains, those plants have a filling duration of over 400 hours and provide seasonal flexibility and storage to the power system.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| RR                                     | Replacement reserve                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Run-of-river hydropower plants         | Mostly located in plains, those plants consist in a small-height dam and can be filled in under two hours. Therefore, their flexible potential is small and their production depends on the river's flow rate.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| S3REnR                                 | Regional Schemes for the Grid Connection of Renewable Energy Sources ( <i>Schémas régionaux de raccordement au réseau des énergies renouvelables</i> )                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| SDDR                                   | French Ten-Year Network Development Plan ( <i>Schéma décennal de développement du réseau</i> )                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| SFEC                                   | French Strategy on Energy and Climate ( <i>Stratégie française énergie-climat</i> )                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| SNBC                                   | National Low-Carbon Strategy ( <i>Stratégie nationale bas-carbone</i> ).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Spot prices                            | The electricity prices set by the day-ahead market coupling, for each hour of the next day                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| STEP                                   | Pumped hydro storage plants ( <i>stations de transfert d'énergie par pompage</i> ) are hydroelectric power plants that have the ability, during off-peak hours, to pump water from a lower basin to an uphill lake. The water is then released downhill during peak hours to produce electricity.                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Sunlight/sunshine                      | According to Météo France, the sunshine/sunlight duration is defined as the amount of time during which solar irradiance exceeds 120 watts per square meter.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Supply-demand balance                  | The possibilities for storing electricity are limited. Therefore, supply and demand must match at every instant, which is RTE's responsibility to ensure. An imbalance between supply and demand causes the power system's frequency to deviate from its nominal value of 50 Hz.                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Synchronous grid                       | Interconnected grid operating at the same frequency (e.g. the Continental Europe synchronous grid).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Temperature-sensitivity of consumption | Refers to the variation of electricity demand linked to the variation of temperature. For example, demand increases in winter, when the weather is cold, due to the high prevalence of electric heating in France.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |

| Key word            | Definition                                                                                                                                                                                                                                                      |
|---------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Ten-year inspection | A major inspection of a nuclear reactor, carried out every ten years. The fourth ten-year inspection (VD4, or <i>visite décennale #4</i> ), for example, refers to the inspection carried out when a nuclear plant reaches 40 years of operation.               |
| TERRE               | Trans-European Replacement Reserve Exchange                                                                                                                                                                                                                     |
| TICFE               | Internal tax on final energy consumption (taxe intérieure sur la consommation finale d'électricité)                                                                                                                                                             |
| Water reserves      | Countrywide French water reserves represent the aggregate weekly filling level, in %, of reservoirs and lakes where there are hydropower production assets. Water reserves are expressed in terms of "producible energy"», in MWh, given the reservoir filling. |
| Wholesale prices    | Can refer either to the spot price (cf. definition), or to forward prices, for which the delivery date ranges from the next week to the next year.                                                                                                              |