Long-term Adequacy Report
on the electricity supply-demand balance in France

2017 EDITION
A new Long-Term Adequacy Report included in the public energy debate and providing an overview of potential developments in the electricity mix by 2035

2018-2025: choices to be made to further diversify the electricity mix and ensure security of electricity supply

2025-2035: contrasting scenarios to guide in the decisions that will build the power system of tomorrow

“No-regret” options common to all scenarios emerge

Points to consider regarding security of supply

Economic balances assessed with regard to energy markets and to the evolution of the European mix

Differential impacts on carbon dioxide emissions from the power system

A report driven by an incentive for further consultation and more in-depth analysis
A NEW LONG-TERM ADEQUACY REPORT
INCLUDED IN THE PUBLIC DEBATE AND
PROVIDING AN OVERVIEW OF POTENTIAL
DEVELOPMENTS IN THE ELECTRICITY MIX BY 2035

The Long-Term Adequacy Report is a comprehensive study of the evolution of electricity generation and consumption and of the solutions to ensure the balance of these. It is provided for by the French Energy Code, which presents its objectives and the conditions under which it is drafted.

This is a reference document linking short-term decisions with long-term developments in the power system.

The legislator has entrusted this task to RTE, a public service company responsible for operating the electricity transmission system and whose independence and neutrality in respect of electricity producers and suppliers are guaranteed under European and French law.

The 2017 edition covers a crucial period: it explores several scenarios for the evolution of the electricity mix between 2018 and 2035.

Several innovations have been introduced:
- the assumptions were the subject of a public consultation of all interested stakeholders (suppliers, producers, electricity and gas distributors, professional organizations, NGOs, think tanks, academics, institutions);
- the economic coherence of the scenarios has been strengthened;
- many variants were carried out to assess the sensitivity of the results to the evolutions of the context (for example: the pace of development of renewable energies).

Each scenario presents the evolution of consumption and generation of electricity, of carbon dioxide emissions from electricity generation in France and their impact on the emissions of the European electricity system, and cross-border electricity exchanges. They draw on an economic framework to supplement the analysis of the physical operation of the power system.

All of these developments were motivated by a desire to firmly establish this exercise as part of the public debate on the future of the power system.
The energy transition targets are set but there are significant uncertainties regarding their implementation

These energy transition targets are highly ambitious: carbon neutrality, reduction of energy consumption and diversification of the French electricity mix.

Their achievement has brought about the most significant change in the power sector since the creation of the nuclear power programme and affects all of its components:

- **Electricity consumption** has been stable since 2010 and seems to have reached a turning point in relation to the growth dynamic of the last several decades. Nevertheless, the prospects of electrification of certain sectors – such as transport, with the development of electric vehicles or plug-in hybrids – fuel the debates on the future of electricity consumption. Questions remain regarding the influence of these determinants on the evolution of electricity consumption over the course of the next few years.

- Major developments have taken place in the last several years in terms of electricity generating capacity, the most significant of which has been the development of renewable energies and the closure of many oil and coal-fired power plants. **Future developments and their temporal sequencing** require the support of a robust analysis of the margins of manoeuvre to guarantee the continuity and quality of the power supply for consumers.

- In terms of the carbon footprint, the signing of the Paris Agreement and the French Climate Plan has demonstrated the commitment to reducing greenhouse gas emissions. Future developments in France and Europe will remain in line with this objective. The consequences of diversifying the electricity generation mix on the performance of France, and more broadly of Europe in terms of greenhouse gas emissions reduction must therefore be analysed in order to gain a comprehensive and coherent approach.

- With regard to the economy, questions face European member states concerning financing of the energy transition. The key issues are to support renewable energies while achieving public objectives, the rise in carbon price, the sustainability of production facilities useful to the power system to ensure security of supply, and the costs passed down to the consumer. The question of funding and **return on investment cannot be overlooked in the context of the study** on the evolution of the power system.

- **Regarding European solidarity,** “the Europe of electricity” has become a reality. Today European markets determine the effective use of generation sources in each country, and thus ensure that only the most economic power plants operate in Europe. We can no longer consider the electricity generation mix as an exclusively national issue. France’s energy transition cannot occur without taking into consideration decisions or discussions among our neighbouring countries. Nevertheless, within the scope of building a Europe of electricity, special attention must be paid to the distribution of expertise between the European Commission and the Member States concerning future developments of the power system. The European Commission’s “Clean Energy for All Europeans” constitutes a key factor in the discussions on this issue.

- In terms of technological innovation, many areas of research or demonstration have opened up without necessarily progressing to industrial stage in future. Enthusiasm for innovation in the electricity sector reflects the importance of the issues. **Future technological advances should be carefully considered so that the power system of tomorrow doesn’t stay “stuck” in today’s technologies,** while maintaining a cautious approach to some solutions reaching the point of technological maturity.

All of these elements are issues which have been discussed during the consultation and integrated into the different scenarios of the Long-Term Adequacy Report.
New scenarios centred on diversification of the electricity mix

The RTE approach differs from the majority of outlooks in the sense that it must consider several scenarios in depth and present a contrasting vision of the evolution of the power system.

There is therefore no single scenario but rather several scenarios; there is no one result or one path to follow but several options and milestones.

All of the analyses incorporate the principle of diversification of the electricity mix: this was the central prevailing assumption when preparing the 2017 Long-Term Adequacy Report.

2018-2022: The analyses aim to identify potential actions on the electricity mix in light of the objectives defined or announced by the public authorities.

The work is centred on the closure of coal-fired power plants and the shutdown of the first nuclear reactors after 40 years of operation\(^1\). This includes an analysis of the mutual dependence between the implementation of these measures and the development of renewable energies or the evolution of power consumption.

The question of extending lifetimes of nuclear reactors beyond 40 years of operation has also been studied to better understand the impact of potential “long” 10-year inspections on the balance of the power system. The conclusions of the Nuclear Safety Authority on extending the lifetimes of reactors could lead us to revisit these analyses.

2022-2035: Five scenarios were studied to present different energy transition options in terms of renewable energies, nuclear power, the carbon footprint, and the role of new technologies or gas generation sources. These outline the conditions to be met to implement a given target (50 percent nuclear energy in the power generation by 2025, technical decommissioning of nuclear power plants, etc.): nothing is impossible when developing these scenarios.

The Ohm scenario describes the range of solutions to be implemented to date to comply with the legislative framework set by the French Energy Transition for Green Growth Act for 2025. In all of the scenarios studied, the analyses identify the major challenges in the area of carbon dioxide emissions, evolutions in nuclear generating capacity and the requirements of new sources (renewable and thermal).

The four other scenarios concern the years 2025, 2030 and 2035. They presuppose the closure of coal-fired power plants and the impossibility of building new ones.

Under the Ampere scenario, the decrease in the share of nuclear energy in power generation occurs without the use of new thermal generation sources. Some reactors can be shut down after 40 years of operation if the development of renewable energies is sufficient to allow a same level of power generation while respecting security of supply. This scenario predicts the date on which the target of 50 percent nuclear energy in the power generation can be reached in a context of intense development of renewables. Once this is achieved, the decommissioning of reactors will cease.

Under the Hertz scenario, diversification of the electricity mix takes place in a context of slower development of renewable sources whilst relying on new thermal generation sources. This evolution has been studied from the standpoint of respecting a ceiling for carbon dioxide emissions so as not to impair the environmental performance of the French power generation capacity. This scenario makes it possible to study the role of thermal power generation in achieving the objective of 50% nuclear share in electricity generation. As in the Ampere scenario, the decommissioning of reactors will end once this goal is achieved.

Under the Volt scenario, the development of renewable energies will accelerate in relation

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1. The 40 years of operation are understood in this document to be the theoretical release date of the report of the fourth ten-year inspection of nuclear reactors.
to the current situation, and the share of nuclear energy in the mix is will evolve as a function of economic opportunities. This scenario looks at the reasoning of diversifying the electricity mix while integrating economic governance in relation to European electricity market opportunities for French generation at low variable costs (generation from renewables or nuclear power).

Under the Watt scenario, nuclear reactors would be shut down on a basis of technical decommissioning (no extension of operating permit beyond 40 years - initial assumption laid down during the design of certain materials and equipment of reactors), and the development of renewable energies would be managed in a proactive manner. This scenario assesses the consequences of a situation in which France would need to rapidly cut back on its nuclear generation units. It raises the question of potential technologies available for ensuring the energy transition, and is an opportunity to study a generation mix which includes a very high penetration of renewable energy.
Scenarios constructed on a coherent economic platform and for which robustness is assessed through many variants

Each scenario is characterized by a set of key parameters, including the group “electricity consumption – renewable generation – nuclear production”.

For all scenarios:

- **a base case was defined.** This was done according to a principle of macroeconomic consistency between all of the key parameters. For example, energy efficiency is greater when GDP is high, and the pace of development of renewable energies is greater when the carbon price is high.

- **variants were established.** These provide an opportunity to vary the key parameters (individually or simultaneously) in order to analyse the robustness of the results presented in the base case and identify the balance and tipping points. For example, they highlight the sensitivity of the results in terms of the development of interconnections between France and its neighbours, developments in generating capacity in Europe or a change in the price of fuels.

The sets of key parameters for a scenario (base case and variants) were therefore defined prior to the simulations. The simulations pertain to the operation of the power system measured “on an hourly basis”, i.e.: 8,760 hours per year: these help identify additional sources of generation or flexibility (gas-fired plants, demand response, storage, renewable energies developed beyond just “input data”) which must be integrated to ensure the balance between generation and consumption and to respect the security of supply criteria defined by the public authorities.

The results are obtained on the basis of:

- **physical Long-Term Adequacy:** this involves verifying whether the power system can effectively operate and guarantee security of supply, which is evaluated every hour of the year by testing 1,000 combinations of variables each time.

- an economic viability assessment: this involves verifying whether the additional sources of generation or flexibility identified in the scenario are profitable on the electricity markets, so as only to “count on” generation plants in which economic actors are actually likely to invest. This requires simulating the operation of European electricity markets and taking into account generation capacity developments in Europe.

Following these simulations, the results are analysed:

- to gain an overview of the evolution of the production mix (in the base case and variants to identify tipping points);

- to shed light on the operating conditions of the power system. For example, France is highly susceptible to winter cold spells. In an electricity generation mix composed predominantly of renewable energies, the risks can vary. These are the points evaluated and presented in the Long-Term Adequacy Report;

- assess the economic relevance of scenarios and variants. For example, variants are used to ascertain whether the trajectory of interconnections retained in the “base case” is coherent from an economic perspective and whether it is a significant element of investment in the power system. The influence of the different parameters on energy prices (European electricity markets) is also taken into account.

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2. In the Long-Term Adequacy Report, eleven countries have been modelled in addition to France.
Building the sets of parameters for the scenarios and their variants

**Electricity demand**

For the sake of readability, this diagram shows the evolution of power consumption only.

**Renewables**

* French Multiannual Energy Programme

For the sake of readability, this diagram only shows the evolution of onshore wind power.

**Nuclear power**

**Fuel costs**

**Interconnections**

For the sake of readability, import capacities are presented in this diagram only.

**European countries**

Simulation carried out over 8,760 hours per year (‘on an hourly basis’) until 2035, taking into account the operation of the electricity markets.

**Hertz Scenario**

**Herz variant**

Sensitivity Devt. RES
A selection of the variants reported in the Long-Term Adequacy Report

A survey of the variants identified around 15,000 possible variants. RTE studied a hundred of them to establish the scenarios, and have reported the results from the 50 most relevant variants in the reference document and its appendices.

The objective of this summary document is to present the main results of the scenarios and to build on the results of the principal variants.

In this way we can identify the major “tipping points” and the major elements for assessment specific to each scenario and to their comparison.

A reference document completes this summary to provide an accurate and detailed analysis of the scenarios and their structuring variants.

The inventory of the variants and the detailed analyses will be presented within the context of the consultation led by RTE to supplement the work and identify areas for further study.

- 5 scenarios + several analyses over the next five years
- 15,000 possible variants
- 100 variants carried out
- 50 structuring variants recorded in the reference document of the Long-Term Adequacy Report
- For each variant, 1,000 simulations were performed to take into account the various climate scenarios as well as the availability of generation units = 50,000 simulations made for each hour of the year
A repository of electricity consumption established specifically for the Long-Term Adequacy Report (energy, power, profile)

For the first time, all of the power consumption trajectories presented by RTE are stable or show a downward trend over the long term. This is a strong outcome of the Long-Term Adequacy Report 2017, widely discussed during the public consultation.

The analyses show that the effects of the downward trend brought on by energy efficiency – through regulations and the continuing improvement in performance of equipment – can equal or exceed the effects of the upward trend resulting from changes in use. France is therefore at a turning point in terms of power consumption.

All of the electricity consumption trajectories take into account transfers towards electricity use and the development of new uses for electricity which could lead to an increase in power consumption, other things being equal. These transfers are marked and, for some trajectories, very ambitious. For example, a fleet of 15.6 million electric vehicles is provided for in RTE’s “high” trajectory and corresponds to a proactive approach compatible with the objectives of the French Climate Plan announced in July 2017.

A number of socioeconomic effects are also taken into account: economic growth, demographic changes, changes in household composition due to “decohabitation” (and, where relevant, “recohabitation”), etc.

The analysis of the effects of energy efficiency on electricity consumption is presented according to sector and use. This includes factors which may moderate the impact, such as the “rebound effect” that could result from increased thermal comfort as a result of insulation work on houses.
2018-2025: CHOICES TO BE MADE TO CONTINUE THE DIVERSIFICATION OF THE ELECTRICITY MIX AND TO ENSURE THE SECURITY OF ELECTRICITY SUPPLY

2018-2020: A “balanced” power system in terms of the public criterion of security of supply, but with no room for manoeuvre

The situation over the next three years is the one we are familiar with today in France: the generating capacity is adjusted, the criterion of security of supply is respected and the operation of the power system is more frequently subject to extreme situations – as was the case during the cold spell of January 2017 and announced by RTE for the winter 2017-2018.

European studies carried out by ENTSO-E or by the Pentalateral Energy Forum\(^3\) have revealed that this is a specific feature of the French system. Other European countries currently have higher operating margins\(^4\).

The closure of additional power generation sources (coal or nuclear) is therefore not possible on the very short term without negatively impacting security of supply.

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3. Forum bringing together Germany, Austria, Belgium, France, Luxembourg, the Netherlands and Switzerland.
4. With the exception of Great Britain which has faced a tense situation over the last years.
**2020-2022: There are various options for the phasing out of coal or the shutdown of nuclear reactors after 40 years of operation**

From 2020, changes in electricity demand along with the arrival of new electricity generation sources (the Landivisiau gas-fired power plant and the first offshore wind farms) and new interconnections (with Italy and the United Kingdom) will represent opportunities for a new wave of developments in France’s generation capacity.

**Between 2020 and 2022, the analysis has shown it is feasible to close all of the coal-fired plants or to shut down the four nuclear reactors reaching the 40-year operating lifetime by the end of 2021**: Tricastin 1, Bugey 2, Tricastin 2, Bugey 3.

The closure of both the coal-fired power plants and the four nuclear reactors cannot be combined without negatively affecting the security of supply, and a choice must therefore be made.

The number of nuclear reactors reaching the end of their 40-year operating lifetime will rise significantly from 2022. A rate of closure based on this end of lifetime could therefore not be sustained over time without negatively impacting the security of supply if this is not done alongside the implementation of new resources. This point has been developed in the scenarios covering the 2025 to 2035 period.

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**Evaluation of the impact of the closure of nuclear reactors and the closure of the coal-fired generation capacity on security of supply**

![Graph showing the impact of various scenarios](image)

*The security of supply criterion is respected when the curves are situated in the upper part or equal to 0*

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5. The shutdown of the Dampierre 1 reactor (February 2022) falls within the time horizon of the study but would essentially affect the winter of 2022-2023.
6. The two Fessenheim reactors will be considered as closed down on the commissioning of the Flamanville EPR, in accordance with the provisions of Decree n° 2017-508 of 8 April 2017.
Where relevant, special attention should be paid to the conditions for extending the lifespan of nuclear reactors and particularly to the duration of works requiring their shut down. In fact, prolonging the lifespan of nuclear reactors beyond 40 years is a major step and subject to the generic opinion of the Nuclear Safety Authority. The NSA recently announced that the outcome of this opinion will be published in 2021. The scale and duration of the works are elements of uncertainty.

RTE has conducted sensitivity analyses to measure the impact on the security of supply of a shutdown of nuclear reactors for a duration of one year. This would make them unavailable during an entire winter before the completion of their 10-year inspection. In these analyses, coal-fired power plants would be closed between 2021 and 2022.

These analyses show that long-term works on the reactors concerned could negatively affect the security of supply. The conclusion remains valid if some nuclear reactors are closed, along with coal-fired power plants, and that only a part of the nuclear reactors is stopped to carry out long term works for a lifespan extension.

The sensitivity analyses thus reinforce the message of caution over the period 2018-2022 and on the need to make choices that are sequenced in a consistent manner to maintain the level of security of supply, while carrying out actions for the development of the electricity generating capacity.

2020-2025: difficulties to combine the objective of 50 percent nuclear power in the electricity generation mix and the reduction of carbon dioxide emissions from the electric power sector

In the absence of additional operating margins prior to 2020, a major upheaval in the electricity generating capacity would be needed to reach the target of 50 percent nuclear power in France’s generation in five years:

- 22 GW of nuclear capacity, corresponding to 24 “900 MW” reactors, would need to be shut down if the pace of development of renewable energies accelerates to reach the high objective set forth in the French Multiannual Energy Programme (PPE). In practice, this would require closing the 22 reactors nearing their 40-year operating lifespan by 2025 and to anticipate the closure of two additional reactors before the end of their operating license. By way of comparison, the nuclear power phase-out plan announced by the German Government in 2011 provides for the closure of an installed capacity of 21.5 GW in a little more than 10 years.
  - The closure of coal-fired power plants should be pushed back beyond 2025.
  - A significant number of new gas-fired power plants would have to be built (in addition to the current facilities) – corresponding to 11 GW of additional installed power, equivalent to the natural gas combined-cycle capacity currently in operation. The long-term profitability of some of these sources is not guaranteed in light of the development of renewable energy in France and in Europe, which will continue beyond 2025.

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7. Extended to 2025.
8. Additional gas-fired generation facilities could also be installed in place of the coal-fired power plants.
9. Or 14 GW of new facilities if the coal-fired power plants are closed.
All variants performed on this scenario confirm the evaluation of the number of nuclear reactors which would need to close to reach the target of 50 percent nuclear energy in electricity generation in 2025: the number of reactors to close is between 23 and 27. In all of the cases studied, reactors which have not reached 40 years of operational life cycle must be shut down.

Achievement of the target of 50 percent nuclear energy in electricity generation by 2025 will systematically lead to an increase in carbon dioxide emissions of the French power system.

These would reach levels between 38 and 55 million tonnes of carbon dioxide per year depending on the variants. This effect is particularly due to the development of new gas-fired power plants and to the continued operation of coal-fired power plants, with increased production in relation to the current situation.

This scenario highlights the issue, to date, with focusing on the achievement of 50 percent of nuclear generation by 2025 in the study of scenarios for evolution of the French electricity mix. It reinforces the need for scenarios developed on a less restricted time horizon.

### OHM Scenario

**Target set by law to reduce the share of nuclear power to 50 percent of generation by 2025**

#### Main results and assumptions for 2025

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<thead>
<tr>
<th>Category</th>
<th>Assumption</th>
<th>Quantity</th>
<th>Energy</th>
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<tr>
<td><strong>Renewables</strong></td>
<td></td>
<td><strong>88 GW</strong></td>
<td><strong>187 TWh</strong></td>
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<tr>
<td>Onshore wind power</td>
<td>30 GW (66 TWh)</td>
<td>26 GW (64 TWh)</td>
<td>10,500 wind turbines</td>
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<td>Offshore wind power</td>
<td>5 GW (16 TWh)</td>
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<td>24 GW (28 TWh)</td>
<td><strong>41 GW</strong></td>
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<td>Hydropower</td>
<td>26 GW (64 TWh)</td>
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<tr>
<td><strong>Nuclear power</strong></td>
<td></td>
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<td>-22 GW</td>
<td>Decrease in the capacity due to the decommissioning of 24 &quot;900 MW&quot; reactors*</td>
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<td><strong>CO₂</strong></td>
<td>22 €/t</td>
<td><strong>42 Mt CO₂</strong></td>
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* Excluding closure of the two Fessenheim reactors

**Fossil-fuel price assumptions based on the IEA “Current Policies Scenario”, prices expressed in €2016**

**Assessment**

- Continued operation of coal-fired power plants + 11 GW of gas-fired plant
- Decommissioning of nuclear reactors prior to their fourth ten-year inspection
- Increase in carbon dioxide emissions

**Energy mix for 2025**

- RES 34%
- Nuclear power 50%
- Thermal 16%
2025-2035: CONTRASTING SCENARIOS TO GUIDE THE DECISIONS THAT WILL BUILD THE POWER SYSTEM OF TOMORROW

The horizon 2035 is a good compromise for studying the dynamics of the power system transformation over the long term, while avoiding a purely prospective vision.

The evolution in generation capacity, consumption patterns, or electricity networks conforms to long time constants. The deployment of new facilities, regardless of their nature, constitutes a challenge for the various stakeholders in the electricity sector today, particularly in terms of the lengthy approval procedures. Issues regarding acceptance are particularly significant in France compared to other European countries, and can lead to even longer delays.

Besides the issues regarding the development of infrastructures as such, the amount of capital to raise for investments in the electricity sector, the sensitivity of the issues for the sector and the wide variety of stakeholders involved are all elements that contribute to extending these periods.

Accordingly, it is commonly accepted in the power sector that there is a significant amount of time between the moment decisions are made to invest in new infrastructure – whether from public authorities or private actors – and the moment they take effect.

In this way, unlike the 2022-2025 horizons, the system in 2035 will be a reflection of the decisions that will be taken today.

Alternatives facilities to replace the annual production of a 900-MW nuclear reactor

- Interconnection: 1,000 MW (10 years)
- Wind power: 2,700 MW (7 years)
- Combined cycle gas turbine: 800 MW (5 years)
- Solar power: 4,800 MW (4 years)

On a basis of operating at full power right throughout the year taking into account average availability.
A reduction in nuclear power generation to match the actual pace of development of renewable energy

Main results and assumptions for 2035

**Power Consumption**
- Approximately +2% of GDP per year
- 72.1 million inhabitants
- 34.2 million households
- 700,000 renovations per year
- 15.6 million electric vehicles
- 480 TWh

**Renewables**
- Onshore wind power: 52 GW (115 TWh)
  - Approximately 14,300 wind turbines
- Offshore wind power: 15 GW (47 TWh)
  - Approximately 2,200 wind turbines
- Photovoltaic: 48 GW (58 TWh)
- Hydropower: 26 GW (68 TWh)
- 149 GW
- 314 TWh

**Nuclear power**
- -14.5 GW
  - Decrease in the capacity due to the decommissioning of 16 “900 MW” reactors*
- 48.5 GW
- 294 TWh

* Excluding closure of the two Fessenheim reactors

**Europe**
- UE Substantial growth of RES: +327 GW
- D Decommissioning of coal and lignite-fired power plants: -27 GW
- GB Nuclear power: 4.5 GW

**CO₂**
- 12 Mt CO₂
- 108 €/t
- Emissions from the power system

**Assessment**
- Closure of coal-fired power plants
- No new additional thermal energy sources
- 50% nuclear energy target reached in 2030
- Reduction of CO₂ emissions
- Variant analysis:
  - The 50% target is reached in 2035 with a less sustained development of RES
  - The results are consistent from the economic perspective, including in the event of less proactive development of interconnections
Reducing the place of nuclear power in electricity generation must be done **without new sources of thermal energy in France**. Decisions to shut down nuclear reactors may be taken only when generation corresponding to the development of renewables produces, on average, as much as the reactors concerned.

**This transition may occur alongside the development of flexibilities** (storage, demand response, smart charging of electric vehicles, etc.).

The scenario allows for a **substantial and rapid diversification of the generation mix**. By 2030, both the 50 percent nuclear power target and the 40 percent renewable energy target can be reached. In ten years, 18 nuclear reactors may be closed, while generation from renewables will have to more than triple what it is today.

The scenario can be tested by forecasting a development of renewable energies which is still as high but slower (244 TWh of generation at the end of the period). **The achievement of the 50 percent target will then be delayed for five years**, and the reduction in the share of nuclear power would be spread over 15 years rather than 10.

**It is technically possible not to install any new thermal power plants**. However, the variants tested confirm that this requires increasing the interconnection capacity, developing the potential of demand response or moderating electricity consumption. If several of these conditions are not fulfilled, the development of flexibilities should be pushed back and/or the pace of decommissioning of nuclear power should be adapted.

**The scenario requires effective development of the flexibility of the power system**. This can be based on demand response, smart charging of electric vehicles, increased flexibility of the nuclear power capacity, or battery storage. These options will compete to supply the system with flexibility.

**The nature of the risks to security of supply will change** throughout the period. On the one hand, the power system will become more sensitive to low-wind periods during cold weather; and on the other hand, periods of strain on the power grid will become increasingly frequent but of lesser magnitude compared to the current situation.

The scenario calls on significant investment in all components of the system: consumption (energy efficiency and promoting electrification, particularly in the transport sector), the generation capacity (development of renewable energies and extension of a part of the nuclear power capacity), and the network. **Economic analyses have shown such investments are consistent with the high price of CO₂**.

**Under this scenario the power system would contribute to the target of reducing carbon dioxide emissions**. French power emissions will be halved in relation to current emissions, to 12 million tonnes by the end of the period, while the European analysis has shown that the French power system will result in 42 million tonnes less carbon dioxide emitted on the European level.

During the period under review, France would increasingly export electricity, given the growth in renewable energy generation and would therefore contribute positively to the balance of trade. By 2035, evolutions in the French and European electricity generation mix would reinforce the need for mutual assistance between countries from a technical perspective (to manage intermittency) and on an economic perspective (to best use the generation capacity of the power system for the collective benefit).
Main results and assumptions for 2035

### Power Consumption
- Approximately +2% of GDP per year
- 72.1 million inhabitants
- 34.2 million households
- 700,000 renovations per year
- 15.6 million electric vehicles
- 480 TWh

### Renewables
- **Onshore wind power**: 40 GW (88 TWh)
  - Approximately 11,000 wind turbines
- **Photovoltaic**: 36 GW (43 TWh)
- **Hydropower**: 26 GW (65 TWh)
- 116 GW
- 243 TWh

### Nuclear power
- -24 GW (Decrease in the capacity due to the decommissioning of 25 "900 MW" and "1300 MW" reactors*)
- 39 GW
- 252 TWh

* Excluding closure of the two Fessenheim reactors

### Europe
- **Substantial growth of RES**: +327 GW
- **Decommissioning of coal and lignite-fired power plants**: -27 GW
- **Nuclear power**: 4.5 GW
- Import capacity: 22 GW
- Export capacity: 28 GW

### CO₂
- 19 Mt CO₂ emissions from the power system
- 32 €/t

### Assessment
- Closure of coal-fired power plants
- +10 GW of gas-fired plants
- 50 percent nuclear energy target reached in 2030
- Stable carbon dioxide emissions

**Variant analysis:**
The 50 percent nuclear energy target cannot be achieved without negatively impacting carbon dioxide emissions if the pace of development of renewables does not increase in relation to the current situation

**RES**: 45%
**Nuclear power**: 47%
**Thermal**: 8%
The scenario is based on steering the generation mix towards the 50 percent nuclear power generation target in compliance with a CO₂ emissions cap CO₂.

This ceiling corresponds to the current level of emissions from the electric power sector.

The scenario allows for a more rapid diversification of the power generation mix. The target of 50 percent nuclear power generation can be achieved in 2030. Under the Ampere scenario variant based on comparable deployment levels of renewable energies (PPE rate), the development of new gas-fired plants would save five years in reaching the target, and would lead to the decommissioning of more nuclear reactors (27 versus 18).

Demand response will grow, thus avoiding the need for further construction of new gas-fired power plants.

As a result, carbon dioxide emissions would remain close to their current level over the entire period.

Steering the generation mix in terms of carbon emissions is not a significant constraint for regulating the development of gas-fired power plants if the pace of development of renewable energies accelerates in relation to now. In contrast, the sensitivity analysis conducted to study a configuration with a slower development of renewable energies (based on the historical rate) highlights in this case that the need for new thermal energy sources will become such that the emissions cap can no longer be respected.

Thermal power can therefore be a tool for the transition of the power sector if its target primarily concerns the share of nuclear power. Under a scenario based on new thermal power generation sources, the development of renewable energy sources will still need to be sustained to preserve the environmental benefits of closing coal-fired power plants.

In any event, the economic gain from significant development of gas-fired power plants is based on weak evidence. If a substantial number of nuclear reactors were shut down, gas-fired power plants would be economically relevant, but this is not guaranteed in the long term with the progress of renewable energy in France and abroad. Building facilities designed to operate for 40 years while their prospects appear to be ensured for only a limited period raises the question of the long-term cost of such a generation mix. Consequently, the balance of exchanges with neighbouring countries will remain based on exports, but only slightly.

This scenario would allow better diversification of the risks to security of supply in relation to today as it would mean replacing part of the nuclear power fleet with other controllable sources.
Main results and assumptions for **2035**

### Power Consumption

- **+1.5% of GDP per year**
- 69.2 million inhabitants
- 32.7 million households
- 500,000 renovations per year
- 8.3 million electric vehicles
- 442 TWh

### Renewables

- **Onshore wind power**: 40 GW (88 TWh)
  - Approximately 11,000 wind turbines
- **Photovoltaic**: 36 GW (43 TWh)
- **Hydropower**: 26 GW (65 TWh)
- **Offshore wind power**: 10 GW (29 TWh)
  - Approximately 1,500 wind turbines
- 116 GW
  - 243 TWh

### Nuclear power

- -8 GW
- Decrease in the capacity due to the decommissioning of 9 “900 MW” reactors*
- 55 GW
  - 346 TWh

* Excluding closure of the two Fessenheim reactors

### Europe

- **SUBSTANTIAL GROWTH OF RES: +231 GW**
- **Decommissioning of coal and lignite-fired power plants**: -27 GW
- **Nuclear power**: 4.5 GW
- Import capacity: 27 GW
- Export capacity: 33 GW

### CO₂

- 32 €/t
- 9 Mt CO₂ emissions from the power system


### Assessment

- **Closure of coal-fired power plants**
- No new additional thermal energy sources
- Decrease in the share of nuclear energy without reaching 50% reduction of CO₂ emissions
- **Variant analysis**: The points of equilibrium change but remain consistent by varying the different settings. Those with the most influence on the economic balance of the scenario are the carbon price and the development of renewables in Europe. The development of nuclear power outside of France also has an impact.

- **RES**: 40%
- **Nuclear power**: 56%
- **Thermal**: 4%
The development of nuclear energy in France is the result of economic trade-offs, in a context of significant development of renewable energies. These economic trade-offs arise from opportunities accessible to the whole of the carbon-free power generation on the European electricity markets.

An overlap of many variants is done to test the physical and economic prospects of the French power generation to be competitive on the markets. This helps determine the evolution in the share of nuclear energy. It is not intended to achieve a fixed percentage ex ante of nuclear power generation in electricity generation mix.

The different variants tested include configurations that would not favour carbon-free generation, to reinforce the robustness of the analysis: (I) delay in the development of interconnections, (II) low carbon and fuel price, (III) increase in the volume of renewable energy in France and abroad, (IV) increase in nuclear power in Great Britain, (V) continued operation of lignite and coal-fired plants in Germany and thermal power sources in Italy and Spain.

This scenario is based on France’s high capacity for exchange with neighbouring countries, but it would not necessarily be essential to strive for proactive development of interconnections: The analysis of the variants shows that a median interconnection trajectory corresponding to that of the last ten-year network development plan while retaining the cautious estimate of commissioning dates, would not prevent this scenario from occurring. From the economic perspective, however, it seems logical to rely on the high interconnection trajectory retained in the Long-Term Adequacy Report to the extent that France is developing generation resources that will allow it to export large amounts and frequently.

This scenario is the most efficient in terms of carbon dioxide emissions. The French electricity mix emissions will be cut by more than 60 percent compared to the current situation, standing at 9 million tonnes by the end of the period. At the European level, the French power system would avoid a total of 56 million tonnes of CO₂ emissions.

The economic gain of the scenario is based, as for the Ampere scenario, on substantial investments in all of the components of the power system, including in the generating capacity. The carbon price assumption is determining: A value of about €30/tCO₂ would ensure the balance, while a lower value would be problematic. The energy choices of neighbouring countries are also determining. A strong increase in nuclear power generation in Great Britain would reduce the opportunities for French nuclear power.

The security of supply in France would be ensured and remain largely dependent on the performance of the nuclear power capacity. Solutions for storage or for adjusting energy consumption to manage situations of “surplus” of low-cost power generation present a strong economic interest for ensuring the real time balance of the French power system, which is predominantly composed of sources with low flexibility (intermittent renewable energy and nuclear power).
### Assessments

**Power Consumption**
- +1.5% of GDP per year
- 69.2 million inhabitants
- 32.7 million households
- 500,000 renovations per year
- 5.5 million electric vehicles
- 410 TWh

### Renewables

- **Onshore wind power**: 52 GW (115 TWh)
  - Approximately 14,300 wind turbines
- **Photovoltaic**: 48 GW (58 TWh)
- **Hydropower**: 28 GW (68 TWh)
- **Offshore wind power**: 15 GW (47 TWh)
  - Approximately 2,200 wind turbines
- **Approximately 14,300 wind turbines**
- **150 GW**
- **314 TWh**

### Nuclear Power

- **-55 GW**
  - Reduced fleet, corresponding to the decommissioning of 52 reactors*
- **8 GW**
- **48 TWh**

* Excluding closure of the two Fessenheim reactors

### Europe

- **Substantial growth of RES**: +327 GW
- **Decommissioning of coal and lignite-fired power plants**: -27 GW
- **Nuclear power**: 4.5 GW
- Export capacity: 28 GW
- Import capacity: 22 GW
- SDDR 2016, dates de mise en service prudentes

### CO₂

- **32 Mt CO₂**
  - Emissions from the power system
  - **108 €/t**
  - The assumptions on fossil-fuel prices based on the IEA 450 scenario, prices expressed in €2016

### Assessment

- **Closure of coal-fired power plants**
- +21 GW of gas-fired plants
- Increase in the share of RES to reach 70% of generation
- Increase in CO₂ emissions

**Variant analysis:**

- Achieving this scenario would require a significant decrease in power consumption and substantial growth of RES

**Nuclear power** 11%

**Thermal** 18%

**RES** 71%
Some of the materials and equipment for the nuclear reactors in service in France were designed under the assumption of an operational lifespan of 40 years. International experience suggests that it is possible to increase the lifespan of nuclear reactors, and the French nuclear plant operator has announced its intention to extend the lifespan by at least ten years. However, the conditions for this extension, which will require works on each site, are not yet known, and the Nuclear Safety Authority recently announced it was pushing back its generic assessment on the extension of the first series of reactors (“900 MW”) by two years.

This scenario examines the consequences of not extending the reactors’ operating license. It is based on the assumption of shutting down each reactor after 40 years of operation.

The need to rapidly do away with nuclear plants raises the question of the technologies available to ensure the transition.

This is a disruption scenario: The production of renewable energies will represent 70% of the generation mix by 2035. Although it will have undergone significant growth (314 TWh by 2035), this generation is insufficient in volume to cover the drop in nuclear power generation over the same period (about 350 TWh, corresponding to the closure of 54 reactors having reached 40 years of operation).

In light of the current state of technology, this scenario could not take place without massive installation of new thermal power generation sources (around double the capacity of gas combined-cycle plants currently in operation). If the needs are very high, the long-term profitability of some of these new facilities on the European electricity markets would not be ensured in the context of substantial development of renewable energies.

Carbon dioxide emissions may not decrease with the current technologies under such a scenario. These would reach 32 million tonnes at the end of the period, which would represent a moderate increase compared to the current level of emissions from the power system. This figure still remains low compared to observed in other countries. The variants based on higher consumption or on less development of renewables could lead to significantly higher levels, which, on the other hand, confirms the importance of the initial assumptions in this scenario.

The French power system would maintain a net export balance in the base case, but France could become a net importer under some variants, including the one based on the high consumption trajectory developed by RTE.

In all cases, the net export balance would be far lower than current levels despite the increased interconnection capacity between France and its neighbours.

Finally, under this scenario, maintaining security of supply represents a real challenge, and would depend on all potential levers. There would thus be room to develop demand response, battery storage, hydraulic dams, or real-time smart charging of electric vehicles. These levers and the new thermal power plants would be complementary and not rivals, contributing to peak demands, or managing intermittency of renewables. From a technical perspective, questions arise regarding the inertia of the power system: these would have to be addressed to identify solutions.
“NO REGRET” OPTIONS
COMMON TO ALL SCENARIOS EMERGE

True diversification of the French electricity mix is possible by 2035

The Long-Term Adequacy Report scenarios foresee contrasting futures but they will all lead to a marked increase in the share of renewables in electricity generation. In particular, the four scenarios for 2035 systematically reach the target of 40 percent power generation from renewable sources.
The drop in power consumption will facilitate diversification of the energy mix and provide room for manoeuvre in terms of security of supply

Consumption, and particularly peak consumption, greatly determines the range of possibilities. In general, energy consumption will need to decline for the share of nuclear energy to be reduced. The faster this is desired to occur, the more the reduction in electricity consumption will need to accelerate imperatively – except if renewable energies can grow at a considerable rate.

In addition, the prospect of reducing electricity consumption in so-called specific uses of electricity, i.e.; in equipment which cannot operate with any other form of energy, facilitates the development of new uses of electricity. For example, the high consumption trajectory set by RTE will remain stable for 2035 in relation to current consumption, even when incorporating a highly ambitious development of electric vehicles (15 million electric vehicles). It illustrates the actual margins of manoeuvre provided by investments in energy efficiency: the apparent stability reflects a “communicating vessels” effect between historical use and new uses.

Opportunities arising from reduced consumption (examples)

- **“Generic” example:** increasing changes in use without increasing total electricity consumption in relation to the current consumption – illustrated with electric vehicles

- **Example “for a scenario”:** limiting CO₂ emissions in the event of massive decommissioning of nuclear plants

10. Lighting, ICT, white goods (washing machine, dryer, refrigerator, dishwasher, etc.).
The decommissioning of some nuclear reactors is possible if visibility can be gained on the trajectory and if the specific milestones have been met.

Regardless of the chosen scenario for 2035, the decommissioning of nuclear reactors is conceivable between 2020 and 2035.

From a technical perspective, this can be achieved while maintaining the level of security of supply, provided that specific milestones have been reached. The decommissioning trajectories can be spread out (Volt scenario), demanding (Ampere scenario), fast (Hertz scenario) or abrupt (Watt and Ohm scenarios).

From the economic perspective, the study identifies:
- an upper limit to the sizing of the capacity. By 2035, this limit appears lower than the legal ceiling of 63 GW if renewable resources are developed (the effect of low-cost and variable generation – whether nuclear or renewable sources – on the balance of trade is reversed beyond a certain threshold, which depends primarily on the carbon price and the development of carbon-free sources in France and abroad).
- shutting down nuclear reactors will come at a cost if they cannot be replaced by renewable energy sources (for all other installations, competition of renewables at the European scale will bring about potentially fewer opportunities, particularly from 2030, consequently resulting in lower profitability).

Under certain configurations, the development of renewables could “naturally” reach, or even exceed, the trajectories based on the Multiannual Energy Programme. This “economical” development of renewable energies depends in part on a high carbon price and varies according to the sectors considered.

In all cases, the question of acceptance of these facilities will be a crucial factor for the coordination of the energy transition. This takes precedence in considerations of a technical or economic nature.

The government has identified this point and launched several legislative and technical initiatives to move forward on this issue.

A high speed of deployment of renewable energies will accelerate diversification

The inflection point for the deployment rate of renewable energy in France is crucial to achieve a real diversification of the electricity generation mix. The pace of median and high pathways, based on the French Multiannual Energy Programme, is accessible compared to other European countries. In relation to the historical performance of the French system, these trajectories should be regarded as ambitious.

Impact of a delay in the development of onshore wind power

The inflection point for the deployment rate of renewable energy in France is crucial to achieve a real diversification of the electricity generation mix. The pace of median and high pathways, based on the French Multiannual Energy Programme, is accessible compared to other European countries. In relation to the historical performance of the French system, these trajectories should be regarded as ambitious.

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The decommissioning of some nuclear reactors is possible if visibility can be gained on the trajectory and if the specific milestones have been met.
The accelerated decommissioning of nuclear reactors requires specific coordination

The different scenarios based on a rapid decommissioning of nuclear reactors (to varying degrees) lead to unprecedented developments in the French electricity mix (not seen since the construction of the nuclear fleet). They require specific coordination to oversee the closure of nuclear reactors and the development of other resources to maintain the level of security of supply in France. This point was raised in the report accompanying the Multiannual Energy Programme of October 2016.

Comparison with other European countries reveals that the pace of the Hertz, Watt and Ohm scenarios is faster than the policy Germany put in place in 2011, even though this country has a substantial coal-fired plant capacity (in contrast to France). In addition, Germany has implemented specific coordination of this evolution, as have other countries which are phasing out nuclear power.

The pace of reduction of the installed nuclear capacity in the different scenarios and in Germany

<table>
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The development of interconnections is a necessary complement to any strategy of diversification of the electricity mix

The median trajectory of development of interconnections corresponding to the ten-year network development plan is economically justified under all scenarios studied in the Long-Term Adequacy Report. This will guide the energy transition by facilitating electricity exchanges, and in practice, it would boost the renewable generation capacity developed within the French power system and ensure that France is well positioned to import electricity during periods of strain on the power grid.

In all cases, spending on interconnections does not dominate the economic analysis of the scenarios (even in those which justify a proactive trajectory of development of interconnections). The sums to invest in the power capacity or energy efficiency dominate considerably.
Self-consumption will develop under all scenarios

For the first time, this Long-Term Adequacy Report includes modelling of the distributed development of photovoltaic energy and batteries, in light of the decisions of individuals, a set of consumers or communities. The aim is to present a new dynamic in decision-making for investments in the energy sector leaving room for short channels, defined locally between electricity generation and supply.

Under all scenarios, it is of economic relevance to significantly develop rooftop photovoltaic systems within the context of self-consumption. The average volume would amount to 10 GW, i.e.: 3.8 million homes, and vary under the different scenarios and variants considered. This development could occur alongside the development behind-the-meter/distributed storage, particularly if the batteries are used on a wider scale within the context of the power system operation.

This trend would be reinforced with the implementation of self-consumption systems in neighbourhoods or industrial areas.

Developments in photovoltaic panel capacity installed for residential self-consumption

Developments in battery storage capacities installed for residential self-consumption

Capacities of self-consumption installations for 2035 under the Ampere scenario according to different variants
The needs for adjusting the power system will increase

Today, flexibility options with the greatest interest for the French power system are those which can handle winter peak demand. These are one-off seasonal events that can be anticipated the day before they occur.

**Demand response is an interesting solution for handling this type of event, as long as it shows adequate performance in terms of reliability.**

This interest will not go away tomorrow: the development of demand response could avoid the need for new thermal power plants for which opportunities for operation would be reduced.

The need for flexibility, however, will evolve in intensity and nature. The scenarios of the Long-Term Adequacy Report all describe substantial development of wind and photovoltaic power. This outlook would go hand in hand with a new need for flexibilities to balance residual demand, i.e.: the consumption to satisfy once renewable generation is deducted. With a high penetration of wind and photovoltaic energy, the indicators of variability of the residual consumption will significantly increase (during the course of a day or a week).

To deal with these events, the reflection on flexibility should not be limited to demand response only, but must broadly embrace the whole range of possible solutions.
New flexibility options will appear in the electric mix

Under several scenarios, the development of wind and solar energy will lead to periods of abundant, low-cost generation. There may not be market opportunities for this generation if demand is low (in summer or during off-peak hours).

To handle these situations, **new load modulation options will be of interest to make the best use of existing generation at no variable cost** (wind and solar) and to operate nuclear power plants in the most cost-effective manner possible.

The development of storage has been considered and emerges in some situations, without amounting to a revolution at this stage. The changing costs of these technologies could lead to increased economic relevance.

In the long term, other emerging technologies could play a part to respond to this type of need. Of particular interest to study would be the role of hydrogen through power-to-gas.

Analysis of this flexibility mix in the new scenarios could rely on the methodologies developed in the works published by RTE and ADEME (French environment and energy management agency) on smart grids in July 2017.
POINTS TO CONSIDER
ON THE SECURITY OF SUPPLY

Peak demands during cold spells are still the main risk factor for the system but will become increasingly rare

Today, there are particularly high demands on the power grid during cold spells. Heating needs can then be substantial and lead to a significant increase in the power utilised to cover electricity consumption during these periods. However, peak energy demand has tended to stagnate since the considerable rise during the 2000-2010 decade.

All in all, over the 2020-2035 period, the four peak power trajectories should follow the outlooks for evolution of electricity consumption in terms of energy, although less pronounced.

In spite of this evolution, the greatest influencing factor for the power system would be a cold spell, including when the share of renewable energy in the generation mix is undergoing significant growth.

Record peaks in power consumption – such as the historical peak reached in February 2012 – should become increasingly rare, provided that actions continue to be undertaken to control peaks.

The identification of the need for a generating capacity adapted to managing record peak periods is therefore not clear cut. This is an important element within the analysis of the Long-Term Adequacy Report, in line with the work on the criterion of security of electricity supply set out in the Multiannual Energy Programme and for which the Commissariat général de l’environnement et du développement durable (French General Council for the Environment and Sustainable Development) conducted a study.
The risks to the security of supply are gradually evolving

Scenarios involving the greatest development of wind and solar energy will no longer be exposed to the same level of risk as today: Periods of strain on the grid could be shorter and concern lower volumes of energy, but they could arise more frequently, particularly outside of the winter period. The nature of the risk will evolve in a generic manner.

The risk factors on power consumption and low-wind periods could be correlated to a certain degree. This characteristic will bring about more marked effects in the Ampere and Watt scenarios, which rely more on wind power. This should be the subject of further work, within the framework of a more general study on the resilience of the scenarios depending on the magnitude of climate change that ultimately takes place.
Availability of nuclear power remains a key factor for the security of supply

Under the majority of scenarios studied, nuclear power will continue to represent a significant share of the generation mix in France. Its performance (availability, time of outage) therefore remains a significant factor for power supply.

The grid will remain vulnerable to prolonged and simultaneous unplanned outages of several nuclear reactors during the winter.

To be extended beyond 40 years of operation, the reactors concerned will need to be stopped to perform works enabling them to pass their fourth 10-year inspection and to be granted a new operating licence.

Particular attention will need to be paid to the duration of these stoppages. Sensitivity analyses carried out by RTE over the 2018-2022 period will have highlighted the impact of a 12-month outage on security of supply, leading to unavailability of these nuclear reactors during the winter.

The Nuclear Safety Authority will submit generic assessments in 2021 on the extension of “900 MW” nuclear reactors, which would make it possible to further refine the analysis. In the meantime, the security of supply diagnosis will remain subject to some uncertainty.
The energy policies of France’s neighbours will have an impact on electricity markets and on the economic opportunities of the French generating capacity.

Today, France occupies a unique position in Europe in light of the structure of its generation capacity. On the one hand, the prevalence of nuclear power means that a sizeable part of the mix is characterized by low variable costs, thus making the country a major net exporter of electricity. On the other hand, unlike several European countries, France is not in a situation of overcapacity during peak demand.

Two of the options being explored in the scenarios highlight this characteristic: in the Ampere and Volt scenarios, the volumes of electricity generated by renewable energies and nuclear power in France will increase. The analysis shows that most of the time there will be market opportunities for these volumes in Europe, and that very high net export balances can be achieved in relation to today.

However, these opportunities are not infinite. Between 2030 and 2035, the export potential may be limited depending on the speed of penetration of renewable energy sources in neighbouring countries, or of nuclear power in the case of Great Britain. These limits arise essentially in summer, and for configurations with highest exports. Under these types of scenario, the energy choices of the neighbouring countries of France limit forecasts to the volume of exports.
Scenarios that include a strong decline in the share of nuclear power would have France relying more on our neighbours

The other scenarios will lead to a rapid reduction in nuclear generation (*Hertz, Watt* and *Ohm* scenarios), which cannot be completely “offset” by generation from renewable sources. **Under these types of scenario, the energy choices of France’s neighbouring countries have a direct impact on the profitability of the French generating capacity.**

At first, the very rapid decline in the share of nuclear energy could be facilitated by the existing overcapacity in Europe. It would then be conditional on the commissioning of new gas-fired plants in France. Nevertheless, their profitability in France over the long term is not guaranteed in a context of a strong momentum of development of renewables in Europe.

**Under these scenarios, changes to energy policies of European countries will therefore have significant impacts on investment needs in France.** The variants provide initial insight into how significant this will be and will help identify areas for further study within the context of the consultation.

The *Hertz, Watt* and *Ohm* scenarios will lead to a decrease in exports, or even under some variants to situations where France will become a net importer despite the commissioning of new gas-fired facilities in the French power system. This effect is due in part to the substantial development of renewable energy in Europe, which largely determines the profitability of the generation capacity.

A decrease in nuclear power generation (regardless of the chosen rate) should occur alongside an increase in renewable energy generation in order to maintain the volume of export. This involves reducing the weight of a low variable cost generation in the mix (nuclear power), to the benefit of a generation with no variable costs (wind and solar power) – a move which will not depend on the decisions made in other countries.
The carbon price has a strong influence on the economic analysis of the scenarios

Under the scenarios considered, the fuel and carbon price has only a secondary influence on the physical balance of cross-border electricity exchanges between France and its neighbours. This parameter mainly influences the relative competitiveness of gas and coal resources, and therefore concerns only a small share of the French generating capacity by 2025-2035.

On the other hand, the carbon price will have an influence on the economic value of these electricity exchanges, and on the conditions for financing the generation capacity. The scenarios all foresee substantial investments in renewable energies, facilitated by a rise in carbon price.

Several scenario variants of the Long-Term Adequacy Report provide an opportunity to analyse tipping points for electricity exchanges across European countries and Europe’s power generation emissions as a function of the predicted trajectories for the carbon price. These confirm the analysis according to which a significant reduction in emissions could be reached from 30€ per tonne.
There are still margins of manoeuvre to reduce emissions from the power system in France

Today, the French power system is already substantially carbon-free, both in absolute (less than 10 percent of carbon emissions are generated in France) and relative terms (the carbon “intensity” of the electricity generation, measured in gCO₂ per kWh, is very much lower than the European average).

The analysis confirms that it is possible to further reduce emissions from the power system in France.

The Long-Term Adequacy Report scenarios reveal a diversification of the electricity mix and a significant growth of renewable energies in France’s electricity generation. However, they do not come out as equal in their role in reducing the carbon footprint set out in the Paris Agreement and reaffirmed in the French Climate Action Plan of July 2017.

The closure of coal-fired power plants, which is acquired under all scenarios (with the exception of the Ohm scenario), contributes to this reduction.
France’s choice of energy policies would have a real influence on Europe’s performance in reducing emissions

Emissions should not be analysed solely in terms of net emissions. In fact, imports are sometimes necessary and require activation of carbon emitting sources elsewhere in Europe, whereas French exports can reduce emissions among our neighbours if they substitute the activation of carbon emitting power generation plants.

The Long-Term Adequacy Report studies these dynamics through modelling of cross-border electricity exchanges between European countries. These analyses were conducted on the European level rather than limited to the French territory, and the characteristics of each of the scenarios were therefore amplified.\textsuperscript{11}

The Ampere and Volt scenarios are therefore not only low emitters in France, but also strong contributors to a reduction of emissions in Europe: by making it possible to export large amounts due to a very low-carbon power generation in France. Under both of these scenarios, annual emissions of up to 40 or 50 million tonnes of carbon dioxide emissions would be avoided depending on the scenario and variants.

While the Ohm and Watt scenarios will see a worsening of emissions from the French power system, the Hertz scenario would have them stabilised in relation to the current situation.

Yet, the carbon dioxide emissions trajectories that would result from the Ohm, Watt and Hertz scenarios would not lead to very high emissions of the French power system compared to other countries. Finally, emissions from thermal power generation could be reduced by integrating gradual conversion to biogas.

11. There are limits to the “all things being equal” logic, and these estimations are only given as examples, but they do indicate where the scenarios are situated in an overall dynamic.
This result is consistent with the developments experienced in other European countries which have followed this type of trajectory. To better apprehend the magnitude of these evolutions in greenhouse gas emissions, they must be compared against emissions from a broader perimeter than just the power system.
The publication of the Long-Term Adequacy Report is part of a process of exchanges with stakeholders on developments in the power system.

The principles behind the Long-Term Adequacy Report and the main “tipping points” and findings have been presented in this summary document. It aims to serve as an initial tool in decision making.

The 2017 edition has helped improve transparency in terms of the assumptions made by RTE and to accompany the work into the definition of scenarios and their variants.

This incentive will continue to grow:

- The detailed set of parameters retained as well as the results of the reference scenarios and variants are included in this summary report.

- Further consultation is needed to bring these scenarios “to life” according to the different turning points for the public and the needs of the various stakeholders. It will thus help firmly establish the Long-Term Adequacy Report in the public debate, in accordance with the mission entrusted to RTE by law.

- Within the framework of research on self-consumption as part of a national study of the elements relating to the decentralisation of investment decisions in the power sector, a specific study will be conducted with any countries wishing to participate, to adapt the tool which constitutes the Long-Term Adequacy Report to their own issues - and in particular to gain a broad spectrum of variants.

- In-depth studies will be conducted on the areas of reflection set out in the Long-Term Adequacy Report: a thorough analysis of the integration of electric vehicles and smart charging, closer examination of the consequences of climate change on the resilience of the system, integration of self-consumption, analysis of the issues of inertia in scenarios that include very high penetration of renewable energies.