FRANCE STRATÉGIE

ÉVALUER. ANTICIPER. DÉBATTRE. PROPOSER.

Security of Power Supply in Europe in 2030: an overview

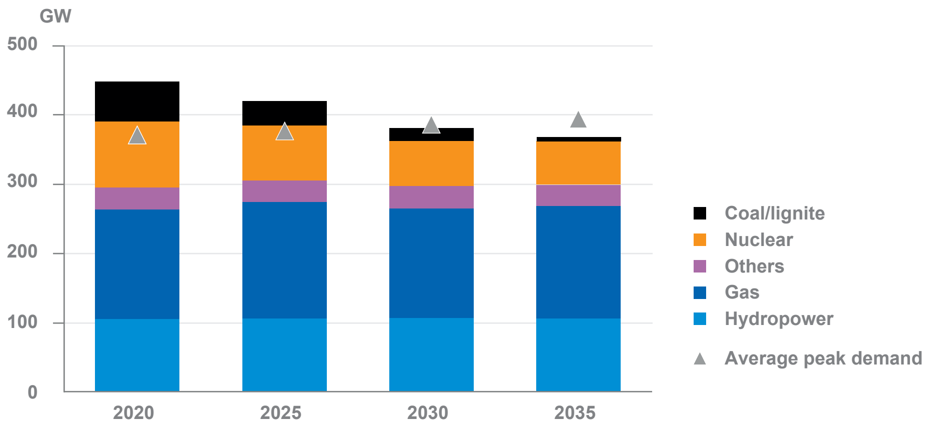
After the grid operator warned in the autumn of potential power supply difficulties in the event of a period of severe cold this winter, the question of possible failures of the electrical systems in Europe and particularly in France arose once again, when it had almost disappeared from the concerns of the general public. In the next decade, the numerous closures of dispatchable power plants, whether coal-fired or nuclear, which are currently scheduled and whose tangible consequences hardly appear to receive public attention, could reinforce the importance of this issue. The purpose of this document is to provide some elements to understand the evolution of these risks of failure in order to initiate adequate policies in time.

Highly ambitious renewable-energy development targets have been set, but solutions in terms of managing demand, storage capacity and, more generally, flexibility and integration into the grid remain insufficiently developed at present. The ability to ensure security of supply as it is defined today is therefore uncertain in periods of tension and will require the appropriate development of flexibility and storage solutions. As European electricity systems are interconnected, it is on this scale that attention must be paid to the dimensioning of production capacity, which is one of the determining factors of security of supply.

After taking stock of the policies and objectives of the main Member States, this document provides a detailed study of the foreseeable evolution of the European power mix, and the possible consequences with regard to our climate and energy objectives. It identifies areas that need to be monitored. It also aims to propose elements for discussion on security of supply, whose terms - which are likely to evolve within the framework of the energy transition process - should receive public attention.

This study notes the limits of policy coordination between European countries on these issues. In particular, while the measures advocated by the new European legislative package constitute progress in this direction, they fail to provide the economic signals needed to trigger the investments that guarantee security of supply. Finally, this document concludes with a number of recommendations for Europe's energy policy.

Forecast of dispatchable electricity capacity of France and neighbouring European countries (2020-2035)



Reading: average peak demand for France is the one evaluated by RTE in its projected supply estimate (BP); average peak demand for the other countries is provided by the corresponding accredited bodies.

Source: France Stratégie based on assumptions by RTE, BNetzA, BMWi, Elia

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Étienne Beeker
with the participation of
Marie Dégremont
Sustainable development and digital technology department

www.strategie.gouv.fr

INTRODUCTION

The health crisis of 2020 disorganised and weakened financially all the players in the electricity sector, or almost all of them[1]. Concerns about possible failures in the power system are coming back to the fore - even if the Covid-19 lockdown measures implemented this autumn and the measures put in place by the government and operators in the sector should temporarily allay them. In the United States, the outages experienced in the summers of 2019 and 2020 in California have also drawn attention to these issues.

This document puts into perspective the short-term economic reflections published in April 2020[2] on the impact of the first Covid-19 lockdown on the electricity sector, while developing the structural elements that weaken the electricity system. While a look at the short-term challenges is necessary, this publication analyses the medium-term changes in the European electricity mix. It examines the expectations placed on the services provided by the French power system and calls for a discussion on the means to meet them.

In the coming decade, numerous closures of dispatchable power plants[3] (mainly coal-fired and nuclear) are scheduled in Europe.[4] The fight against global warming implies a major transformation of power systems, which must be combined with the protection of access to this essential resource. Are these changes being addressed in a satisfactory manner? What risks can be anticipated and what paths can be proposed to ensure that these goals are met under good conditions?

It is essential to consider all possible solutions, which implies taking stock of recent transformations.

This reflection is all the more necessary as electricity is expected to meet a growing share of energy needs. In France, the energy and climate strategies adopted in the spring of 2020 enshrine the role of electricity. Representing nearly 25% of final demand today, it is expected to represent 54% of final demand in 2050. The European Union has set a target of 50%.[5]

As European power systems are interconnected, the dimensioning of production capacity and the coherence of policy decisions in this respect must be addressed at the European level. After recalling the conditions required to ensure a system's security of supply, this document reviews the evolution of the electricity mix in the main Member States.

While European states consult one another on a technical level, coordination of the policies on the mix chosen by each of the Member States is virtually non-existent.[6] On the basis of this observation, the last part of this document puts forward a series of recommendations.

HOW DO WE CHARACTERISE SECURITY OF SUPPLY?

For consumers, security of supply is equated with the absence of a blackout, regardless of its origin and nature. More official definitions and typologies exist, including the ability of a system to supply consumers reliably and, in the event of an incident, to restore supply quickly and at a reasonable cost. This requires players to take actions ranging from the long term (choice of investments) to the very short term (management of the system), knowing that they are linked.

Matching supply and demand in the long and medium term

Upstream, the right technical and economic choices must have been made so that the electrical system has a composition (a "mix") that is consistent with consumption which, it should be remembered, varies permanently, while electricity is not stored, or is stored very badly or at a cost that remains very high. This is the main subject of this document. RTE, the French electricity transmission system operator (TSO), points out in its 2019[7] projected supply estimate (BP) that, in such a system, the "electricity mix must have enough capacity to ensure the supply-demand balance in most situations [...] such as cold spells, unforeseen damage to means of production or even low-wind episodes. A statistical criterion set by the public authorities defines the level of risk accepted by the community in terms of imbalance between supply and demand."

In France, this criterion was defined in the multi-annual energy plan (PPE) of April 2020. It corresponds to an average failure duration of three hours per year.[8] A failure is understood to be the use of exceptional means to ensure the balance between supply and demand: interruption of consumption at major industrial sites, voltage reductions or calls for voluntary

1. The income of producers of certain types of renewable energy is guaranteed.
2. https://www.strategie.gouv.fr/point-de-vue/impacts-de-crise-covid-19-systeme-electrique
3. Dispatchable means of production enable demand to be met when it changes. These means include, in particular, hydroelectric dams (which are the most flexible), coal, gas, oil, nuclear and biomass power plants. Wind, solar and run-of-river hydroelectric means are not dispatchable.
4. The shutdown scenarios are described in the appendix.
5. European Commission (2020), *Clean Energy for all Europeans Package; Impact Assessment on Stepping up Europe's 2030 Climate Ambition*, part 2, https://ec.europa.eu/clima/sites/clima/files/eu-climate-action/docs/impact_en.pdf
6. Reinforced recently by the legislative package "Clean Energy for all Europeans".
7. RTE (2019), *Bilan prévisionnel de l'équilibre offre-demande d'électricité en France*. (Projected estimate of the electricity supply/demand balance in France)
8. Energy Code, Article D 141-12-6: "The electrical system failure criterion mentioned in Article L 141-7 is set at an average annual failure duration of three hours due to an imbalance between electricity supply and demand."

actions by consumers. As a last resort, RTE can perform temporary, localised and rotating blackouts. In other European countries, this criterion may be different or not even defined.

The current energy transition process is bringing about a paradigm shift and may lead to a change in the very definition of security of supply, which is currently based on one kWh deliverable at any time, to anyone and anywhere in the country. Faced with the rise in the share of intermittent renewable energy and the slow progress in electricity storage, ensuring security of supply for all could imply much greater recourse to contracts that reduce demand when the balance is threatened. This would imply an extension of contractual interruption or reduction clauses with industrial firms, and could also extend, if necessary, to more diffuse uses, such as those of the Internet of Things.

Today, tension generally arises during consumption peaks, which, due to the high proportion of electric heating in France, occur on winter evenings. Analyses (by TSOs in particular), carried out on the basis of climate statistics, show that with the penetration of intermittent renewable energy sources[9] the nature of the risks for the power system is changing: the probability of occurrence of a failure is decreasing, but the failure's depth (power, in GW) and duration increase very significantly; these situations generally correspond to windless cold spells that can last several days.[10] Tension may therefore also occur during production troughs, particularly in the case of wind power, at any time of the day and in any season. What is known as the "failure landscape" is therefore likely to evolve in the coming years, putting traditionally available solutions to the test.

Finally, a grid must be in place to transport power from areas of production to areas of consumption. Although the existence of a solid and well-meshed grid is one of the essential conditions for security of supply, this issue is not the main focus of this document, but reference may be made, where appropriate, to France Stratégie's recent work on this subject.[11-12]

Short-term steering of the system

Incidents affecting the electrical system can vary in nature (breakdown of production means, loss of infrastructure on the grid, etc.) and origin (maintenance failure, extreme weather event, malicious acts, etc.). Some of the risks to be controlled are well known, others are more changeable. For example, the integration of electrical and digital systems increases vulnerability to cyber attacks, during which terrorists could take control of a production plant, a transmission or distribution grid or the electrical equipment of a consumer, generally an industrial firm.

It is the TSO that must ensure operational security and control of the electrical system by making sure that it retains sufficient power in reserve and flexibility to deal with any contingencies that may arise in real time: unforeseen variation in consumption, unexpected power-plant failure, loss of a very high voltage line, sudden wind shifts, etc.

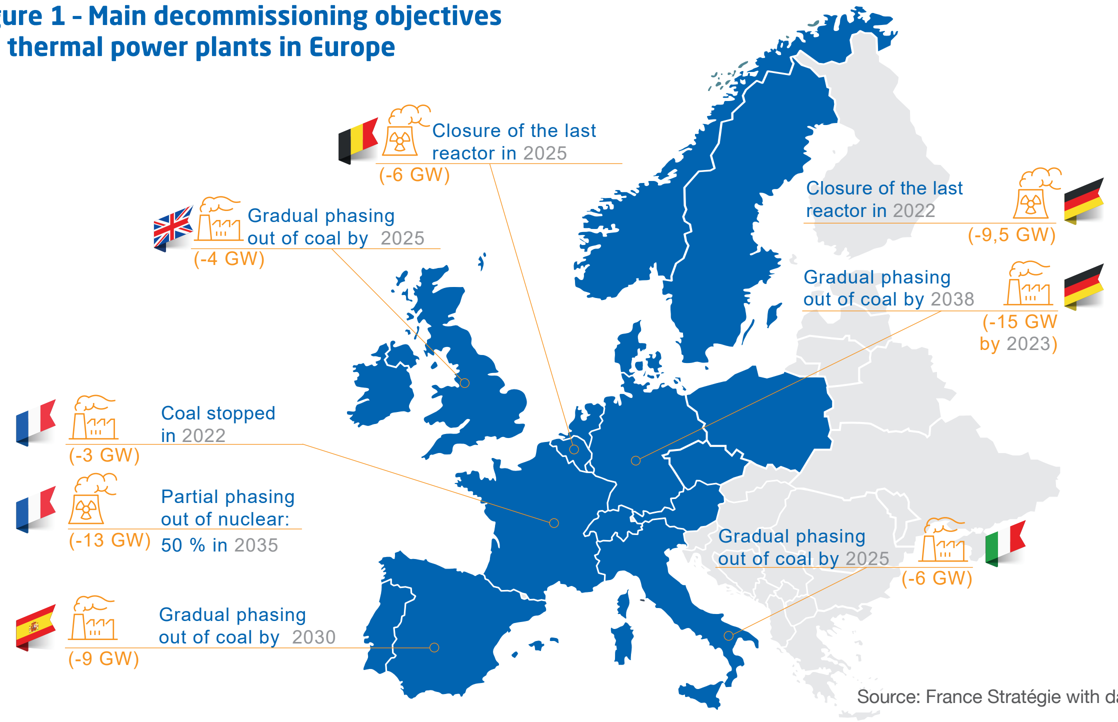
It will not necessarily be possible to respond to brief contingencies or to longer or deeper breakdowns with one type of means. This assumes that the means are available in good time, that they have been maintained, that the power plants are supplied with fuel, if necessary, that hydroelectric dams contain a sufficient amount of water, etc. In the long term, structural factors play a more decisive role.

SCHEDULED CLOSURE OF DISPATCHABLE CAPACITY IN EUROPE NEEDS TO BE BETTER TAKEN INTO ACCOUNT TO ENSURE SECURITY OF SUPPLY BEFORE 2030

In the coming years, most European governments plan to decommission a large capacity of dispatchable production. By 2030-2035, Elia, the Belgian TSO, estimates in the 2019 edition of its bi-annual study[13] that more than 110 GW of dispatchable power will be withdrawn from the European grid,[14] namely: 23 GW of nuclear power (including approximately 13 GW in France and 10 GW in Germany), 70 GW of coal/lignite (including approximately 40 GW in Germany) and 10 GW of gas or fuel oil. Apart from Germany and France, which account for almost two-thirds of these decommissioning operations, Belgium, the United Kingdom, Italy and Spain are also concerned (see map above). France Stratégie compiled the development assumptions regarding the European mix of French, Belgian and German TSOs or regulators. A spreadsheet was produced and lists for the six countries bordering France (including the UK but

9. Intermittent renewable energy, almost exclusively wind and solar, to a lesser extent, tidal and, perhaps one day, marine turbine.
10. According to RTE (BP 2019), there is a one in twenty chance of experiencing nearly thirty hours of failure during the harshest winter, in 2022-2023. See also the Météo France graph in the appendix.
11. As a reminder, investment choices must take into account a number of factors such as dependence on gas, strategic metals and technologies essential for the energy transition process, which are further illustrations of existing threats. A broader definition of security of supply may include the capacity of European industrial sectors to meet these new needs: issues of industrial property, availability of technologies, labour in areas such as batteries, production units, electrical engineering, new uses (electric vehicles, heat pumps), digital (software).
12. Beeker E. (2019), *Les réseaux de distribution d'électricité dans la transition énergétique*, (Electricity distribution networks in the energy transition) Working Paper No. 2019-07, France Stratégie, November.
13. Élia (2019), *Adequacy and flexibility study for Belgium 2020-2030*, June
14. Countries concerned: Austria, Belgium, Switzerland, Czech Republic, Germany, Denmark, Spain, France, Finland, United Kingdom, Hungary, Republic of Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovenia, Slovakia, Sweden.

Figure 1 - Main decommissioning objectives for thermal power plants in Europe



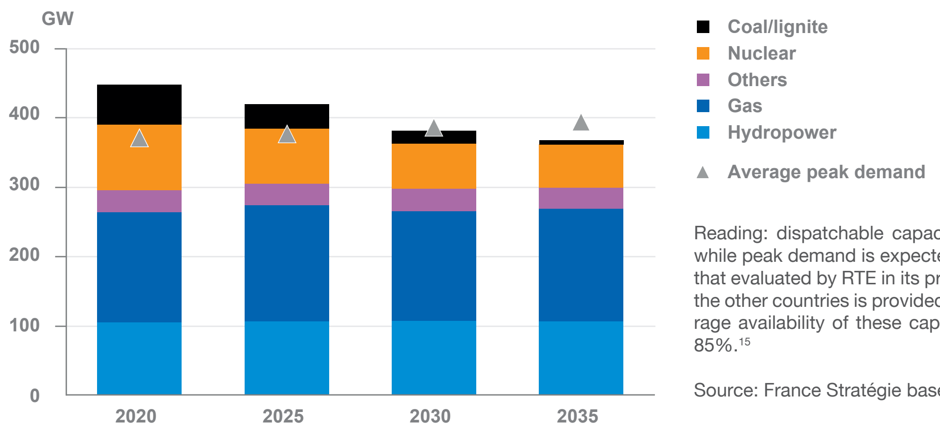
Source: France Stratégie with data from RTE - BP 2019

excluding Luxembourg) the means of production, demand, flexibilities and interconnections for the years, 2020, 2025, 2030 and 2035. When these were missing, generally after 2030, or differed among the TSOs, France Stratégie inserted its own assumptions, the choice of which is explained. This spreadsheet is published and commented in the appendix, and summarised in Graph 1.

This graph shows that by 2030 and probably sooner, if current trends continue, dispatchable means on their own will not be able to satisfy all average peak demands (their definition is discussed below and in more detail in the appendix). This new finding calls for all the solutions available to remedy this shortfall to be considered (flexibility and demand management, availability of non-dispatchable means of production, etc.).

The health crisis of 2020 provides an insight into the consequences of such a situation, with the deterioration in the availability of French nuclear power (but not only) and the insufficient development of flexible solutions. In France, RTE has stated that it is paying particular attention to the winter of 2020-2021: the risk of having to resort to exceptional means is high, particularly in cold weather and in the absence of wind. It is therefore advisable to anticipate a challenge that could become structural at the end of this decade.

Graph 1 - Forecast of dispatchable electrical capacity of France and neighbouring European countries (2020-2035)



Reading: dispatchable capacity decreases over the period by about 100 GW while peak demand is expected to increase. Average peak demand for France is that evaluated by RTE in its projected supply estimate; average peak demand for the other countries is provided by the corresponding accredited bodies. The average availability of these capacity values during consumption peaks is around 85%.[15]

Source: France Stratégie based on assumptions by RTE, BNetzA, BMWi, Elia

15. The choice of this value is explained in the appendix.

Box 1 – Capacity mechanism and medium peak power

In order to ensure compliance with public security-of-supply goals, France introduced a capacity mechanism that imposes a capacity obligation on "obliged players" (suppliers and consumers) These players must have capacity guarantees equal to their obligation, which reflects the consumption of their customer portfolio in a defined cold spell.

RTE regularly publishes an estimate of the total capacity obligation for France, based on the latest consumption trends. This is the value that France Stratégie has adopted, calling it "average peak power". In the median scenario of the latest projected supply estimate for 2019, RTE considers this value to be stable for five years at 94.3 GW. Its definition is complex, but according to RTE it corresponds to a ten-year cold spell, with an average temperature that is -2.6°C lower than normal seasonal temperatures.

The capacity guarantees of the obliged players are calculated by applying an abatement coefficient to the means of production at their disposal, known as a "capacity credit". These coefficients, evaluated each year by RTE, relate to the median availability of the corresponding means of production during peaks in average consumption. France Stratégie retained 85% for conventional thermal means, 10% for onshore wind power and 2% for photovoltaic solar power. These values are different from the reference values used for the capacity mechanism.

THE DEVELOPMENT OF INTERMITTENT RENEWABLE ENERGY SOURCES MUST KEEP PACE WITH THE DEVELOPMENT OF MEANS OF BALANCING THE ELECTRICITY SYSTEM

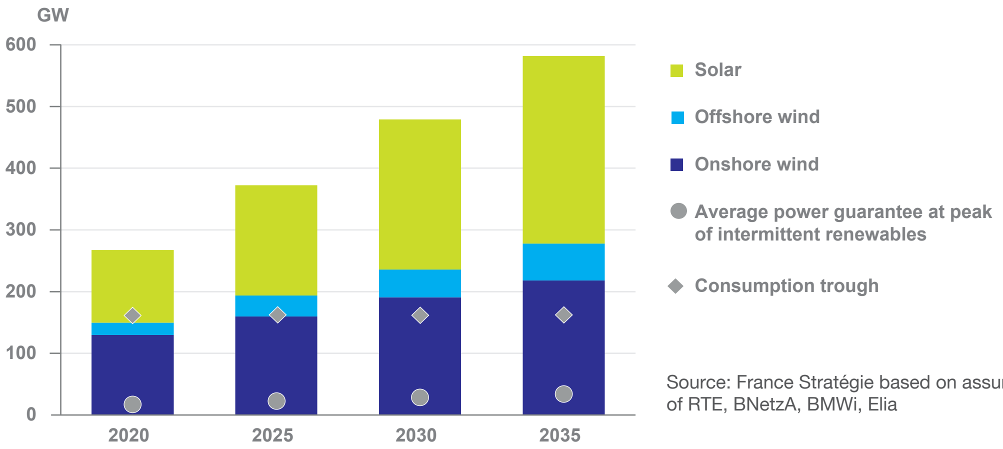
Intermittent renewables offer reduced guaranteed power

As part of their different energy transition processes, European countries have set themselves very ambitious targets for the development of wind (onshore and offshore) and solar photovoltaic (PV) energy. Thus, by 2030, nearly 200 GW of intermittent renewable energy should be installed in Germany according to the latest EEG 21 law, and 75 GW in France, 20 GW in Belgium, 100 GW in Spain, 70 GW in Italy, etc. France Stratégie applied the assumptions of the European TSOs in the spreadsheet published in the appendix, which is summarised in Graph 2.

As this graph illustrates, intermittent renewable energy capacity is very significant: with about 400 GW, it should exceed that of conventional means (including large hydropower) shortly after 2025. But 1 GW of intermittent renewable energy is not the same as 1 GW of dispatchable power and its participation during moments of tension on the electrical system is not guaranteed because it depends on the weather (temperature, presence or not of sunshine and especially of wind). In its 2019 projected supply estimate, RTE indicates that wind power contributes to the peak at a level equivalent to its average contribution over the year, but points out that minimum wind generation can reach 1% of installed capacity, and that the passage of production peaks is achieved in 90% of cases thanks to the use of dispatchable means.

A supply/demand matching study must therefore involve probabilistic random draws, and only TSOs and specialised study groups have the tools to carry out this type of complex calculation, which requires the compilation of very large amounts of data. This is how RTE operates to define

Graph 2 - Forecast of intermittent renewable energy production capacity of France and neighbouring European countries (2020-2035)



Source: France Stratégie based on assumptions of RTE, BNetzA, BMWi, Elia the parameters of its capacity mechanism.[16-17] It mainly concerns the total capacity obligation for France, which corresponds to RTE's assessment of average peak demand, and then "capacity credits", which provide a flat-rate assessment of the median participation at the peak of the obliged players' means of production. Load shedding operations participate in the capacity mechanism and are therefore assimilated to a means of production.

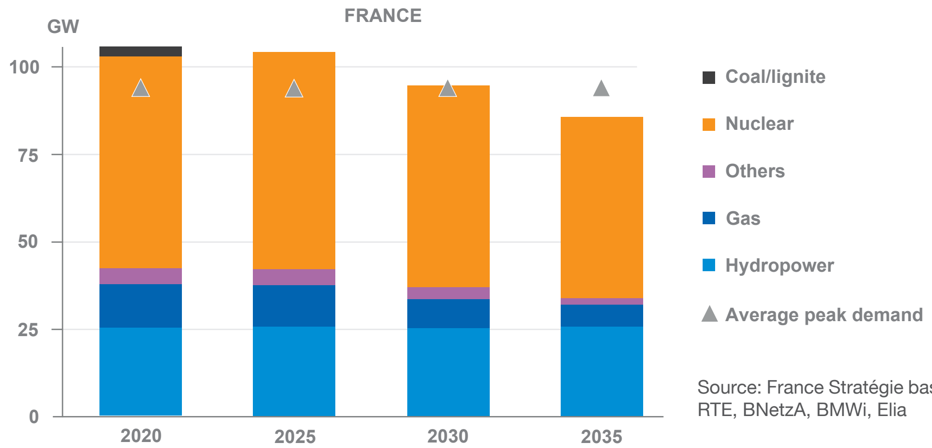
In its spreadsheet, France Stratégie integrated the parameters of this capacity mechanism for the seven countries studied. The assumptions retained for average peak demand are those contained in the publications of the bodies in charge of assessing security of supply (TSO, regulator or ministry) or academic bodies. The "capacity credits" are based on various scientific publications (references are provided in the appendix): average peak availability retained for onshore wind is 10%, 20% for offshore wind, which is much more regular, and 2% for solar PV, with peak demand generally occurring on winter evenings but increasingly also in the morning.[18] Graph 2 provides an overview of the intermittent renewable energy goals in the countries studied and their average guaranteed power.

The application of these criteria does not guarantee security of supply in all situations. RTE, in accordance with regulatory provisions, conducts its studies on the basis of a loss of load probability of three hours per year. However, it has detected several "stress test"[19] situations, in particular a long cold spell (of the type that occurred in February 2012), windless spells resulting in very low wind generation (at the beginning of January 2017, the load factor of French wind farms was sometimes 1%) or the simultaneous and unforeseen unavailability of several nuclear reactors.

France Stratégie does not have the means to carry out the simulations that can be performed by specialists; consequently, it refers to the levels of capacity obligation placed on producers and suppliers. However, the assessments carried out constitute a good "proxy" as they reveal deviations from the average, the importance of which indicates that there is a problem regarding the adequacy of the electricity mix in any case. The magnitude of the risks involved is such that, if solutions are not found, we are entitled to demand much more detail on the simulations proving that we could overcome windless and sunless days.

The notion of "magnitude of risk" also deserves consideration because the relationship between the duration of failure and the power deficit is not linear. For example, RTE announces that "moreover, certain combinations of particularly unfavourable contingencies lead to relatively high failure durations: there is therefore a one in twenty chance of having almost thirty hours of failure during the harshest winter, in 2022-2023."[20] This event is certainly rare (and most likely corresponds to a long, cold and windless period), but its consequences are potentially more serious than ten three-hour failures combined. It would be useful if RTE's probabilistic studies were supplemented by economic assessments of the consequences of the most extreme contingencies observed.

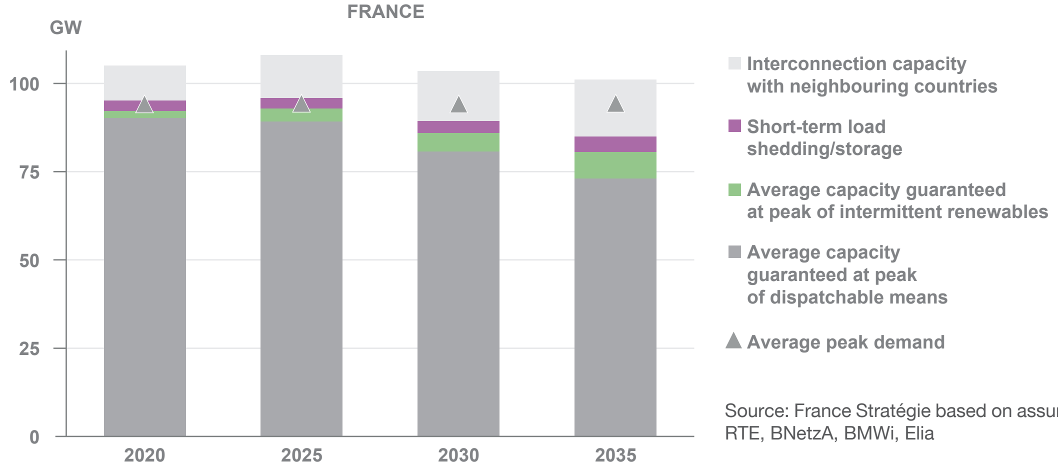
Graph 3 - Forecast of dispatchable electricity production capacity in France excluding interconnection (2020-2035)



Source: France Stratégie based on assumptions of RTE, BNetzA, BMWi, Elia

16. RTE, 2019 projected supply estimate, technical report, p. 31.
17. For a more detailed definition: https://www.services-rte.com/fr/decouvrez-nos-offres-de-services/participez-au-mecanisme-de-capacite.html.
18. The contribution of solar PV is expected to increase with the possibility of storing this energy for a few hours during the day, but this remains uncertain over a 10-year time span.
19. RTE, 2019 projected supply estimate, p. 35.
20. RTE, 2019 projected supply estimate, p. 93 (as the estimate was published before the health crisis, this date can be brought forward).

Graphique 4 – Forecast of average electricity capacity available at peak consumption in France (2020-2035)



Source: France Stratégie based on assumptions by RTE, BNetzA, BMWi, Elia

France, Germany and Belgium have the greatest dispatchable power deficits

For the seven countries studied, if no dispatchable means other than those already foreseen are added to the grid during this period and assuming that the renewable-energy development goals are respected, the margins increase from +34 GW in 2020, to +16 GW in 2025, then become negative at -7.5 GW in 2030 and -10 GW in 2035. However, these figures hide disparities between Spain, Italy and Switzerland, on the one hand, which maintain positive margins throughout the period, and France, Germany, Belgium and the United Kingdom, on the other, some of which become negative before 2025.

In the medium term, in France, coal-fired power plants are scheduled to be closed by 2022 at the latest, the share of nuclear power in the electricity mix is expected to fall from around 70% today to 50% in 2035, and the construction of power plants running exclusively on fossil fuels is now forbidden (see Graph 3 on the previous page).

Graph 4 integrates guaranteed average capacity of intermittent renewable energy sources at peak consumption. The years, 2020 and 2025 show slightly positive margins, 1 and 1.7 GW, respectively, very close to the forecasts of RTE[21] in its 2019 projected supply estimate, which makes it possible to validate the choice of abatement factors. In 2030 and 2035, without the construction of new dispatchable means, and assuming the trajectories of wind and photovoltaic power are respected, these margins become negative at around -5 GW and -9 GW.

Without the development of additional flexible solutions, France would have to rely on imports, knowing that at European level the margins are also negative, that it will not always be possible to rely on imports[22] to strike a supply-demand balance, and, it should be remembered, that not all countries will be able to import 100% of their interconnection capacity at the same time. Due to different lifestyles, the different electrification of the economy and sometimes different time zones between countries, tension does not necessarily occur at the same time, which brings a little flexibility to the European system, as the grid enables uses and production to thrive.

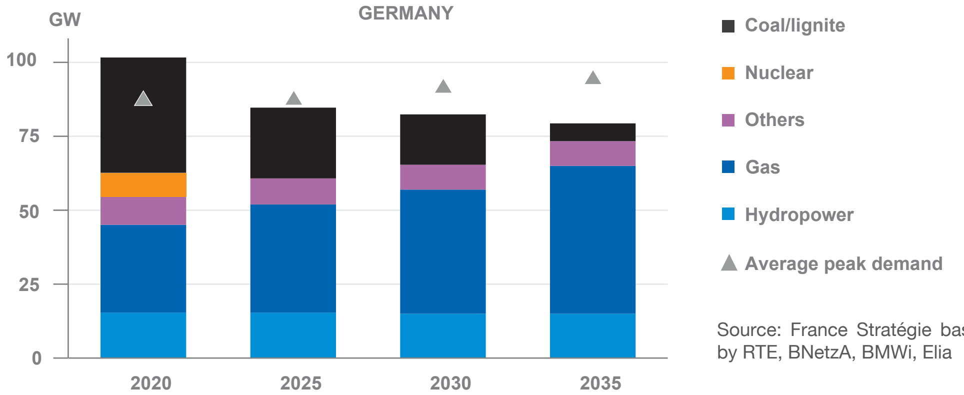
Achieving carbon neutrality by 2050 requires commitments to shut down fossil-fuel power plants to be fulfilled; in turn, the solutions to replace these future missing capacities are limited. However, meeting climate targets and ensuring reliable access to electricity in the medium term remains an open question as the government's choices have not yet been published.

In a November 2020 report[23], the think tank, EMBER regretted the fact that the French energy-climate plan "only provides data for 2023 and 2028", whether for energy production or demand. RTE makes a distinction between energy efficiency efforts to reduce consumption, and therefore the level of demand during winter peaks, and specific management of demand that makes it possible to eliminate daily peaks. Its potential and implications still receive insufficient public attention, whereas, according to RTE, "each of these actions can lead to a reduction in peak power demand of a few dozen to a few hundred megawatts", which remains modest for the moment and needs to be increased.

The situation is similar in Germany, where nuclear power is scheduled to be phased out in 2022 and coal is to be phased out in 2038. At this stage, the means to replace them remain to be determined (see Graph 5 on the next page). Gas-fired power plants are likely to play an important role. This poses a twofold problem: environmental, because they emit greenhouse gases, and geopolitical, because they are dependent on gas, especially from Russia. The tensions surrounding the Nord Stream II project illustrate this point.

21. Assessments made before the health crisis for 2020.
22. RTE's analyses indicate that our country already has to rely on interconnections to get through cold peaks.
23. Moore C. (2020), *Vision or division? What do National Energy and Climate Plans tell us about the EU power sector in 2030?*, EMBER, November.

Graph 5 - Forecast dispatchable electricity production capacity in Germany (2020-2035)



Source: France Stratégie based on assumptions by RTE, BNetzA, BMWi, Elia

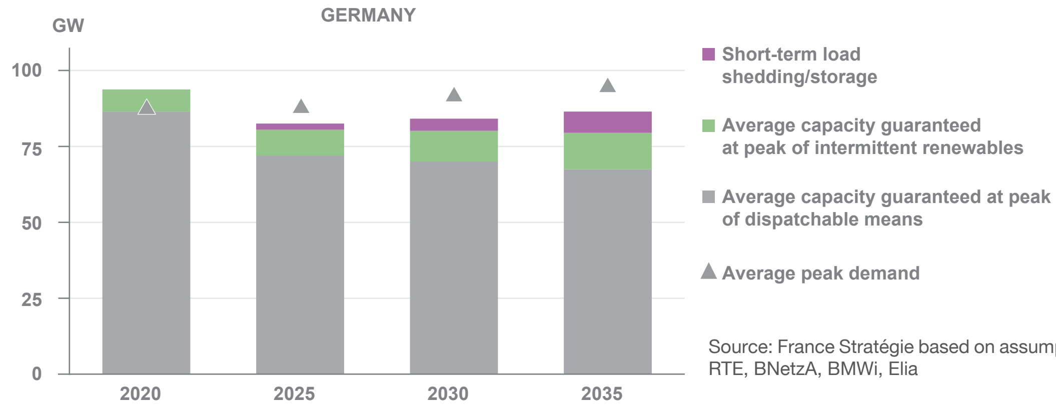
While the margins are positive by more than 6 GW in 2020, the guaranteed generation capacity deficit reaches -4 GW in 2025 and even before, with the last nuclear power plants and about 10 GW of coal-fired plants to be shut down before 2022 (see Graph 6 on the next page). This deficit remains stable until 2035, but there is some uncertainty, on the one hand, about the number of gas-fired power plants that will be installed and, on the other, about Germany's ability to meet particularly ambitious wind-power development targets. In fact, increasingly strong opposition has emerged to the construction of wind turbines and of the high-voltage lines needed to carry the current produced.

The European electricity system, and in particular the French, Belgian and German systems, is therefore entering a decade of transition, the major issues of which are slow to receive public attention. A share of missing dispatchable power has to be rebuilt, while electricity production capacity is characterised by relatively long construction periods of around a decade. The technologies likely to meet demand within the next ten years are primarily those that are currently available. This limits the range of possibilities up to 2030, and even 2035. Moreover, decarbonised technologies are very capital intensive to mobilise, while return-on-investment periods are long. It is therefore advisable, from now on, to address these issues while taking into account all these dimensions.

A high share of intermittent renewables in the electricity mix increases the probability of grid destabilisation and makes it more complex to manage

Until the beginning of 2010, the first gigawatts of installed power from intermittent renewable energy were absorbed without affecting the balance of the power system, as the share of dispatchable power plants was dominant. However, the situation completely changes when this proportion is reversed - as shown in Graphs 1 and 2 - and the total installed power of intermittent renewable energy far exceeds demand during consumption troughs, reaching almost three times as much in 2035. These situations, typical of non-working days from May to August, but potentially also of a mild and very windy end-of-year festive period, are just as critical for the electrical system. They increasingly frequently lead to negative prices on the markets, proof that some producers lack the flexibility to manage their power plants.[24] These negative prices constitute incentives to consume power during these troughs, which should be better exploited by players who have access to them (large industrial consumers or suppliers that can offer special contracts to their customers).

Graph 6 - Forecast of average available electrical capacity at the peak of consumption in Germany (2020-2035)



Source: France Stratégie based on assumptions by RTE, BNetzA, BMWi, Elia

24. Some plants are "must-run", like nuclear power plants at the end of their fuel cycle, or have to remain at constant power to stabilise core neutron fluxes, either because the costs of shutdown and restart operations are prohibitive or because the equipment degrades during load monitoring, which has a cost.

Furthermore, high proportions of intermittent renewable energy make it more difficult to manage the grid, as shown by the first Covid-19 lockdown period.[25] The appearance of increasingly frequent periods of congestion on the grids, particularly on the distribution networks, forces the TSOs[26] to carry out "redispatching" and to selectively disconnect a certain number of installations (known as "curtailment"). These operations are all the more complex[27] as renewables have priority when it comes to the injection of energy sources into the grid, are widely distributed throughout the country and can experience very rapid variations in production. The Capgemini Observatory pointed out in its edition dated 3 November 2020[28] that Germany and the United Kingdom suffered for these reasons from near black-outs on 21 April and 23 March 2020, respectively, in the midst of the Covid-19 crisis, as network operators ran out of means to maintain the balance of the system. During this period, consumption had fallen, making it possible to analyse *in vivo* the impact of a larger proportion of intermittent renewable energy sources. For Capgemini, the grids and regulations are not yet adapted to cope with the high proportion of renewable energy sources expected by the end of the decade. In Great Britain, for example, the grid operator, National Grid, has asked the regulator, OFGEM, to change the regulations in this respect.

The more extensive the system, the greater the possibility of benefiting from complementarities between different areas of production and consumption. As various studies[29-30-31-32] have shown, a small non-interconnected system (an electric island) becomes unstable with less than 20% intermittent renewable energy (in energy). This threshold is currently estimated at 40% for the European electricity system as a whole.

The European mix in 2020 is composed of around 20% intermittent renewable energy[33], but this figure masks great disparities between countries. Thus, while the proportion is around 60% in Denmark and 35% in Germany, it is only 5% in most Eastern European countries and 10% in France. The case of Denmark stands out because this country is a veritable electric "corridor" between Scandinavia, which is well endowed with hydroelectric power stations, and Germany. The latter benefits from its central geographical position and its strong interconnection with neighbouring countries enables it to easily export its surplus electricity or to import electricity, when necessary.[34]

Box 2 – Energy transition in California: a mixed success story?[35]

California is a pioneer in the accelerated liberalisation of the electricity sector and the rapid development of renewable energies. It was confronted earlier than others with the pitfalls of failing to anticipate the technical constraints associated with these ambitions. Black-outs, frequent in the 2000s due to the lack of planning and coordination of the players and infrastructure (the ENRON scandal was an indirect consequence), are once more a reality for Californians. In the summer of 2020, in particular, power cuts occurred due to a shortage of production capacity in relation to demand. Between 2010 and 2019, its fleet of conventional power plants fell from around 50 GW to 43 GW[36], while peak demand remained stable and not very flexible. 33% of its electricity production (excluding large hydroelectric plants) is from renewable sources, and the state's battery storage capacity, approximately a few hundred megawatts, remains insufficient.

Adapting the grids and developing demand flexibility

RTE, in its work on medium-term network development plans (SDDR) and in its projected supply estimates, insists on these needs for flexibility, which are substantial in all scenarios up to 2035. Mountainous sites capable of hosting hydraulic pumping stations in Europe are practically all equipped with these stations. As an alternative to curtailment, the possibility of using the hours of surplus intermittent energy to produce hydrogen by electrolysis (*power-to-gas*) to reuse it elsewhere is often mentioned. For RTE,

25. Beeker É. and Dégremont M. (2020), "Impacts de la crise du Covid-19 sur le système électrique", (Effects of the Covid-19 crisis on the electricity system) *Point de vue*, France Stratégie, April.
26. Transmission System Operators, generally responsible for forecasting studies on the country's security of supply (in France, RTE).
27. The term "acrobatic" was used at the time by F. Brottes, Chairman of RTE.
28. 22nd edition of the World Energy Markets Observatory, Capgemini, November 2020.
29. Hirth L. (2016), "The Optimal Share of Variable Renewables", *The Energy Journal*, n° 36.
30. Burtin A. and Silva V. (2015), *Technical and economic analysis of the European electricity system with 60 % RES*, EDF, R&D, June; RTE (2019), "Schéma décennal de développement du réseau"; ENTSO-E (2020), *Ten-Year Network Development Plan. Completing the Map - Power system needs in 2030 and 2040 - Draft version prior to public consultation*, August.
31. Keppler J. H. and Cometto M. (2013), "L'interaction entre les énergies nucléaires et renouvelables et ses effets systémiques dans les réseaux électriques bas carbone", (The interaction between nuclear and renewable energy sources and its systemic effects on low-carbon electricity grids) *Annales des Mines - Responsabilité et environnement*, vol. 69, n° 1, p. 29-35.
32. Finon D. (2020), "Évaluer le coût des politiques climat-énergie à base de renouvelables. Du bon usage des modèles d'optimisation sectorielle", (Assessing the cost of renewable energy-based climate-energy policies. Correct use of sectoral optimisation models) in *Revue française d'économie*, 2020/2 (vol. XXXV), pp. 81-127.
33. https://ember-climate.org/project/renewables-beat-fossil-fuels/
34. This does not prevent Germany from experiencing grid congestion between the north and south of the country in these situations, with the construction of EHV lines being hampered by opposition from part of the population. The surplus electricity then passes through certain neighbouring countries (*loop-flows*) whose grids can suffer serious disruptions.
35. See Dégremont M. (2020), "Même la Californie peine à relever le défi de l'électricité verte", (Even California is struggling to tackle the challenge posed by green electricity) in La Recherche, No. 563, November-January 2021. Available online: https://www.larecherche.fr/chronique-transition-%C3%A9nerg%C3%A9tique-climat-energie/m%C3%AAme-la-californie-peine-%C3%A0-relever-le-d%C3%A9fi-de
36. https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/electric-generation-capacity-and-energy https://www.caiso.com/Documents/CaliforniaISOPeakLoadHistory.pdf.

this solution does not appear to be economically viable before 2030-2035, as the installation's service life is insufficient to amortise the investment to make the installation profitable.[38] However, this does not solve the question of long-term storage because the reconversion of this hydrogen into electricity is not conceivable before an even later date, due to the low efficiency rates.[38]

Regarding the short term, i.e. on the same day, solutions that reduce the risk of failure and costs for the system emerge, such as decentralised and short-term storage[39] and demand management.[40] However, the regulation of these solutions, particularly in terms of tariffs, whose economic equation needs to be confirmed, remains inadequate and their pace of development between now and 2030 is uncertain. These solutions are limited, as they do not allow energy to be moved from one season to another.

To date, the grids remain the primary vehicle for the integration of intermittent renewable energy, but their development is hampered by opposition from part of the population, as shown by the German example (see footnote 35). Moreover, economic regulations, in particular of distribution networks, do not fully reflect their new role[41]. In its SDDR published in September 2019, RTE also pointed out the risk of deoptimizing the system if the lack of coordination of investments and regional action plans is not resolved.

UNCOORDINATED TRANSITION AT THE EUROPEAN LEVEL ADDS TO THIS FRAGILITY

Interdependent national electricity systems

In RTE's 2017 projected supply estimate, all the scenarios studied show an increase in electricity exchanges, and underline the importance of technical and economic integration on a European scale to manage intermittency and optimise production capacity. The economic development and management of the French system and of each of the national systems depend largely on the development of the fleets in other European countries.

The choices of individual European states have an impact on the range of possible policy decisions regarding the national energy mix. Although all Member States recognise such interdependency, coordination between them remains limited. The Electricity Coordination Group, which enables an exchange of views between regulators, grid operators, the European Commission and Member States, seems to play a secondary role in this respect. The Pentalateral Energy Forum seeks to establish policy dialogue between regulators, grid operators, market players and national executives for Germany, Benelux, France, Austria and Switzerland. However, the structural decisions are made independently, with Member States taking advantage of their right enshrined in European law (TFEU, Article 194) to decide alone on their supply and the structure of their electricity mix.

Germany's decision to withdraw from nuclear power in 2011 was unilateral (like that of Belgium and other countries), and its withdrawal from coal was organised on an administrative level outside the European framework. Great Britain, after having led Europe in the 1990s towards market liberalisation, including energy markets, decided in 2014 to go it alone by retaking control of its electricity sector. It introduced Contracts for Difference, which can be described as a long-term guaranteed feed-in tariff, which gives investors visibility, determines an optimal mix and remunerates assets through an auction system. At the same time, this country unilaterally implemented a carbon floor price that enabled it to withdraw from coal within a few years.

These decisions alter the structure of available generation solutions and demand on an interconnected European grid, which is governed by market rules on this scale. We have thus seen that several Member States rely on imports to ensure their security of supply, while these decisions concern the sovereignty of neighbouring states.

Furthermore, although the extent of the consequences of the health crisis on the energy sector is still unknown, the health crisis makes it all the more important to reflect on the role played by public authorities in steering strategic investments. Energy companies have been in a weak financial position for several years - a situation that can only be amplified by the crisis - which undermines their ability to make long-term investments. On a global level, the IEA anticipates a 20% drop in investments in the electricity sector in 2020, which could be lasting and threaten the fulfilment of our energy and climate goals.

The European electricity sector awaits reorganisation

These reasons support the need for the priorities given to national and European energy policies to be clarified. This is all the more pressing as the organisation of the European electricity sector has many weaknesses.

37. RTE (2020), The transition to low-carbon hydrogen, https://assets.rte-france.com/prod/public/2020-07/rapport%20hydrogene.pdf.
38. Académie des technologies (2020), *Hydrogen, the new green eldorado?* Report, July.
39. RTE, in its 2017 projected supply estimate, estimates that the volume of energy consumed per day that needs to be moved should increase from around 60 GWh in 2017 to a level of 95 to 130 TWh in 2035.
40. Etienne Beeker (2019), *Les réseaux de distribution d'électricité dans la transition énergétique, op. cit*. See, among others, the chapter on digital technology.
41. *Ibid*.

Several publications, such as those of France Stratégie,[42] have analysed the causes of these weaknesses. The arrival of massive quantities of intermittent renewable energy, with almost zero marginal costs, without taking into account the conditions of integration into the power system, has led to a fall in wholesale market prices, which are increasingly negative. This market is no longer able to trigger the investments necessary for the energy transition process, or simply for maintaining reliable access to electricity.

In order to make up for the deficiencies of this market, most Member States have set up capacity mechanisms, the aim of which is to enable and encourage these investments. However, they are very heterogeneous[43] and, above all, are not interconnected, each one retaining its own rules, as exemplified by the definition of the failure criterion (see above), whereas limited coordination makes it more difficult to optimise the mix and meet European goals in this respect. This criterion plays a structural role with regard to the measures to be taken in the areas of demand management and flexibility as well as production. Policy management fragmented between the different Member States and concerning an electricity system connected at the European Union level is therefore a weakness for the future. It may render the fulfilment of climate ambitions under satisfactory economic conditions hypothetical.

For illustration purposes, in 2014 the BMWi[44] welcomed the introduction of a capacity market in France. It saw this market as a means of encouraging the emergence of additional capacity in our country that would contribute to Germany's security of supply: "Power plant capacity in Germany can drop to the same extent as additional French power plant capacity is available for the electricity market in Germany through the cross-border interconnectors available."[45]

The new European regulation in this area (the Green Deal)[46] is ambitious and should strengthen coordination between Member States. It introduces reflections on technical and economic cooperation: European integration of balancing markets, coordination of grid operators, interconnection development objectives, technical dialogue on the convergence of security of supply criteria, etc. It reinforces the efforts towards harmonisation and technical convergence made by European grid operators several years ago, through the drawing up of concerted medium- and long-term network development plans or joint analyses of the capacity of grids to ensure security of supply (10-year network development plans, medium-term adequacy studies).

This new European governance framework tends to value virtuous investments from an environmental point of view, in particular with the green taxonomy. However, to ensure that its goals are met, it is essential to assume its political implications.

CONCLUSION

While electricity is a particular type of good, essential to the continuity of the nation's life, the situation of the electricity system calls for ambitious measures in the medium term to guarantee reliable and affordable access to carbon-free electricity. The tangible consequences of the shutdown of dispatchable conventional power plants, whether fossil-fuel or nuclear, in the coming decade seem to have received little public attention. On the other hand, very ambitious goals for the development of renewable energy sources have been set, while solutions in terms of piloting and managing demand, storage capacity and, more generally, flexibility and integration into the grid remain insufficiently developed at present. Above all, in order to reduce possible future tensions, it is necessary to conduct a proactive policy to manage energy consumption, such as the one the government is pursuing regarding the thermal renovation of housing. This "no-regrets" measure will also facilitate the electrification of uses such as heat pumps or electric mobility, which will have to be flexible so as to be able to reduce consumption peaks.

Concerning supply, with a 10-year time span (2030), investments can only be made in existing proven and mature technologies, without closing the door to innovation. Decarbonised energy sources present the particularity of a cost structure that mainly comprises CAPEX, while OPEX is hardly dependent on production. Their marginal costs are therefore very low and contribute to depressing energy-only market prices, which are insufficient to remunerate investments. Originally, capacity mechanisms were created to provide necessary additional remuneration, but the higher the proportion of decarbonised energy in the mix, the greater this additional remuneration, distorting the balance of remuneration between power and energy. For these reasons, in the very spirit of their designers, the capacity mechanisms were only intended to be a temporary solution.

42. Auverlot D., Beeker É., Hossie G., Oriol L. and Rigard-Cerison A. (2014), "La crise du système électrique européen. Diagnostic et solutions", (The crisis of the European electricity system. Diagnosis and solutions) January; France Stratégie
43. Broadly speaking, a system of strategic reserves, retained by the Germans, or capacity markets, retained by France, coexist.
44. Federal Ministry for Economic Affairs and Energy of Germany.
45. Federal Ministry for Economic Affairs and Energy (2014), *An Electricity Market for Germany's Energy Transition (Green Paper)*, October. https://institutdelors.eu/wp-content/uploads/2018/01/mecanismescapacite-grigorjeva-jdib-mai15.pdf
46. Legislative package 'Clean Energy for all Europeans'.

RECOMMENDATIONS

More robust mechanisms to support decarbonised energy sources must be devised now. As the cost of projects is largely determined by their method of financing[47], the involvement of the state can be an asset. Its forms remain to be defined and discussed: long-term contracts guaranteeing a level of remuneration for the electricity produced, additional remuneration, "contracts for difference" based on the British model, direct financing of the investment by the public authorities, for example.

Mature renewable energy sources pose specific grid integration problems, even though they are expected to see their share of power exceed that of conventional power plants in the short term. In order not to risk rendering the power system unmanageable, they must be able to contribute to its technical balance as quickly as possible (participation in the reserve, handling of grid congestion, etc.).[48]

At the European level, it can be observed that, in contradiction with climate-change and energy-independence goals, several European countries have decided to offset the shutdown of coal-fired or nuclear power plants by commissioning gas-fired plants, a flexible means of production that requires little capital. This is being done urgently for some (Belgium), in a more planned way for other countries (Italy, Germany, Spain) or on a forward-looking basis for others (Eastern European countries).

Rather than focusing on the means to achieve this, Community policy must put the goal of reducing greenhouse gas emissions first in order to put investments on a course that is consistent with our goals for 2050. The European carbon market is still waiting for structural reforms that provide a clear price signal for long-term investments. The introduction of floor and cap prices should be closely studied.

If Member States wish to continue to play an important role in the choice of the general structure of their energy supply, and therefore to retain the freedom to choose their capacity mechanism, coordination between European governments is essential. This must occur without undermining the principle of subsidiarity through work that seeks to make the various national scenarios consistent. Cooperation does exist, but it should be strengthened and institutionalised as soon as possible, for example through working groups common to the various governments.

The measures advocated by the new EU legislative package are a step in this direction but are still insufficient to provide the right economic signals. With regard to security of supply, the level of assurance chosen and the means to be devoted to it are not made explicit, even though it constrains the choices regarding the energy mix and has repercussions on their financing and proper functioning.

This coordination must include reflections on industrial policies to bring the objectives into line with the technological means available to Europe, and on geostrategy, identifying the external resources on which industrial policies depend and the conditions of access to them. They must also include new risks to power systems, such as cyber-terrorism.

Keywords: security of supply, electricity system, black-out, renewable energies, renewable energy sources, European energy policy

47. Cour des Comptes (2020), (Court of Auditors) *La filière EPR*, (The EPR sector) July.
48. Some of the recommendations of the aforementioned 2014 report are therefore still valid, as are those drawn up in November 2019: (https://www.strategie.gouv.fr/sites/strategie.gouv.fr/files/atoms/files/fs-2019-dt-systeme-electrique-auverlot-novembre.pdf) by the same experts.

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Head of Department Edition-Communications-Events,
01 42 75 61 37, matthias.lefur@strategie.gouv.fr