French transmission network development plan

2019 EDITION

MAIN RESULTS - ENGLISH VERSION

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2019 EDITION

MAIN RESULTS

SUMMARY

1

AIMS

1.1 Transforming the networks is essential if we are to successfully deliver the energy transition

France is fully engaged in the energy transition. The draft energy-climate law currently being considered by the French Parliament has committed the country to being carbon neutral by 2050.

This aim is underpinned by the national low-carbon strategy *(stratégie nationale bas carbone,* or SNBC), which sets forth trajectories for various sectors (housing, energy, agriculture, transport, etc.) until 2050, detailing the strategies that need to be adopted if we are to reduce greenhouse gas emissions. The energy policy aims form part of the multi-annual energy programme *(programmation pluriannuelle de l'énergie,* or PPE), which defines the ways in which energy production, transport and consumption will need to change in France over the next 10 to 15 years.

These various documents are in the draft phase. However, the fundamental decisions underpinning them were clarified by the French government back in 2017.

As far as the electricity sector is concerned, they are based on dramatically developing renewable energies (onshore and offshore wind power and photovoltaic solar energy in particular), closing the last coal-fired power plants between now and 2022, gradually reducing the country's nuclear capacity (closing the two Fessenheim reactors in 2020, followed by a dozen or so others between 2025 and 2035) and a policy of stepping up the use of (significantly decarbonised) electricity in the mobility, construction and industrial sectors, as well as in hydrogen production.

This is a transformation on a massive scale. In terms of how wide-ranging it is, it can be compared to the expansion of France's nuclear power fleet after the second oil crisis, which involved making significant changes to its energy supply systems in a very short period of time.

Although public debate regarding the electricity sector has largely focused on generation sources, its operational reality involves creating a premium-quality network industry: one in which all generation sources and consumption sites are interconnected on a permanent basis, with a requirement for instantaneous balancing that does not exist in any other industry. And any changes to the mix involve a connection being created, and perhaps changes being made to the network. In the overall energy transition equation, the networks have a major role to play.

These networks are going to have to evolve – and very quickly – if the energy transition is to be possible. The industrial impetus behind this evolution and the way in which it is funded will need to be gauged over the long term. Several years of preliminary technical and economic studies are vital in order to create a new piece of infrastructure. A regulatory investigation is then required (numerous permits are needed, granted under urban development, environmental and sectoral energy policy law), together with a dialogue process with the relevant stakeholders lasting several years (depending on how complex the project is). Some infrastructure can operate for up to 85 years once the building work is complete and it has been brought into service – provided it is appropriately maintained on a regular basis.

This transformation needs to happen in a societal context in which results need to be delivered quickly, and in which there is systematic opposition – even when this infrastructure is vital for the energy transition.

It is now widely accepted that two factors play a key role in enabling renewable energies to be rapidly deployed: regulatory stability and thought given beforehand to the way in which they can be integrated into electricity grids.

RTE's new *"schéma décennal de développement du réseau*[1]*"* (or SDDR) is the French transmission network development plan. It has has been published at a key moment. It sets forth a proposal for the way in which the transmission system should evolve over the next 15 years in order to meet public targets, highlighting the challenges and possible margins for manoeuvre, as well as the areas in which there needs to be coherence. It serves as an operational interpretation of the draft multi-annual energy programme and may change, depending on the end documents (the energy law, the national low-carbon strategy and the multi-annual energy programme) and opinions formulated about the draft SDDR (by the ministry, the French energy regulator and the Environmental authority). It lists the existing levers that need to be actioned in order to ensure that the networks do not end up constituting an insuperable obstacle to the energy transition, but instead end up facilitating it.

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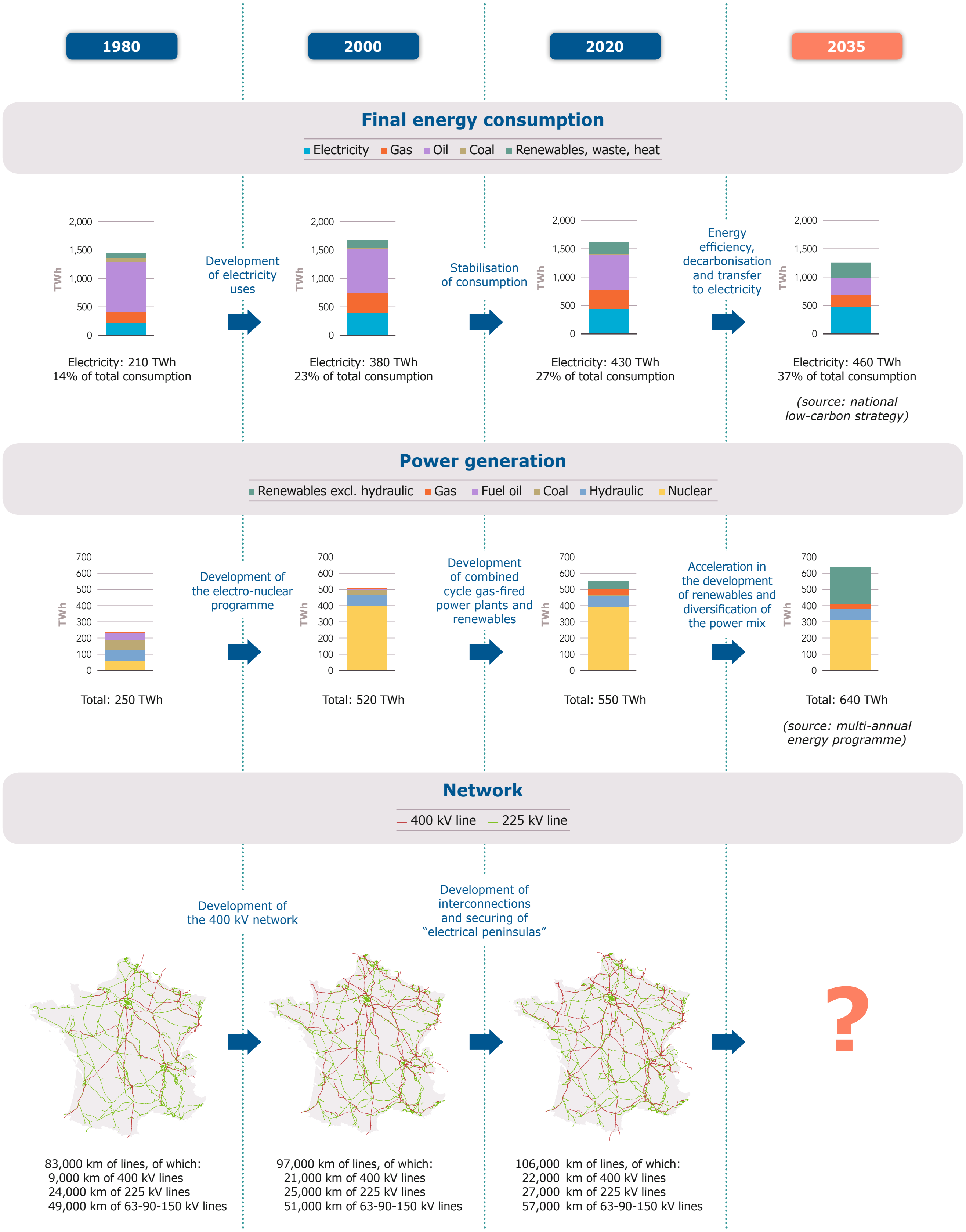
[1] Literally : ten-year network development plan

Figure 1. Changes in the power mix and network since 1980



1.2 The electricity transmission grid: obvious, but poorly understood

What the power transmission system is may seem obvious.

Many people think of the extra-high voltage power line pylons which supply electricity across the country when they hear it mentioned. Others think of control centres, which monitor the electricity supply at all locations throughout France and at all times – 24 hours a day, 7 days a week. For everyone, it is something taken for granted: electricity has never been so present and so important in our everyday lives, and very few people remember that 50 years ago, supplying electricity to the whole country was still a challenge.

But in reality, the transmission grid is something that is poorly understood. At a time when it needs to undergo a major transformation if it is to meet the needs of an energy policy that caters to the challenges of climate change, we should remind ourselves of what it does and what its characteristics are.

Infrastructure for transferring large quantities of energy from where it is generated to where it is consumed…

The confusion lies in just seeing the counterpart – for electricity – of motorways or the major lines of the railway network.

The electricity power grid is effectively a linear physical infrastructure that transports high-voltage electricity over great distances, interconnects European countries and directly connects up the largest power generation assets (nuclear power plants, hydraulic dams, major ground-mounted solar power plants and ultimately offshore wind farms), as well as the largest (industrial) consumers and "pockets" of local consumption. Within these "pockets", electricity is transmitted to end domestic consumers via distribution networks.

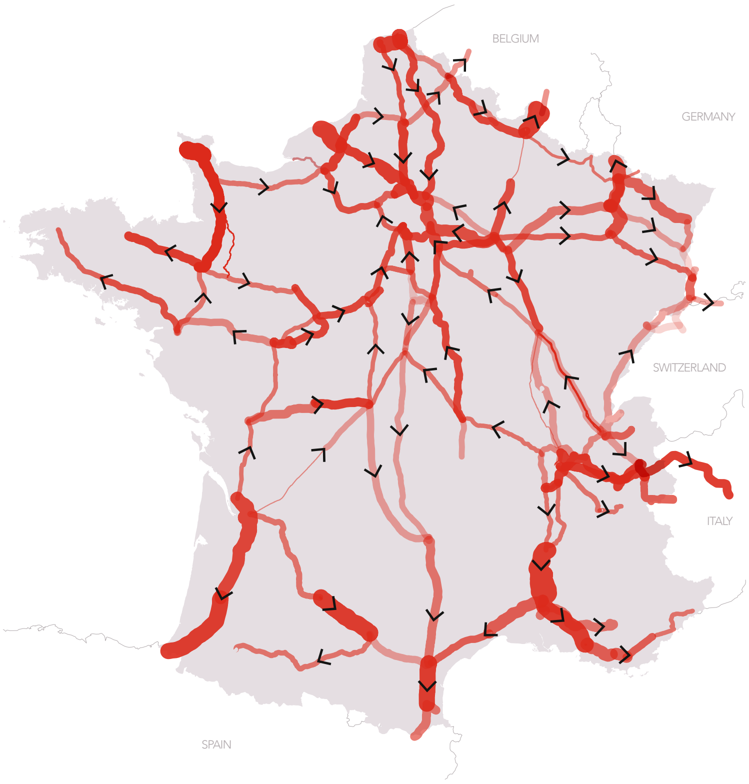
To connect up the various generation centres and supply the locations at which energy is consumed, the electricity transmission network is divided up into several voltage levels:

- the *higher-voltage transmission network* (very high-voltage network made up of the 400 kV network and part of the 225 kV network) constitutes its main arteries, providing national coverage and interconnecting with neighbouring countries in order to evacuate electricity from the main generating sites (nowadays, nuclear power plants and major hydraulic dams): an example of electricity flows over the 400 kV network in the winter is provided opposite (figure 2.1);
- the *subtransmission networks*, made up of part of the 225 kV network and lower-voltage infrastructure (mainly 63 kV and 90 kV). These provide supra-regional and regional coverage and deliver power to territories at local level.

The transmission system is operated in a coordinated way: the example given of the way in which electricity is supplied to the Lille urban area (figure 2.2) shows how various lines of different voltages are entwined so as to meet consumption requirements.

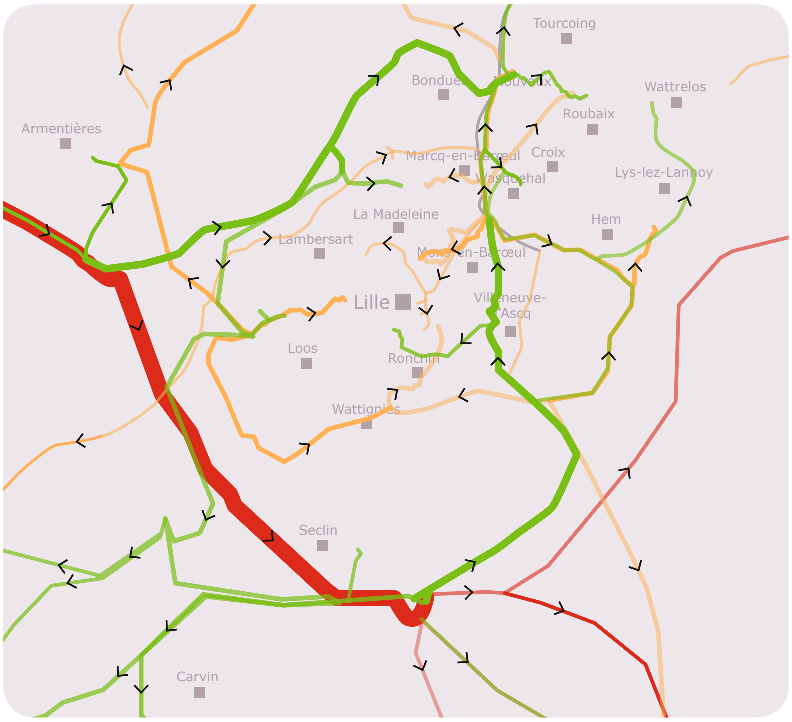
This major integrated network was built at the same time as other major networks and fully participated in delivering on the policy to bring electricity to the country in the second half of the 20th century. Although it now serves the whole interconnected urban area, the network has to adapt to changes in lifestyles (and will need, for example, to be reinforced so as to factor in suburbanisation, or undergrounded in areas with high levels of land pressure), and needs to enter a crucial renewal phase for its older infrastructure.

Figure 2. Illustration of flows over the higher-voltage transmission network and subtransmission networks



Instant use of the higher-voltage transmission network (400 kV) – Winter situation

- The line thicknesses represent the intensity of flows passing across the various axes
- The thinner line generally denote corresponding powerlines of a low capacity (and not a low load rate)



- 🟥 400 kV line
- 🟩 225 kV line
- 🟧 90 kV line

Instant use of the Lille urban community network – Summer situation

… but most importantly a hub for pooling available resources

After transporting electricity from point to point, the primary function of the transmission system is to enable the various generation sources to be pooled together on a large scale. *Via* the transmission system, people's electricity requirements in France, taken as a whole, are supplied by all available power generation assets, with preference given to using the least expensive first. From a physical perspective, electricity delivery is the responsibility of the transmission and distribution system operators.

To do this, a particular organisational structure needs to be implemented.

On the one hand, this is structured around a deregulated market. In France, as in other European Union member states, every consumer is free to choose their electricity supplier: relationships between generators, suppliers, intermediaries and consumers are governed by a set of private contracts.

They are also underpinned by specific schemes which ensure that the system works from a technical and economic perspective. As such, the transmission system operator must ensure at all times that the quantities of electricity injected into all points across the territory are equal to the quantities of electricity extracted, and must direct the flows based on the network's capacities. To do this, RTE is responsible for modifying power generation in real time, and even for regulating consumption. This balancing is achieved across all residents, wherever they are located: whether they are in their homes and connected up to a distribution network, in a train and connected – via catenaries and railway infrastructure – to RTE's network, or at an industrial facility directly connected up to the public transmission grid.

RTE manages the financial flows between the various stakeholders once the electricity has been transported so as to reflect the actual physical reality that differs from the exchanges made on the electricity markets. The role of the electricity generators is to inject electricity into a point on the network; consumers can then extract it and the networks manage the interface. Reference is often made to the system's "physical compensation house" when describing this role played by the public transmission system's operator.

This type of organisational structure is specific to electricity, since it is difficult to store it on a large scale (with the current state of infrastructure) and there are stringent requirements regarding the quality and continuity of the electricity signal – in particular, the frequency depends heavily on instantaneous balancing between electricity supply and demand. For a motorway management company, such a role would involve checking, at each moment, that the number of people getting into a car was exactly equal to the number of people getting out of it. In this sense, a transmission system operator should not be compared to "electricity motorways".

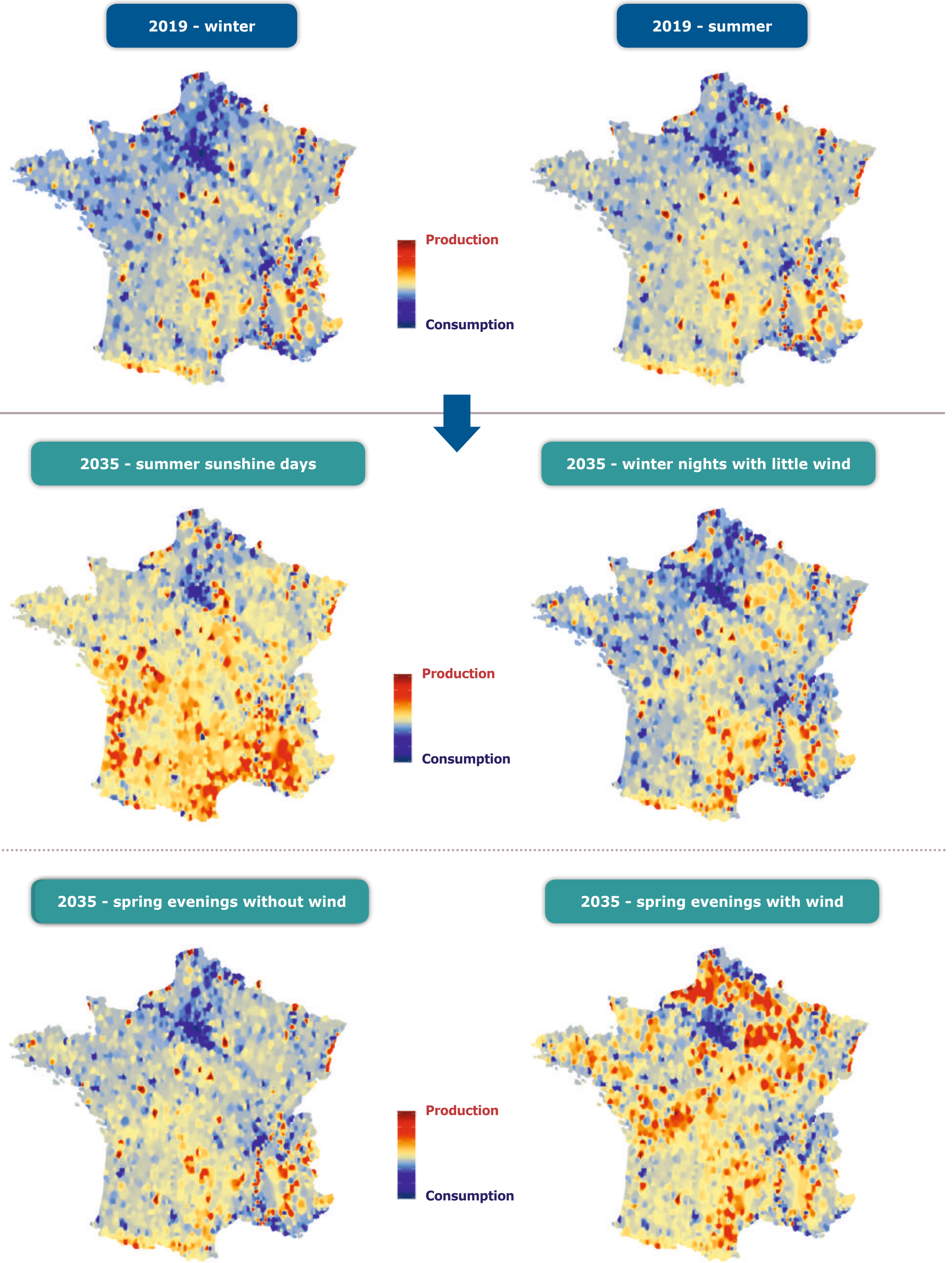
This hub function is set to become more important as the energy transition gets under way. To produce the SDDR, RTE has created a model of the way in which the European power system works, integrating its geographical dimension. **This model highlights changes in the energy mix in terms of the geographical distribution of generation on the one hand and its temporal variability on the other** (see opposite):

1) generation distribution across the whole country will change and become less concentrated (with the closure of nuclear reactors) and will move to different areas (with increases in generation in zones which currently have none, a reduction in generation potential on rivers and increased concentration in certain coastal areas);

2) Daily and seasonal generation will become more variable in terms of volume, as well as spatial distribution: there will be more of an alternation between episodes of high generation in the south of the country (sunny summer days) or in the north (windy spring nights) than there is currently.

This type of energy mix can only work through increased pooling of assets, overseen by the transmission system operator. Changes in the network therefore "naturally" follow changes in power generation.

Figure 3. Distribution of power generation (red) and consumption (blue) zones for typical situations with the current energy mix shown (at the top) and the energy mix predicted for 2035, according to the scenario in the draft multi-annual energy programme



2019 - winter

2019 - summer

2035 - summer sunshine days

2035 - winter nights with little wind

2035 - spring evenings without wind

2035 - spring evenings with wind

A system driven by an increasingly European operating rationale...

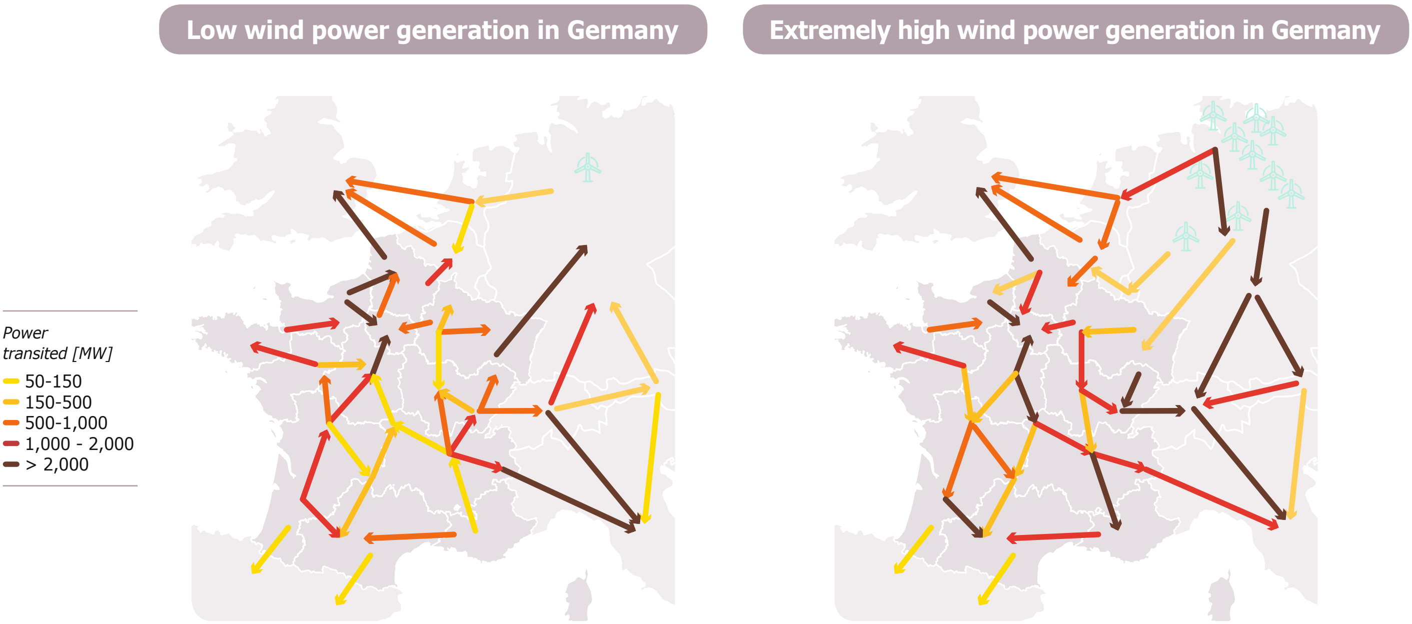
The power system is currently undergoing structural change: the focus of the way in which it is structured is shifting from a national perimeter to a European scale.

Growing interdependence among European countries in terms of power is the logical expression of the EU project's aim and is the result of its strengthening over the last 20 years in the energy sector. The European internal electricity market is underpinned by countries being increasingly physically interconnected and is the prevailing rationale governing the way in which flows are managed across Europe. In Europe, France does not "decide" to export electricity any more than it "calls upon" its neighbours when its electricity supply is starting to run low: such operations are market-driven, resulting in the most competitive generating facilities coming into operation, regardless of where they are located. Electricity flows between countries result from this automatically.

In this context, lines of force can be identified. For a long time, France has been a major electricity exporter. And it looks set to export even more over the next few years if the targets set by the multi-annual energy programme for power generation are reached (see the 2017 French Long-term Adequacy Report and additional studies on the cross-border exchanges published in September 2018). Its nuclear power fleet – in the same way as wind power generation in Germany and hydraulic power generation in Scandinavia – plays a major role in the way in which electricity flows are structured at European level. The data analysed in the Long-term Adequacy Report and in the SDDR illustrates this situation in Europe.

Increased interconnection among European countries has meant significantly greater integration of renewable energies than a number of people would have thought possible ten years ago. A country such as Denmark has only been able to meet its target of having 45% of its electricity generated by wind power by being fully integrated into the European market and by making extensive use of its neighbours during periods of low wind power production. At the same time, it is no longer possible to manage flows at country level. For example, the development of wind power and photovoltaic solar energy in Germany has had major consequences for its neighbouring

Figure 4. Influence of wind power generation in Germany on flows across the network in France



countries, through which increased electricity flows now pass, while Germany's internal network was becoming less and less suited to the new geographical distribution of electricity generation across the Rhine.

The power system that France has chosen is – for the most part – based on forms of decarbonised power generation that are highly competitive on the electricity markets: renewable energies and nuclear currently account for 93% of generation (96% in 2030, under the multi-annual energy programme). Generation fleets of this nature need to be underpinned by a highly interconnected system: interconnections between countries mean that France can sell the decarbonised electricity that it produces to the rest of Europe, while importing it during periods of peak demand and reducing balancing reserves requirements.

… with impetus at local level as well

The Europeanisation of the power system may seem to be in contradiction with some of the calls for it to be more decentralised. However, the situation only appears to be paradoxical.

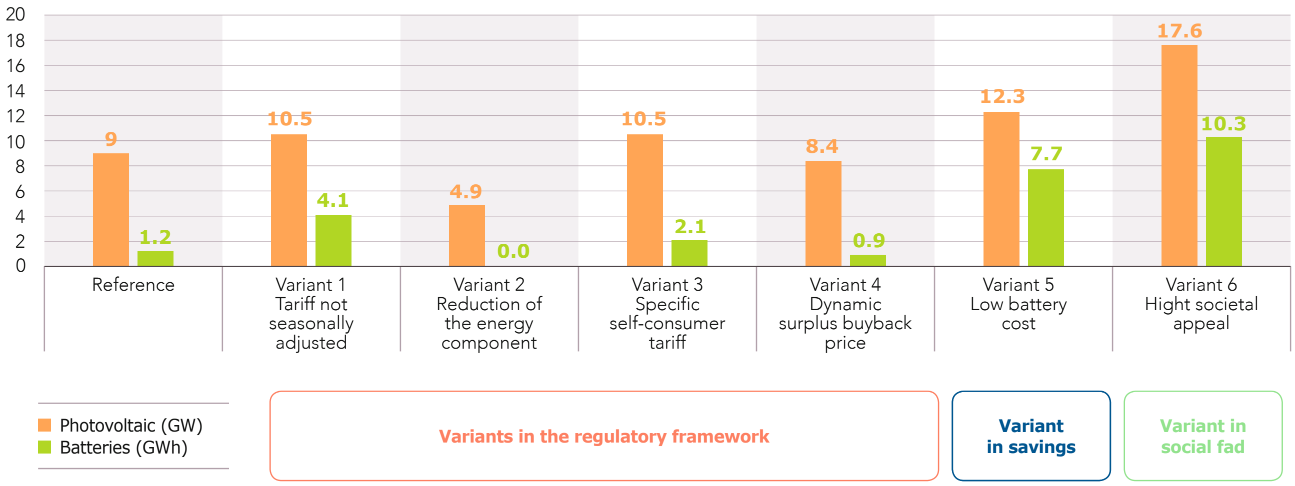
In reality, it is completely possible for local-level management rationales to coexist alongside an interconnected system that is operated on a larger scale.

Increased self-consumption forms part of the scenarios that have been envisaged for the next few years. Work on forecasting the consequences that it will have on the power generation mix has already been undertaken as part of the Long-term Adequacy Report, and has emphasised the wide diversity of the possible models (see figure 5 below).

This work is continued in the SDDR. It involves assessing how the interest that French people might have in "short channels" can be operationally reflected in the way in which the network works and alter its balancing, and so provide answers to questions being debated about the issue.

There is nothing obvious about this issue: as long as people and companies installing solar panels on their roofs remain connected to the national grid and expect the same service guarantees from it, the current rationale for sizing the infrastructure will not be substantially modified. Nevertheless, various scenarios about the development of self-consumption have a bearing on the locations of photovoltaic solar energy installations and so influence the global distribution of flows.

Figure 5. Estimated development of individual self-consumption in the residential sector by 2035 in the *Ampere* scenario, according to various variants (analyses from the 2017 Long-term Adequacy Report)



A system used on a permanent basis – not as an "occasional insurance"

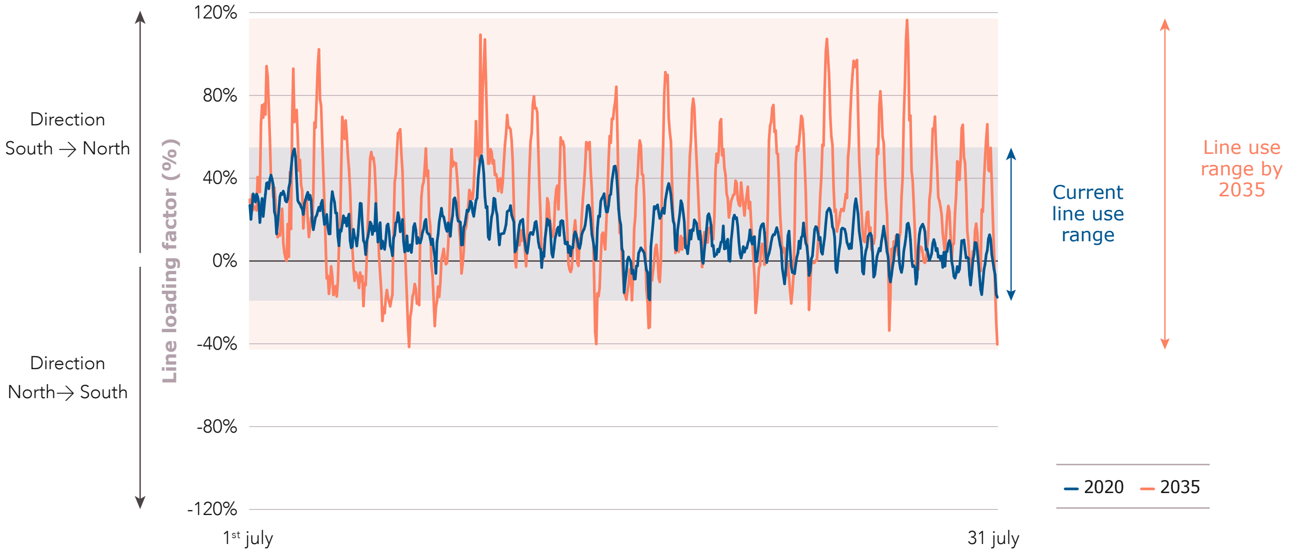
In France, the architecture and structure of the higher-voltage transmission network are a direct reflection of the electricity supply rationale which is applied at country level[2] and increasingly influenced by European factors.

The public transmission system's installations do not work on an *ad hoc* basis, importing or exporting local surplus. Even with the development of decentralised generation sources, the transmission system's infrastructure is used on a permanent basis to transport electricity. This way, sources of production can be pooled at national or even European level and electricity can be supplied to all consumers without disruption.

In this highly interconnected system, the primary role of the network is therefore not to "guarantee" power supply to the various autonomously structured territories.

The well-established structure of this network, which covers the territory via major vertical and transversal axes, is an asset for accommodating wind and solar power. Prospective studies show that the variability of flows on certain axes (particularly along the north-south vertical axes) should increase significantly over the next few years, initially without creating any major constraints. By 2030, however, some of these axes look set to become more restrictive and will need to be reinforced (see page 30).

Figure 6. Envisaged changes in flows along the higher-voltage transmission network's north-south axis in France (between now and 2035)



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[2] With the exception of Corsica and France's overseas departments, local authorities and territories

A system which needs to provide uninterrupted power in the face of frequent unforeseeable factors

Disruptions to the power supply are feared by consumers and are renowned for being very costly for the community, with economic losses resulting from disruptions to industrial or professional activity, damage to equipment, risks to people's health, etc.

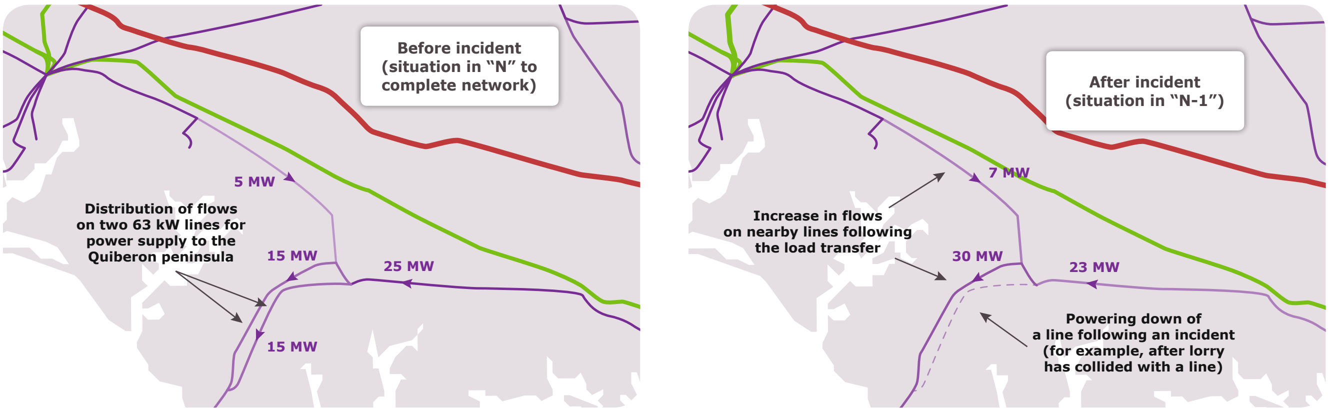
The network has been designed and is operated in such a way as to be able to offset such incidents transparently for consumers, i.e. by avoiding power failure at consumption sites. In other terms, the way in which the network is operated must ensure that it can be protected against a "N-1 situation", i.e. a configuration in which an unforeseeable factor results in a powerline on the network being accidentally unavailable. This way, electricity flows can circumvent the damaged section of the network and are able to reach the consumption point as planned.

Such damage occurs continuously on the network. Most of the time, it is invisible to consumers and does not disrupt their power supply in any way (see example below for the Quiberon peninsular in 2018). Only certain combinations of unforeseen factors (with a very low probability of occurring and which can only be prepared for by implementing extremely costly measures) can result in power outages. These remain extremely rare in France: in 2018, the "equivalent outage time" (the indicator used to measure the performance of the service delivered to users) resulting from transmission system failures was under 3 minutes per year on average[3].

The network's performance should therefore be analysed across all of its infrastructure, not simply by analysing the load rate on a "line by line" basis. On the contrary, it is the overall cost of the "network solution" – compared with the benefits it provides for users – which should be used to assess the network.

It is this type of economic analysis that governs how the network evolves. For this reason, over the last few years RTE has suggested not strengthening certain axes insofar as the costs of doing so would be greater than the benefits for the community. Such a decision was taken, for example, for the proposed extremely high-voltage subsea subterranean line between La Gaudière and Ponteau (Midi-Provence connection).

Figure 7. Illustration of the influence that an unforeseen event on a high-voltage line can have on electricity flows (south of Morbihan)



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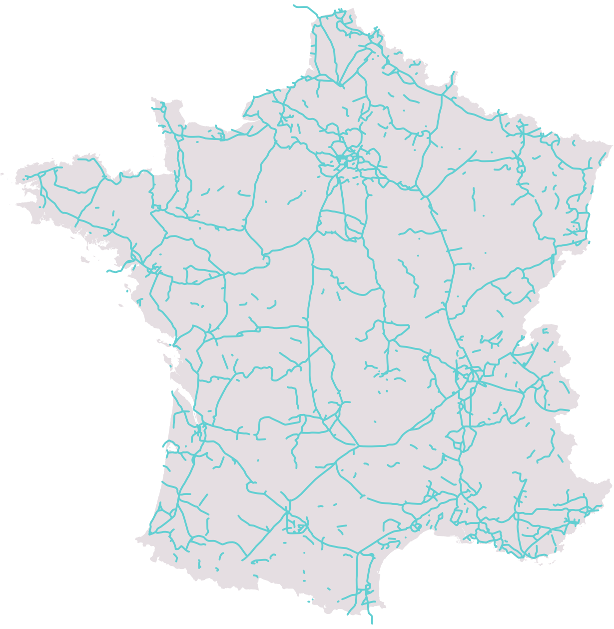
[3] This figure is for the average duration, for all consumers, of outages resulting from unforeseeable factors on the transmission system only. It does not include outages caused by other types of unforeseen factor (on the distribution network or supply-demand balance, for example). This indicator is therefore not to be compared with the "three-hour criterion" which is for the average duration of the risk of there being an imbalance between supply and demand.

A system whose operation is already based on a coupling with the telecommunications networks

The transmission system cannot be reduced to just a set of electric cables. Being able to maintain the system's balance in real time and the protocols for guaranteeing the reliability of all of the system's installations (network, power plants, industrial sites, sites of strategic or vital importance, etc.) is made possible by telecommunications networks and IT resources – IT resources used to process extremely large volumes of data and take action directly on the components making up the network.

This is not new: even as far back as the 1930s, the way in which networks were designed factored in the telecommunications resources of the era (telegraph lines). Since then, the choices made about energy in the 1980s (development of nuclear power, increase in temperature-sensitive power consumption, etc.) quickly meant that "finer" management of the power system in France was required, together with specific protection mechanisms for tackling the various unforeseen factors that could affect its operation.

Figure 8. Optical paths deployed across France as of 31 December 2018



The electricity transmission system is therefore a telecommunications network as well. Highly complementing the major telecoms operators' networks, the fibre optic network deployed over the last few years is made up of nearly 23,000 km of optical cable and is significant at country level. This network currently manages more than 300,000 data items per second and this figure looks set to increase dramatically over the next few years.

Increased production of wind and solar power means the need to more accurately control the power system – given the high levels of daily variability in these means of energy production. This is leading to the IT and telecoms resources needed for this control being reinforced.

This network's security is of the utmost importance: connecting up 58 nuclear reactors, major dams and numerous factories, the transmission system is infrastructure of vital importance, subject to specific performance and IT safety and security requirements. The way it has evolved, its resilience, the technologies used in it and the types of relationships with subcontractors are all to do with reasons of national security.

The SDDR's industrial choices are directly related to it, particularly for IT and telecoms equipment.

1.3 A network which “ensures stewardship”, but the evolution of which is subject to long procedures and challenges to do with acceptability in the eyes of local residents

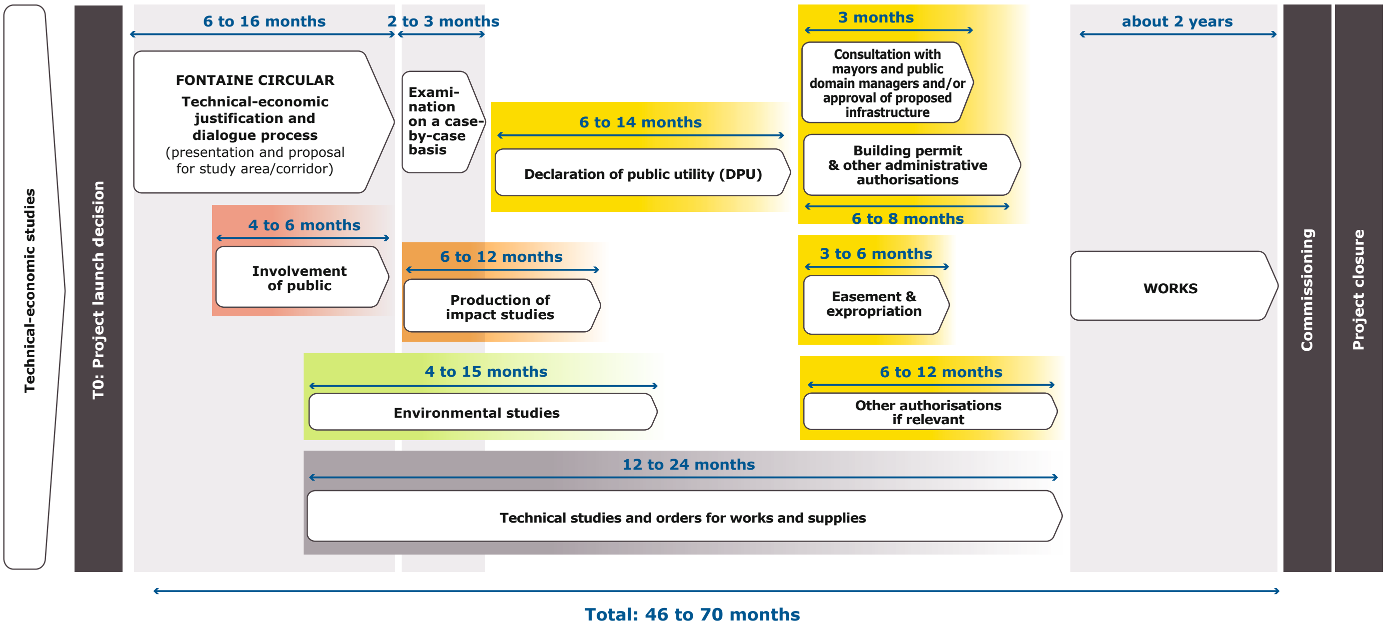
The need for speed in implementing new energy infrastructure (for generation and for the network) is in evidence today. In particular, a rhythm for developing renewable energies that is in compliance with the new multi-annual energy programme’s strategic aims needs to be gradually reached.

In France, it takes 7 to 10 years to build an offshore wind power farm, including 5 to 7 years of procedures. The same applies for large photovoltaic solar energy farms. Connecting these facilities up to the national grid requires that new network infrastructure be developed, and the same lead times apply for such infrastructure.

These lead times can be significantly lengthened when there are systematic appeals against the granting of administrative authorisations.

This can happen with the transmission system. For example, people are appealing against certain substations specifically built to collect energy produced by wind power, in the name of preserving the environment. This is the case with the “Sud Aveyron” substation in Saint-Victor-et-Melvieu. Should such situations become more commonplace, they could be particularly restrictive, resulting in the network becoming an obstacle to the generation mix being transformed.

Figure 9. Simplified diagram showing the procedures involved in a structural project (example for a 225 kV substation)



2

A NEW NETWORK PLANNING DOCUMENT

2.1 A new expanded and rethought network plan to inform the debate about the energy transition

The law makes RTE responsible for producing a ten-year network development plan.

For this edition, and within the framework of overhauling the scenarios begun in 2017, RTE is presenting a new, completely redesigned SDDR to serve as the counterpoint to the Long-term Adequacy Report for the network. It will also serve as a tool for debating key strategic aims regarding the development of networks, as well as a vector for operationally applying the multi-annual energy programme.

This new SDDR therefore represents progress in several ways:

- It is the result of work involving a **major public consultation process with stakeholders** (public consultation in spring 2018 about the hypotheses, with presentations of its various sections at consultation meetings, etc.)
- It shows how **all of the issues affecting the transmission system** have evolved – industrial, societal, environmental and financial issues (investment and operating spending), and sets out detailed financial trajectories;
- It uses a **15-year** time period (2021 to 2035), comparable to the multi-annual energy programme's general framing and the scenarios

Figure 10. Simplified diagram showing how the SDDR relates to other planning documents

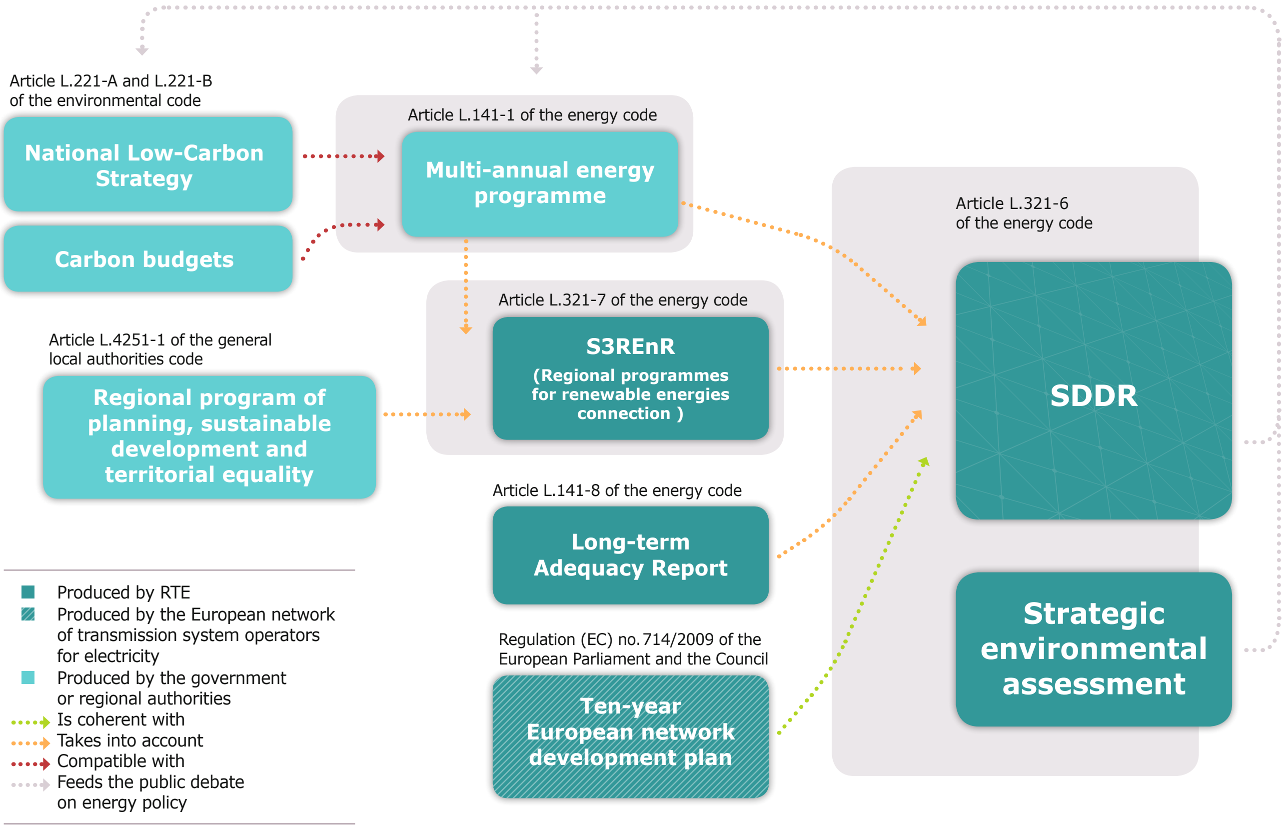
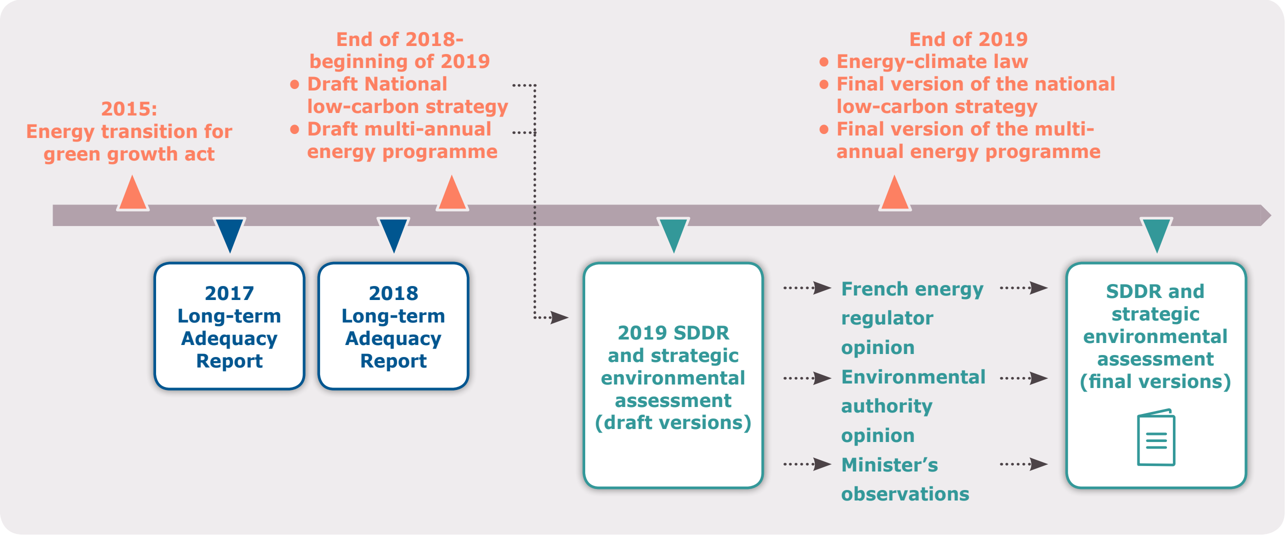


Figure 11. Deadlines for producing the SDDR



outlined in the Long-term Adequacy Report published in 2017;

- It adopts a **scenario-based approach, centred around the draft multi-annual energy programme** published in early 2019 (reference scenario) and enshrined by the scenarios outlined in the Long-term Adequacy Report *(Ampere, Volt* and *Watt* in some cases), and includes numerous variants and sensitivity analysis (consumption, geography of the development of renewables, geography of the transformation of nuclear power fleet, etc.);
- It uses the methodological principles of the **2017 Long_term Adequacy Report:** the hypotheses are explained, all scenarios are costed and the main inductors are subject to specific analyses via variants;
- It is subject to a **voluntary strategic environmental assessment,** conducted with the help of a specialist firm.

The SDDR is to be submitted to the ministry for energy, the French energy regulator and the environmental authority (EA). This way, the plan's compliance with the key aspects of the national energy policy can be checked, its funding can be discussed and it can be established as being part of a strategic environmental approach. Once this dialogue process is complete, the SDDR can be amended and become operational.

2.2 A transformation plan for the network to succeed in delivering the multi-annual energy programme

Context: the transformation of France's power mix as provided for in the multi-annual energy programme and the national low-carbon strategy involves making changes to the network accordingly

This "new SDDR" has come at a time when the government's strategic aims in relation to developments in France's electricity sector have been clarified and specified via the draft multi-annual energy programme and the national low-carbon strategy. It has been designed as the operational consequence of the draft multi-annual energy programme's strategic aims. The network of the future will need to serve as a support for the major changes to the energy mix envisaged in these planning documents.

Until now, the transmission system has always been able to keep pace with strategic decisions made about the generation fleet (development of the nuclear power fleet, first stages in the installation of wind power or solar power) or with changes in consumption (increased popularity of electric heating, digitalisation of uses, etc.). Adapting it was financed and quality commitments were maintained.

The starting point is therefore healthy.

On the one hand, the transmission system is sturdy – thanks in particular to the set of initiatives put in place to mechanically secure it in the wake of the December 1999 storms: it should now be able to withstand similar unforeseen climate events.

Figure 12. Public targets for transforming the power mix, derived from the draft multi-annual energy programme and national low-carbon strategy

Capacities of onshore wind farms and solar panels
Increased threefold in 10 years
Increased fivefold in 15 years

More than 10 GW of offshore wind power brought into service in 15 years

Decommissioning of
14 nuclear reactors
in 15 years

Phasing out of coal-based electricity production
by 2022

Interconnection capacity
doubled in 15 years
to ensure the technical-economic balance of the mix

More than 15 million electric vehicles between now and in 15 years

Connecting of electrolysers to reach a rate of decarbonised industrial hydrogen of 20% to 40% between now and in 10 years

Development of self-consumption photovoltaic power

On the other hand, the system provides dense coverage, meaning that it can deliver electricity of an excellent quality and manage flows less expensively: annual congestion costs of a few million euros, as opposed to more than a billion euros per year in Germany.

But the infrastructure is ageing and it will need to be replaced: in France, the current network is older than the networks of its European neighbours, which replaced theirs earlier. **This state of affairs is the result of conscious decisions that were made:** it was not necessary in previous years to undertake a widespread replacement of equipment – overall, it has been kept in good working order thanks to appropriate maintenance operations. This decision has benefited to the community, as well as keeping consumer energy bills down.

So fundamentally, the infrastructure has not undergone any major structural changes over the last few years.

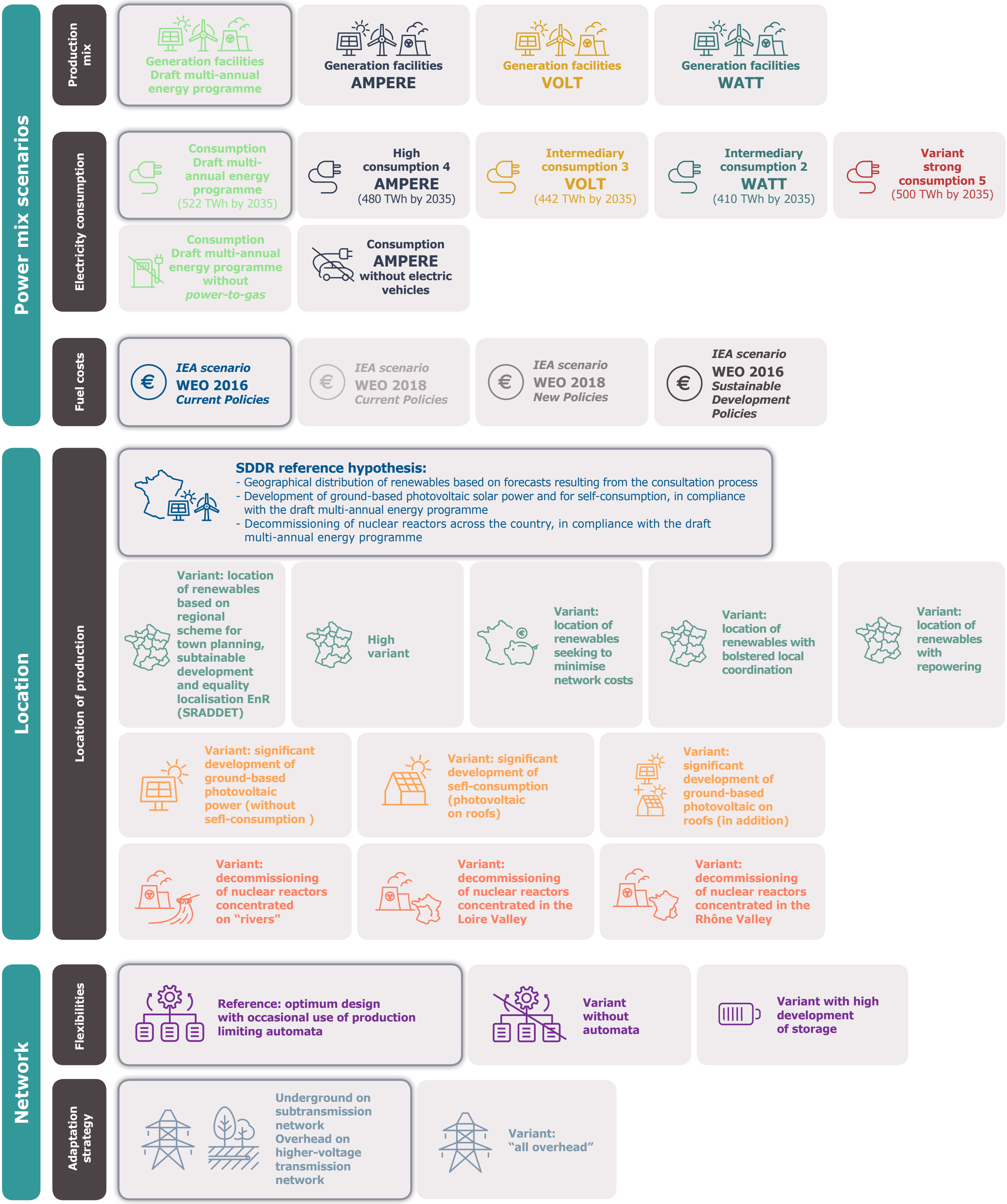
- The current network map is close to the 1990s map (see page 9): since that time, the changes made have mainly been marginal adjustments.
- Its coverage of France has remained stable overall: new powerlines brought into service have been offset by the ad hoc dismantling of old or unsuitable infrastructure;
- Unlike countries such as Germany which have already developed wind power and solar power on a significant scale, there are relatively few major network transformation projects under way in France: the "safety net systems" for securing the power supply to Brittany and the Provence-Alpes-Côte d'Azur region have been finished, as are the major projects involving the installation of extra-high voltage transmission lines at virgin sites, the most recent example of which is the Cotentin-Maine line.

While major changes to the power mix are on the horizon with the multi-annual energy programme, the current rates at which the infrastructure is evolving are not high enough if the targets set in the multi-annual energy programme are to be reached, while at the same time maintaining a high-quality service for users.

The method: a scenario-based approach to reflect the sector's uncertainties and the transformations it is undergoing

From an institutional and geographical perspective, particular attention has been paid to regions' aims. The network's strategies have been designed so they can adapt to the very high levels of uncertainty that still exist today. The SDDR provides analyses and the tools for discussing the convergence required between national planning and needs expressed at regional level (within the framework of *regional schemes for town planning, sustainable development and equality* or SRADDET). For each administrative region, the issues in the SDDR have been described and contextualised within the framework of local debate. The adopted approach falls very much within the framework of a multi-scenario initiative (see figure 13 below).

Figure 13. Reference hypotheses and variants studied in SDDR



Power mix scenarios

Production mix

- Generation facilities Draft multi-annual energy programme
- Generation facilities **AMPERE**
- Generation facilities **VOLT**
- Generation facilities **WATT**

Electricity consumption

- Consumption Draft multi-annual energy programme (522 TWh by 2035)
- High consumption 4 **AMPERE** (480 TWh by 2035)
- Intermediary consumption 3 **VOLT** (442 TWh by 2035)
- Intermediary consumption 2 **WATT** (410 TWh by 2035)
- Variant strong consumption 5 (500 TWh by 2035)
- Consumption Draft multi-annual energy programme without *power-to-gas*
- Consumption **AMPERE** without electric vehicles

Fuel costs

- *IEA scenario* **WEO 2016** *Current Policies*
- *IEA scenario* **WEO 2018** *Current Policies*
- *IEA scenario* **WEO 2018** *New Policies*
- *IEA scenario* **WEO 2016** *Sustainable Development Policies*

Location

Location of production

SDDR reference hypothesis:
- Geographical distribution of renewables based on forecasts resulting from the consultation process
- Development of ground-based photovoltaic solar power and for self-consumption, in compliance with the draft multi-annual energy programme
- Decommissioning of nuclear reactors across the country, in compliance with the draft multi-annual energy programme

- Variant: location of renewables based on regional scheme for town planning, subtainable development and equality localisation EnR (SRADDET)
- High variant
- Variant: location of renewables seeking to minimise network costs
- Variant: location of renewables with bolstered local coordination
- Variant: location of renewables with repowering
- Variant: significant development of ground-based photovoltaic power (without sefl-consumption)
- Variant: significant development of sefl-consumption (photovoltaic on roofs)
- Variant: significant development of ground-based photovoltaic on roofs (in addition)
- Variant: decommissioning of nuclear reactors concentrated on "rivers"
- Variant: decommissioning of nuclear reactors concentrated in the Loire Valley
- Variant: decommissioning of nuclear reactors concentrated in the Rhône Valley

Network

Flexibilities

- Reference: optimum design with occasional use of production limiting automata
- Variant without automata
- Variant with high development of storage

Adaptation strategy

- Underground on subtransmission network Overhead on higher-voltage transmission network
- Variant: "all overhead"

The structure of the detailed report: split into 12 sections, including five industrial sections dealing with the electricity grid's major projects over the next few years

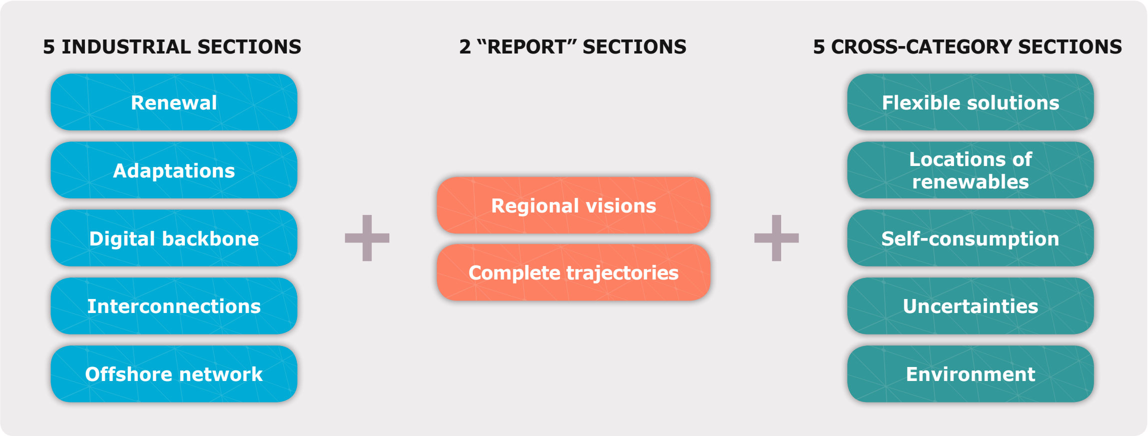
The multi-annual energy programme involves orchestrating the first major transformation of the network since the nuclear power fleet was introduced in the 1980s:

- The first **renewal of the network** since it was created needs to get under way, and we need to be in a position to dramatically increase efforts by 2030 (by around 30%): this priority given to everyday networks is one of the key aspects of the SDDR in order to guarantee today's service quality, all things being equal elsewhere.
- The network needs to be adapted to the new power mix: this involves processing new flows that are more variable and more powerful by increasing the capacities of current powerlines, building new ones or taking down lines that are less useful.
- Efforts need to be continued and the digital backbone of the network needs to be adapted for new technologies, bolstering cybersecurity requirements and enabling new technologies to be developed so that current infrastructure can be further leveraged and the need for new powerlines can be reduced.
- France's interconnection capacity needs to be doubled over a 15-year period, selecting the most profitable projects, so as to make best use of consumption and production differences in Europe and end up with a power mix that is balanced and sustainable from an economic perspective, mostly based on renewables and nuclear power by 2035.
- A network to connect up marine energies needs to be built, i.e., a marine network that is planned out in a coherent and effective manner with onshore reception capabilities and offshore development potential, in such a way as to keep costs down.

These actions together form the five ways in which the network needs to change from an industrial perspective and are dealt with in detailed chapters in the SDDR.

They are supplemented by two summary sections (mid-term projects and regional visions, and financial trajectories), together with five cross-category sections presenting specific information and sensitivity analyses (about flexible solutions, uncertainties, issues to do with where renewable energies are located, the development of self-consumption and environmental issues).

Figure 14. Content and structure of the SDDR



Synthesis: a summary of the main messages in three areas

In addition to the complete report divided into 12 sections as mentioned above, the summary document sets out the key issues in the SDDR in three areas, one for each of the three types of challenge posed by the network's transformation:

- **a societal and environmental component** which describes the initiatives implemented and the options under consideration, focusing on a global environmental approach (which includes focusing on issues to do with moderating our usage of resources and regenerating natural environments) and a societal approach (by making frequent use of underground infrastructure);
- **an industrial component** which focuses on identifying and preparing the main industrial projects for developing the network over the next 15 years, in order to ensure that RTE and its suppliers have the capabilities needed to implement these various projects;
- **an economic component** which on the one hand sets out to summarise the spending needed to transform the network so as to keep pace with the energy transition, and on the other hand to identify potential savings in order to ensure that funding is available for the necessary investments and keep the cost of the system down for consumers.

3

SOLUTIONS TO ALL CHALLENGES THAT THE EVOLUTION OF THE ELECTRICITY GRID BRINGS

3.1 From a societal and environmental perspective

The energy transition involves fostering an awareness of the need to speed up the network's adaptation

It is not possible to think about transforming the generation mix without transforming its network counterpart. Closing (or activating) nuclear reactors, developing onshore and offshore wind power and solar power, means making changes to electricity flows in France and Europe.

As long as total onshore wind power and photovoltaic solar energy remain lower than around 50 GW (it was 23.6 GW at the end of 2018), current infrastructure seems well adapted overall – provided that it is technically and politically possible to further optimise it by making ad hoc use of targeted generation curtailment in certain well-equipped zones.

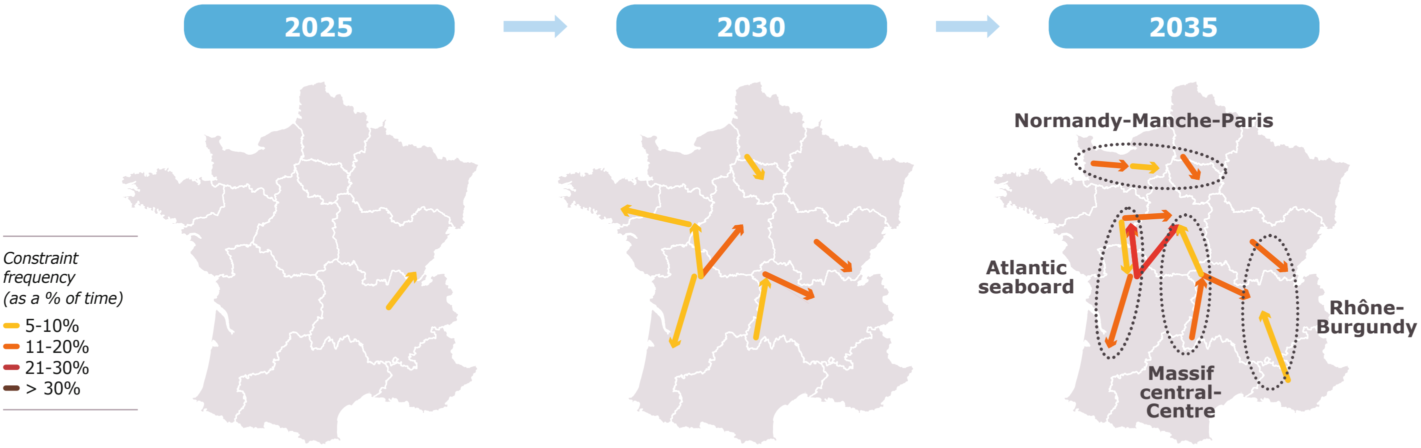
However, should total production exceed 50 GW, more fundamental changes will be needed in order to accommodate new renewable installations and handle the changes in flows that will result from the planned closure of certain reactors in the Rhône and Loire valleys.

Based on these outlooks for the future, significant changes to the subtransmission networks need to be scheduled now, some of which will need to be implemented by 2025. In concrete terms, this scheduling will be implemented in the future regional connection programmes for renewable energies (S3REnR) produced for the new administrative regions. Discussions under way in the regions that have made the most progress with this scheduling process confirm the trajectory presented in the SDDR.

In addition to the above, four vulnerable zones have been identified on the higher-voltage transmission network and will need to be reinforced between 2030 and 2035: the centre of France and the Massif central, the Atlantic seaboard, the Rhône-Burgundy axis and the diagonal line from Normandy and north-western France to Paris. However, the network does not need to be completely reconfigured and the work required should not be compared with the need to build new major north-south subterranean lines, currently under way in Germany.

In all events, the current infrastructure will still form the basis of the network over the next 10 to 15 years. The rate at which it is being adapted will need to be faster than it has been over the last few years, but not as fast as it was in the 1980s when the electro-nuclear programme was introduced.

Figure 15. Projection of main constraints on the higher-voltage transmission network if no changes are made to the network – scenario outlined in the draft multi-annual energy programme and the SDDR reference hypotheses



The SDDR debates the strategic aims of the major decisions that will need to guide the infrastructure's development and recommends increased use of underground technology

Changes made to the network will need to take place in today's societal context.

The new SDDR is built on the firm belief that the network's development can no longer be thought about in the same terms as it was 30 or so years ago. Indeed, society's expectations have evolved since this time, when the network was synonymous with technical progress and better living conditions, and welcomed by everyone or nearly everyone.

The needs expressed as part of dialogue processes with residents frequently focussing on undergrounding infrastructure. Some people even request that certain existing powerlines be undergrounded, particularly in areas with particularly high land pressure.

The strong preference for widespread underground infrastructure is not to do with environmental reasons: on the basis of their advantages and disadvantages in terms of their impact on natural environments alone, it is not easy to separate overhead and underground. More specifically, they are to do with a societal issue about preserving landscapes.

This wish may come up against the preoccupation of reducing network costs. Arbitrations therefore need to be found between society's various expectations. Indeed, it is impossible to demand a low-cost network (made up of overhead powerlines and built in straight lines), while at the same time granting the numerous requests resulting from local dialogue processes.

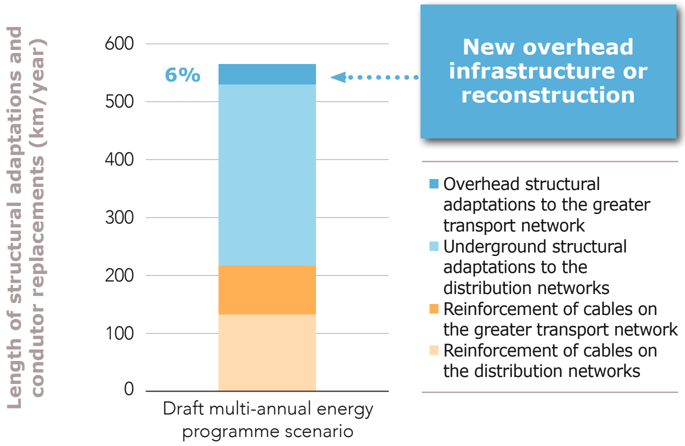
Striking a balance between these various aspirations will need to be done on a case-by-case basis, factoring in the specific features of each region. The SDDR sets forth general principles, integrating the strong preference for underground infrastructure, as well as economic reality: the increased cost of subterranean infrastructure throughout its lifetime is low for 63 kV and 90 kV voltages, but very significant for higher voltages. It therefore provides for:

1) **a "by default" principle that involves laying all new lines underground when they form part of subtransmission networks** (mainly 63 kV and 90 kV), unless doing so proves technically, environmentally or economically impossible;
2) the potential for existing lines to be undergrounded should be systematically examined when replacing them for age reasons (for subtransmission networks);
3) **the search for solutions based on reinforcing existing corridors and undergrounding for changes to the higher-voltage transmission network.** The most economical solution for the community, however, is still overhead infrastructure. But a combination of subterranean lines and reusing existing overhead corridors is also possible, if the additional cost is assumed and shared.

Even factoring in the increased needs placed on the transmission system, implementing these principles would result in a slight lessening of the transmission system's visual footprint between now and 2035.

These principles, which are as much to do with urban planning as with sectoral energy policy, will be adjusted once regulatory opinions about the SDDR have been collected, while allowing for differentiated application on a regional basis.

Figure 16. Types of changes to the network (forecast)



The SDDR describes the strength of a high-performance network from an environmental perspective and in terms of its contribution to reducing emissions, reducing the use of mineral resources and preserving biodiversity

The SDDR describes the way in which the network needs to help ensure that France's environmental goals are met.

This analysis focuses primarily on the contribution to reducing greenhouse gases.

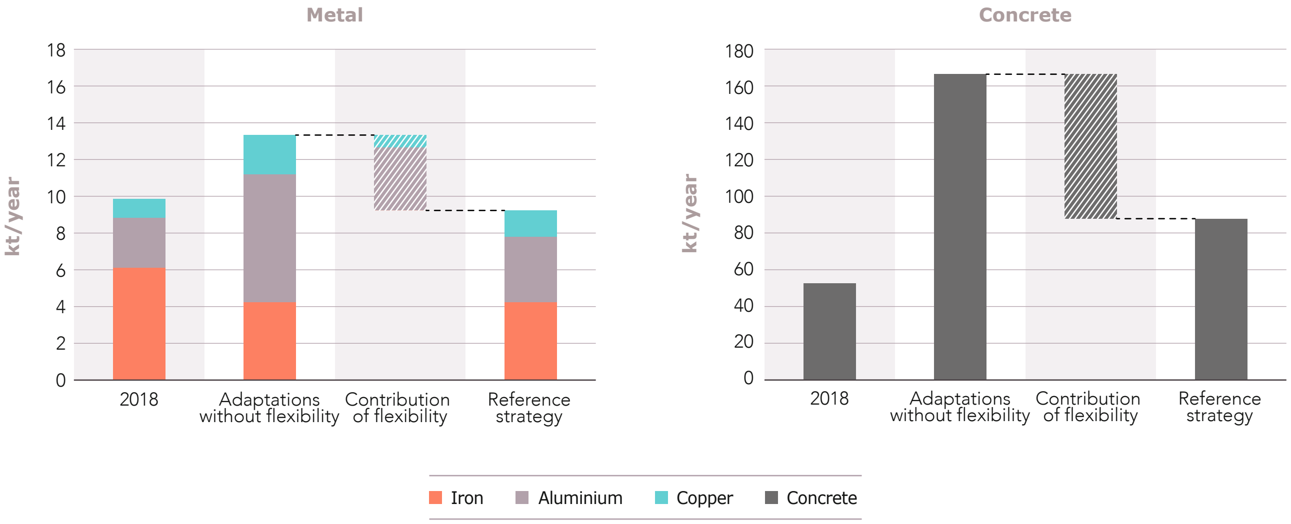
The network development work scheduled in the SDDR makes a major contribution to this: unless they are connected up to the network, offshore and onshore renewable energies, and new electricity uses (electrolysers, electric vehicles, etc.) cannot play a part in the power mix's transition. By making it possible to meet the targets set forth in the national low-carbon strategy, the electricity grid makes a significant contribution to reducing CO_2 emissions, estimated to be around 50 to 70 $MtCO_2$ per year between now and 2035.

In addition to these general targets, the specific choices outlined in the SDDR about the network's sizing have an influence on how the generation fleet works and its emissions. Without major adaptations, power generation using renewable energies would indeed need to be frequently limited in certain regions. The proposals for adapting the network described in the SDDR would therefore reduce the European power system's CO_2 emissions by 5 to 10 $MtCO_2$ – that's the equivalent of the emissions generated by coal-fired power plants in France today.

The environmental analysis also emphasises the need to **control mineral resource requirements resulting from initiatives to replace and adapt the electricity grid.**

Using flexible solutions – which is possible with a reinforced digital backbone – for reducing the need to make structural adaptations, extending the service lifetimes of infrastructure or pooling offshore platforms is, for example, proposed within the framework of the SDDR. Adopting an eco-design approach will help reduce the environmental footprint of the solutions implemented. Specific analyses have been conducted of iron, aluminium,

Figure 17. Estimated annual consumption of materials for adapting the network (draft multi-annual energy programme scenario)



copper and concrete consumption, and are illustrated in the graphs below. They can be used to locate the network’s requirements in relation to specific issues to do with these various materials.

Finally, making changes to the network is in line with the aim of preserving biodiversity across the region (zero net loss).

This results in an “avoid – reduce – compensate” approach being adopted (long before new projects are actually implemented), factoring in the idea that replacing and maintaining infrastructure helps preserve and – in some cases – restore biodiversity in the areas around the existing network. It also takes the form of a €140 million programme to modify substations so that they can be maintained without phytosanitary products.

The SDDR is supplemented by a strategic environmental assessment produced by a specialist firm and sent to the Environmental authority.

Developing a network that performs well from an environmental perspective comes at a cost. For example, with each proposal to adapt the infrastructure, this requirement could come up against the aim of minimising costs. The examination of the scheme simultaneously by the ministry, the French energy regulator and the Environmental authority is an opportunity to set down a certain number of guidelines for adapting the network over the next few years within a framework that is coherent from an economic perspective.

The network adaptation strategy described in the SDDR is compatible with various options for the geographical distribution of renewable energies and can adapt to regions' strategic aims

The organisational principles described in SDDR have not been designed as part of a centralised scheduling, "to be either taken or not taken". On the contrary, they have been designed as principles that need to be adaptable; several sections in the SDDR describe the factors that are likely to have a bearing on the choices and methods for managing uncertainty.

The SDDR therefore includes an analysis of the local issues associated with the network's development for each of France's administrative regions, factoring in the specific features of each one from both a technical perspective (geographic location, condition of the generation fleet and prospects of changes in electricity consumption, network characteristics) and a political perspective (nature of discussions conducted at regional level, long-term aims regarding the development of the generation fleet, etc.).

Since the future geographical locations of new wind power and solar power installations are one of the main uncertainties, the SDDR explores several possible futures:

- the SDDR's reference scenario was formalised after the dialogue process in 2018 with stakeholders involved in the power system: it integrates the various factors influencing the locations of renewable energies (technical potential, assessments of available land, acceptability in the eyes of residents, positions of local authorities, etc.);
- its main variant is built around the aims expressed by regional councils about changes to the energy mix, insofar as they are known at this stage via proposed regional schemes for town planning, sustainable development and equality of regions provided for by the NOTRe law on France's new regional organisation;
- other variants (high vision based on the maximum short-term achievable potential, analysis of different locations for reducing the need for new infrastructure at national or local level, etc.) are investigated to produce varied scenarios.

This systematic study highlights several important results, which establish that the strength of the **future network proposed in the SDDR is such that it is globally compatible with the various options for locating renewable energies.**

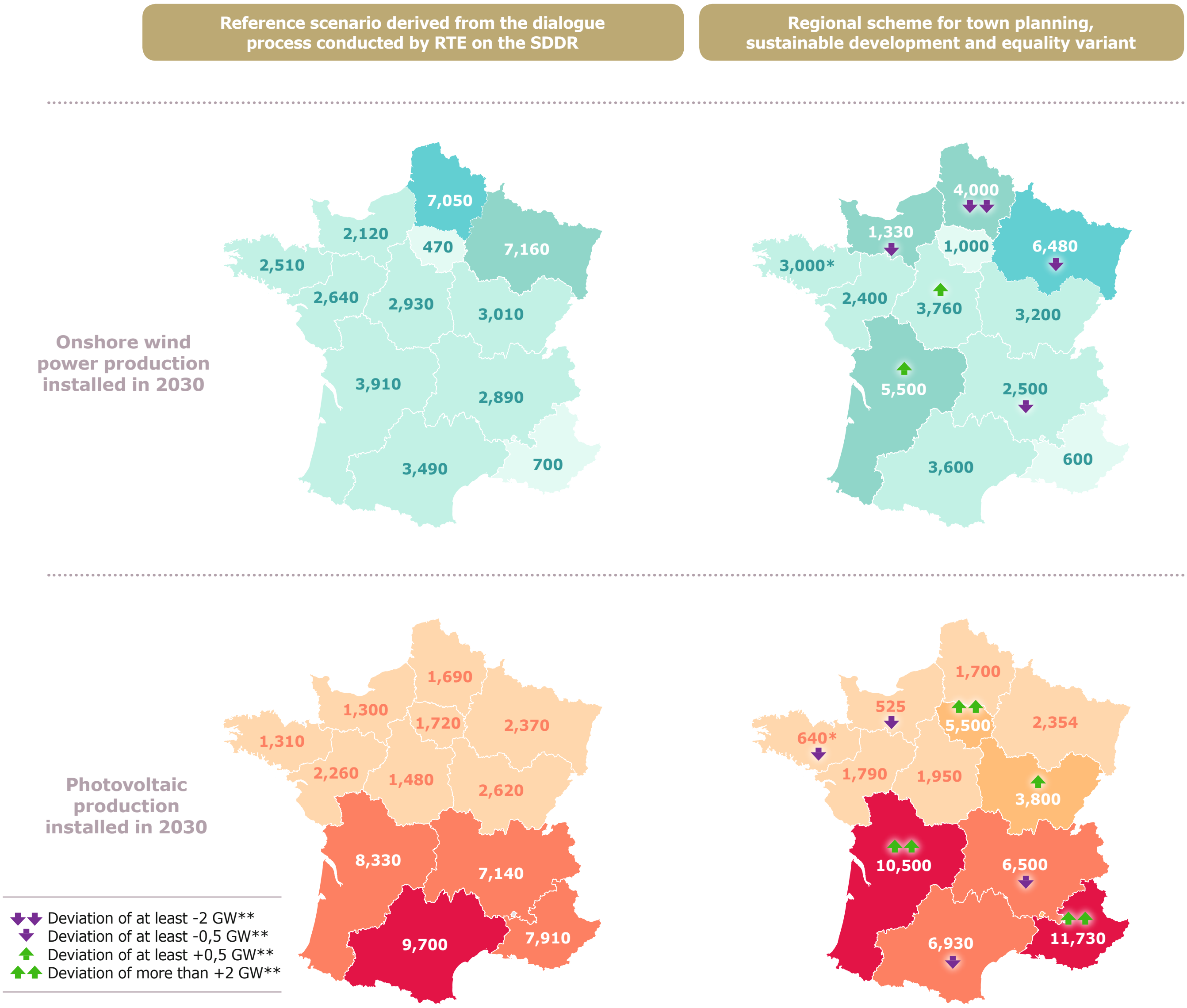
On the one hand, beyond a number of symbolic controversies regarding the role played by wind power in certain regions which already have a great deal of infrastructure (in the Hauts-de-France region, for example), the outlooks articulated in the proposed regional schemes for town planning, sustainable development and equality of regions do not appear, at this stage of their development, to be significantly out of step with the national scenarios.

There are differences about the roles of various sectors (share of solar power and wind power) and their distribution (more power produced in the south as a result of solar power generating targets). The locations of regional schemes for town planning, sustainable development and equality of regions lead to an increase in the need to adapt the higher-voltage transmission network (with an increase in north-south flows) and the subtransmission networks in certain regions (to connect up and evacuate energy generated using wind or solar power). Nevertheless, it results in a network the strength of which is comparable to that of the reference scenario, with costs which remain similar.

The analysis also shows that there would be an additional cost in "forcing" the geographical distribution of future renewable installations around the existing network so as to limit their development. Indeed, this would involve being deprived of the best technical potential and would result in a significant increase in production costs.

Regarding the locations of renewable energies, issues to do with producible energy (wind, sunshine), the availability of land, acceptability and environmental impacts will therefore remain the primary factors influencing the choices of generators, and will logically result in changes to the infrastructure, including changes across the higher-voltage transmission network.

Figure 18. Comparison between the location scenario derived from the dialogue process and the variant based the draft regional schemes for town planning sustainable development and equality



* Region for which the aims are not known for the period 2021-2030. The figures given reproduce the aims of the previous scheme.
** Compared with the reference location in the multi-annual energy programme scenario in 2030.

Estimated investments in the transport network and congestion costs (2021-2030)	~€4.3 billion	~€5.9 billion
Estimated investments in the wind and solar farms (2021-2030)	**~€50 to €60 billion**	

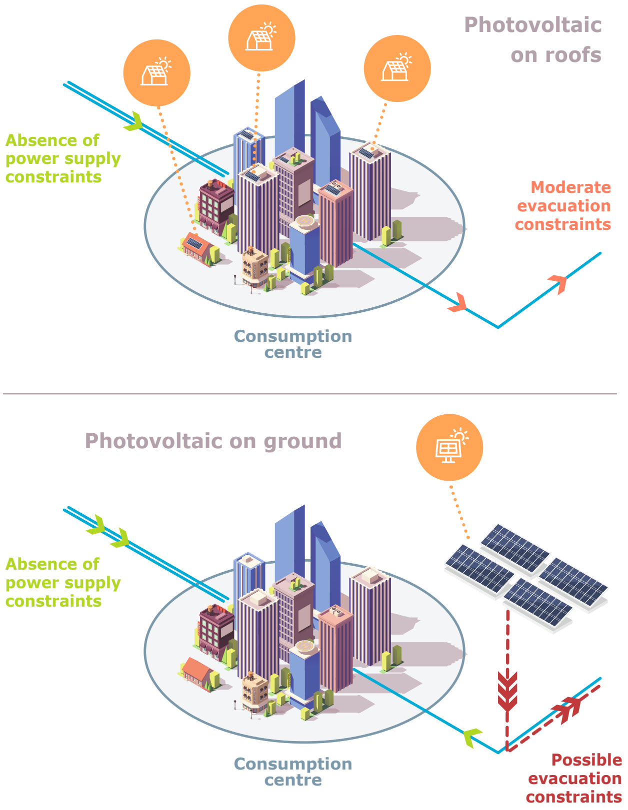
The development of self-consumption does not – as such – have any influence over predictions for the way in which the transmission system will change. The geographical distribution and power of future solar installations, on the other hand… yes.

The lower costs of photovoltaic panels over the last few years has led to increased interest on the part of households and companies in self-consumption.

The debate about self-consumption features several competing arguments: some people see it as a way of reducing network usage, and a way for infrastructure to be less involved in supporting the energy transition; for others, on the contrary, self-consumption still has to prove that it has a positive impact on network sizing, since the guarantees demanded by consumers are still the same: they need to be able to extract a defined power from the network.

To move forwards, a systematic analysis of consequences for the networks is required. The SDDR seeks to contribute to this analysis, with a dedicated section which is an extension of the work published in the 2017 provisional long-term forecast plan. Based on a new analysis of the development prospects in the residential, tertiary and industrial sectors, a number of scenarios for the development of self-consumption are analysed (limited boom, massive boom to the detriment of or in addition to ground-mounted solar power plants, with or without demand response and with or without diffused storage).

Figure 19. Illustration that the impact of where photovoltaic production is located has on a fictitious network



Several lessons result from this.

On the one hand, the development prospects for the transmission system are not – as such – influenced by the development of self-consumption. Even if one banks on significant developments in solar power, the quantities of electricity that are likely to be produced for self-consumption remain relatively low between now and 2035 (approximately 6% of the electricity generated in France under the multi-annual energy programme scenario): by this time, the power system will still mainly be characterised by the massive transfer of electricity from generating sites to consumption sites. Furthermore, the networks remain characterised by peaks in electricity extraction, which are not necessarily reduced, since solar production and consumption requirements do not tally.

On the other hand, if self-consumption is developed to the detriment of large ground-based solar farms, it will lead to a significant amount of solar production being located in urban centres, on parts of the network that are often sufficiently dense, rather than in rural areas. This is a factor that will reduce the need to adapt the transmission system, all other things being equal.

Nevertheless, the impact on the transmission system appears to be of secondary importance compared with the economic challenges (installations on roofs are significantly more expensive than major ground-based installations) or environmental challenges (the consequences in terms of footprint are different). The analysis presented in the SDDR does not seek to choose between the various visions.

These analyses are without prejudice to the impacts on the distribution networks, which are not assessed in the SDDR.

3.2 FROM AN INDUSTRIAL PERSPECTIVE

Adapt the network: moderate investments in the mid-term, underpinned by the use of flexibilities, more structural reinforcements beyond

Changes to the energy mix – firstly the development of renewable energies, as well as the decommissioning of the 14 nuclear reactors provided for by the draft multi-annual energy programme – involve adapting the network for the new geographical distribution of generation sources.

In the short-term, the current infrastructure and its extensions – either those that are already under way or those envisaged within the framework of the regional programmes for connecting renewable energies up to the network – can still handle new installations for producing renewable energies for a few more years, without the need for any major changes to the network upstream. This will involve further optimising the current lines by using smart grid solutions and accepting the principle of optimum sizing.

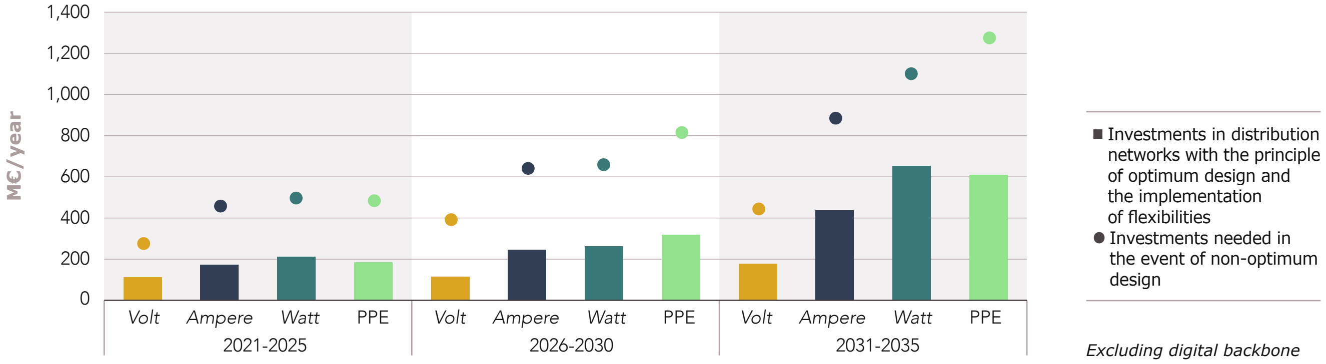
Within this framework, ad hoc production curtailment may be used in certain specific zones, in order to avoid building network infrastructure which may only prove useful for a few hours in the year. Given the natural increase in the production of renewable energies, the curtailed volume would be very limited (0.3% by 2035), generating significant network savings. The generators affected by curtailment would be compensated by RTE and would not suffer any loss in revenue.

To be implemented with peace of mind, these principles must be shared and responsibility taken for them collectively. Otherwise, the need to make changes to the network would already be significantly higher, and would lead to a much bigger increase in the shares paid by generators than currently envisaged. Furthermore, these principles require that a specific strategy be implemented (with the deployment of thousands of active network management controllers over the next 15 years in particular).

Despite these cost-saving effects on the network upstream, a significant amount of connection infrastructure still needs to be developed (particularly the creation of new source substations with the distribution grid operators).

Beyond 50 GW of installed capacity for onshore wind power and solar power – a threshold that is reached towards 2025 in the draft multi-annual energy programme – structural changes are needed on the subtransmission and higher-voltage transmission networks (see page 30). This requirement is evidenced in all the scenarios studied in the SDDR by 2030 or 2035, depending on the case.

Figure 20. Projected investment in subtransmission networks, with or without the contribution of flexibilities



Excluding digital backbone

Renew the current network: priority given to electricity for everyday purposes

France’s electricity transmission network is 50 years old on average – which is older than elsewhere in Europe. This is deliberate and is not an accident: the adapted maintenance policy implemented by RTE until now has made it possible to operate the network over a longer period of time, significantly reducing replacement needs compared with other European countries.

However, the network’s service lifetime cannot be extended indefinitely. Over the next 15 years, renewing the existing network is going to become crucial. In 2030, an increasing number of lines which date from when the country was being rebuilt after the Second World War are going to turn 85 years old. The budgets earmarked for infrastructure renewal will therefore need to be increased.

In addition to this mechanical effect, urgent infrastructure renovation operations are already required for some of the components making up the network. This applies in particular to pylons that are most vulnerable to corrosion in certain regions across the country; some of these will need to be replaced and others will need to be better protected. Several specific plans have been produced for maintaining service levels.

These characteristics help determine the challenge over the next 15 years: either the efforts to renew infrastructure are gradually increased, or the service levels delivered by the infrastructure will need to be reduced.

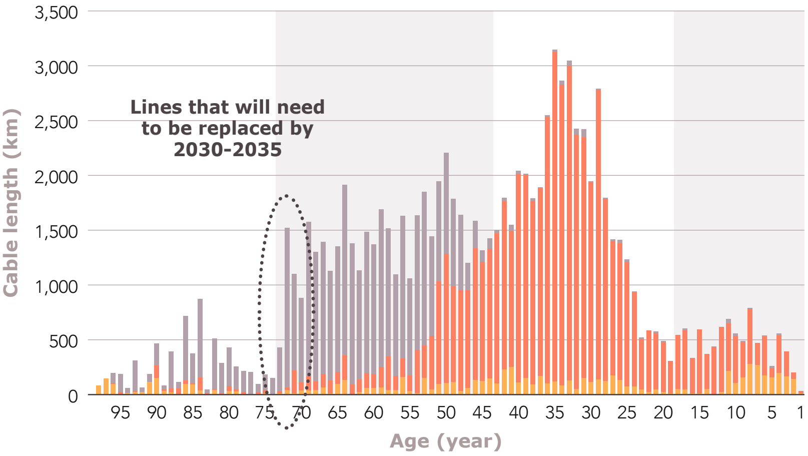
The renewal policy detailed in the SDDR is underpinned by three major strategies.

1) **It seeks to maintain current average service levels** across the country. It would not be useful from an economic perspective to increase this level, which is among the highest in Europe.

2) **It emphasises the “everyday network”,** giving preference to investments for renewing and maintaining existing powerlines, which are admittedly less visible than major projects such as new interconnection lines, but which are nevertheless essential.

3) **It is based on a desire to economically optimise infrastructure, so as to smooth out the differences between components that have been replaced and others which have not, and to ensure that the best-performing assets can be used for longer.** It uses several levers for this: redefinition of the asset management policy via new tools, joint scheduling of renewal and adapting it on a zone by zone basis, criticality analyses and prioritising so as to renew infrastructure based on observed performance and not normative criteria, etc.

Figure 21. Age pyramid of overhead conductors



Before 1945: First development of electricity networks for evacuating hydraulically generated electricity and supplying the regions. The cables used are made of aluminium and steel.

1945-1975: Development of a first-level greater transport network (225 kV) to interconnect the regions with widescale use of aliminium and steel cables.

1975-2000: Development a new 400 kV network alongside the emergence of electro-nuclear facilities and widescale development of a new aluminium-magnesium cable technology providing a better technical-economical compromise.

2000-2018: More moderate development of the overhead electricity network through more frequent use of subterranean infrastructure and emergence of new “low dilation” cable technologies providing better transit capacities.

🟥 Aluminium-magnesium ▨ Aluminium - Steel
🟧 Other

Transform the network using digital technologies: a modernisation of the electricity grid's "central nervous system" that is needed to increase its resilience and optimise the way in which it is used

To support these transformations of the power system and the development of flexible solutions (controllers, sensors, etc.), the SDDR provides for a bolstering of the network's digital backbone to help it reach a new functional target by 2035.

Indeed, over the next few decades, the electricity grid will be subjected to phenomena which will profoundly change the ways in which it used and maintained.

On the one hand, this will be the dramatic increase in variable renewable energies for electricity. To use existing infrastructure effectively and limit the need to build new infrastructure, more reactive operating modes are needed for the power system.

The strategy put forward within the framework of the SDDR is therefore based on an area controller deployment plan, line monitoring tools and high-performance communications protocols, starting in 2021-2025. It is part of a large-scale smart grid approach.

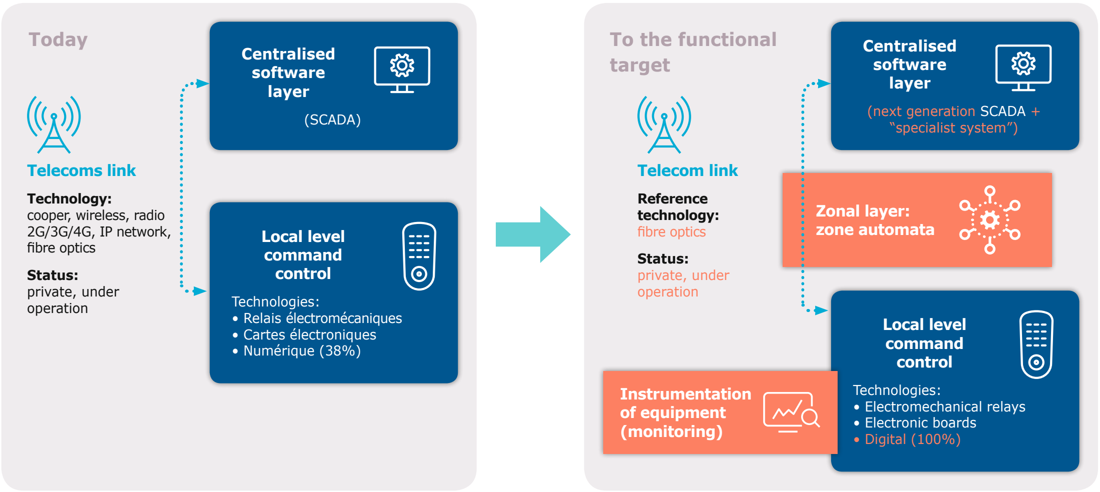
On the other hand, the prospect of a more wide-ranging renewal of existing infrastructure made necessary by the network's ageing requires in-depth knowledge of the actual state of equipment so as to ensure that the most urgent maintenance and renewal operations are carried out first. Sophisticated instrumentation of equipment is therefore needed.

The functional target also includes renewing the command control systems at local level along with the IT systems. Telecommunications lines will also need to be adapted. It will be deployed by coherent functional batches:

- a "renewal" batch 0 to tackle the natural ageing of existing command control systems, that have been installed at substations since the 1970s;
- a "fundamental" batch 1 for modernising telecoms links and reaching service levels that meet the network's specific requirements (need to guarantee network operation in the event of an electricity blackout);
- a "performance" batch 2 for deploying optimisation strategies on the adaptations and renewal.

This strategy has been adjusted to the multi-annual energy programme scenario, leading to a third batch being removed at this stage (faster digitalisation of the network backbone and bolstering of telecommunications lines).

Figure 22. Command control and telecommunications backbone of the electricity network



Interconnect France: a doubling of capacity for exchanges in 15 years

For a long time, developing electrical interconnections has been one of the mainstays of the European Union's energy policy and a factor in securing the supply of electricity to all member states. At national level, the energy roadmap set forth in the draft multi-annual energy programme also provides for significant development of interconnections, in line with the outlook drawn up by President Macron in September 2017.

The SDDR sets forth the prospect of doubling France's interconnection capacity in 15 years (increasing it from around 15 GW today to around 30 GW by 2035). To succeed in doing this, interconnectors will need to be created at all French borders, focusing on projects the utility of which has been proven.

This approach is based on an operational method which seeks to prioritise projects and structure them into a coherent industrial and economic programme. All of the projects considered (around 15) have therefore been organised into coherent subsets so they can be developed in a sequential manner, integrating the internal network's associated changes. The result is three batches of projects:

1) In the short-term, "batch 0" needs to be completed, i.e. the three structural projects that are under way in the UK (project IFA2 – the new submarine cable link between Calvados and the south of the UK – and Eleclink – the cable passing through the Channel Tunnel) and Italy (Savoie-Piémont project between Chambéry and Turin, that passes through the Fréjus tunnel in particular).

Figure 23. Illustration of sequenced interconnection development programme

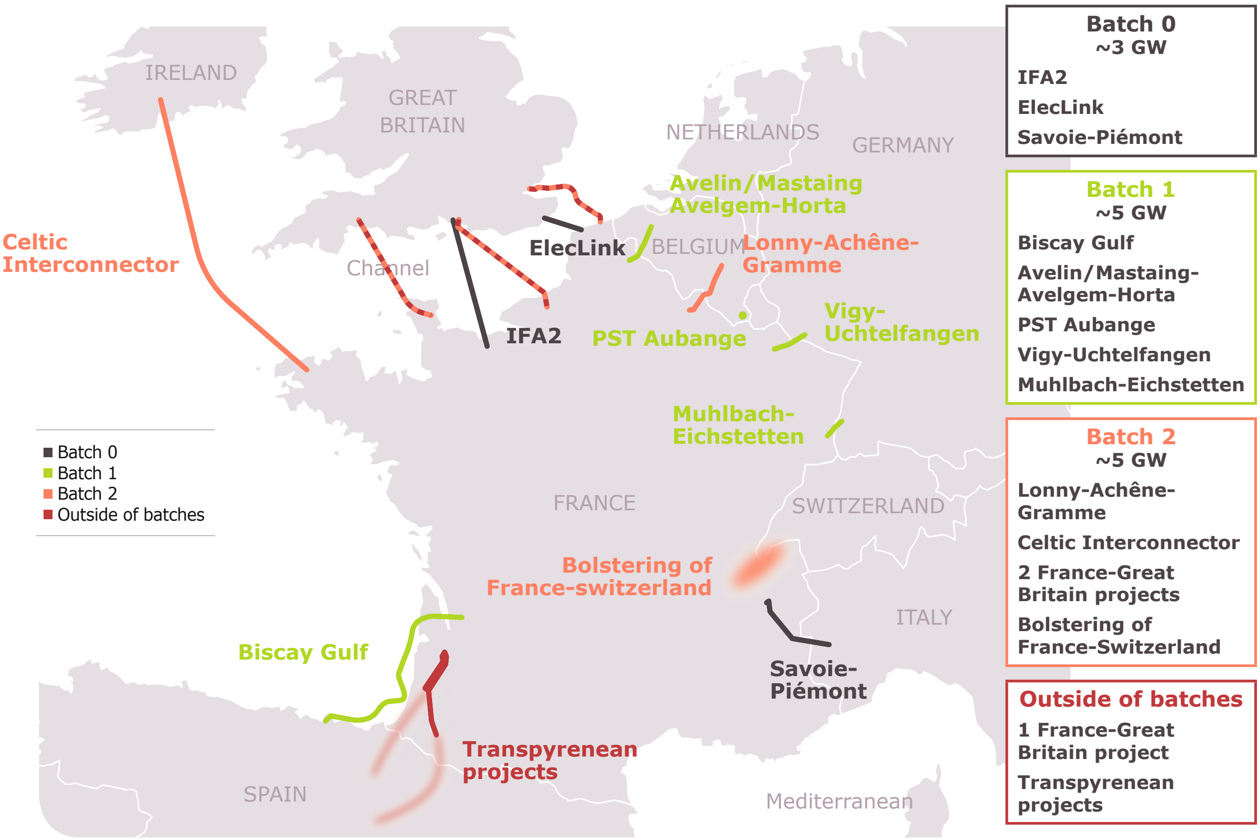
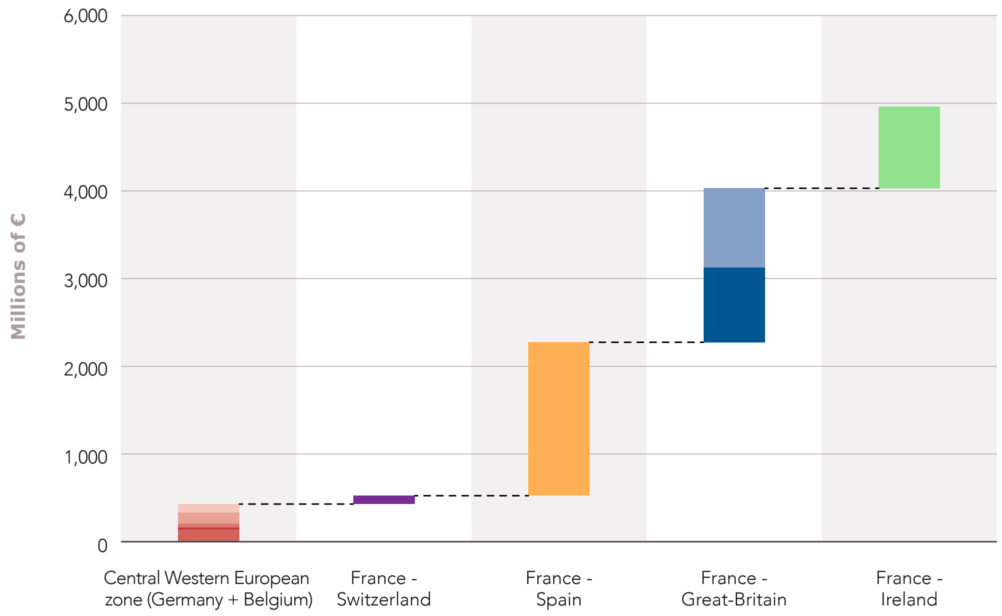


Figure 24. Estimated total costs (France and neighbouring countries) of batch 1 and 2 interconnection projects in the SDDR, excluding subsidies



The different shades of each colour represent different interconnection projects

2) The next phase will involve work commencing on the interconnections making up "batch 1". This covers all the "no regrets" interconnections, i.e. those interconnections which have been technically and economically justified in all scenarios: new link to Spain (Biscay Gulf link connecting Bilbao and Bordeaux), bolstering of existing links to Germany and Belgium which are relatively inexpensive compared with the benefits they bring. All of these interconnectors are scheduled to come into operation around 2025.

3) Other new cross-border interconnection projects have been included in a "batch 2": their profitability can only be guaranteed under certain conditions, and additional investigations are required before decisions can be made about whether or not to commit to the project. These conditions can be political in nature (the outcome of Brexit, etc.), financial (total European subsidies) or can depend on the technical-economic justification of projects if they are heavily dependent on certain hypotheses about how the power mix will change in the various countries concerned. If these projects end up being justified, they could be launched in the next few years so that they come into operation after 2025.

This programme involves giving priority to increasing effective electricity exchange capacity in the Pentalateral region (France-Germany-Benelux). Changes to France's internal network making it possible to make use of interconnections in accordance with EU law have already been agreed as a whole.

This sequenced programme will therefore lead to the emergence of an ambitious but realistic trajectory for developing interconnections over the next 15 years.

Connect up renewable marine energies: construction of a new offshore network to generate 10 to 15 GW of offshore wind power over the next 15 years.

The development of renewable marine energies is one of the key aspects of the policy to diversify France's energy mix. The results of the third invitation to tender for the Dunkirk zone published by the government in June 2019 revealed that the costs of offshore wind power production had fallen dramatically. Connection is now a major component of the overall cost of offshore wind power, and so optimising this component would appear to be an essential condition for enabling the long-term development of the sector, as well as bringing energy bills down for consumers.

The new legislation, introduced over the last couple of years, has clarified the framework for developing offshore wind power. RTE, as the contractor responsible for connecting up facilities under the multi-annual energy programme, is now also responsible for their financing (via the transmission system access tariff or the "TURPE").

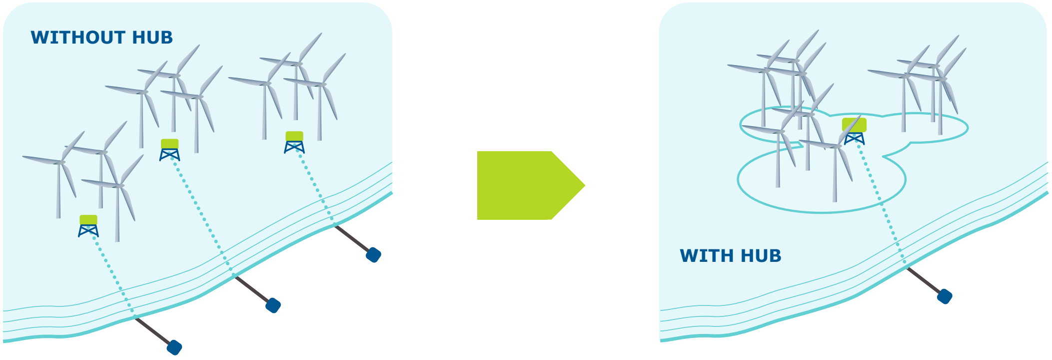
The SDDR describes the industrial plan that will need to be implemented to connect up between 10 and 15 GW of marine energy by 2035, in accordance with the targets announced by the government. This is underpinned by an updated and refined cost assessment, based on a European benchmark, together with three levers for optimisation, the actioning of which is made possible by the connection reform:

- development of shared, modular platforms (hubs) and diversification of usage of these platforms;
- appropriate sizing of wind farms' powers, in order to avoid threshold effects;
- standardisation of certain infrastructure components deployed.

For the wind farms that will be built following future invitations to tender, these levers can generate significant savings – of around 15% – on connection costs. These results are contingent on the government adopting long-term scheduling for these wind farms and on locations being chosen – in time and space – such that connection infrastructure can be pooled.

As a general rule, long-term planning of marine energy projects will be needed to effectively anticipate the network's capacity to accommodate

Figure 25. Illustration of the shared connection principle using hubs



1 individual connection
for each facility

1 shared connection
for several facilities

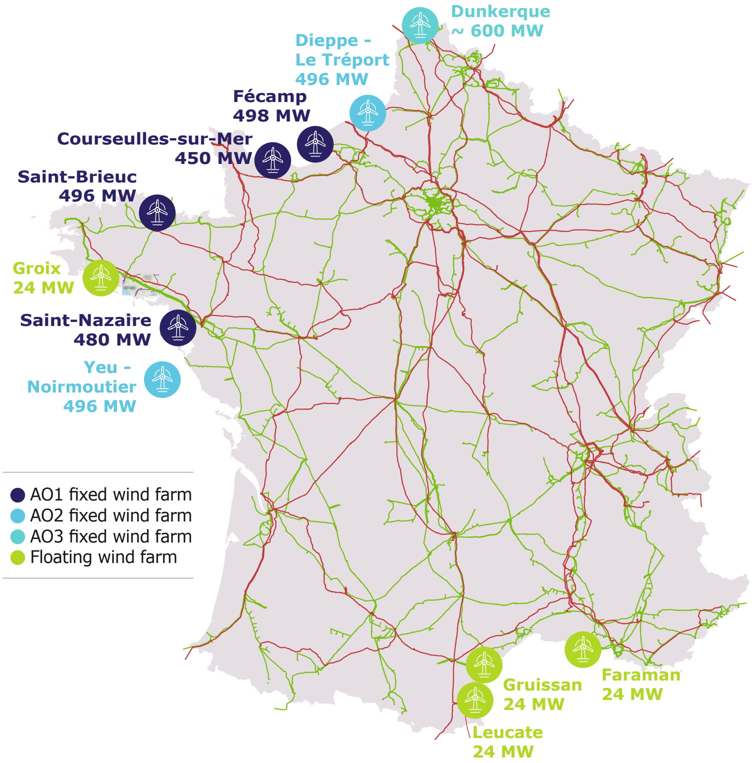
infrastructure along the length of its various seaboards in a context which is seeing major changes in the energy mix – not just the incorporation of marine energies.

As things currently stand, potential onshore capacity to accommodate infrastructure (capacity to evacuate energy generated to a particular point on the network) is significant along the length of France's four seaboards. This potential will gradually fall with the effect of increased wind power (onshore and offshore) and solar power production. In a restricted system – which is what the north-western-North Sea and South Atlantic seaboards is – the sequencing of the various connection requests becomes an issue of premium importance. The factor which triggers network reinforcements is the factor which leads to the potential for it to accommodate new infrastructure being exceeded, but once it has been increased by network reinforcements upstream, other projects can be connected up.

For onshore renewable energies, this difficulty has been addressed by the regional connection programmes for renewable energy, which create a target vision for the network and define keys for sharing the associated investment, such that equality between generators can be guaranteed.

Regarding offshore wind power, no such schemes exist. Without a shared "target vision" for the power generation assets in the zone, connections will be handled as they are requested based on a "first come, first served" approach, in application of the current regulatory framework.

Figure 26. Proposed offshore wind farms



This analysis highlights the utility of having a long-term plan for developing various generation sources along these seaboards, so work can commence now on preparing the network to accommodate them. RTE's proposals for producing an additional planning document for developing the offshore network aim in particular to shed light on these issues.

Integrated scheduling for all the planned changes is required, on a zone by zone basis

The five industrial sections presented on pages 37 to 43 require a long-term projection capability, without compromising on the ability to adapt. Specifically, they show that planning means better socio-economic performance of the network:

1) On the subtransmission networks, knowing upstream where the renewable energies are located means that the network's adaptations can be prepared for and scheduled;

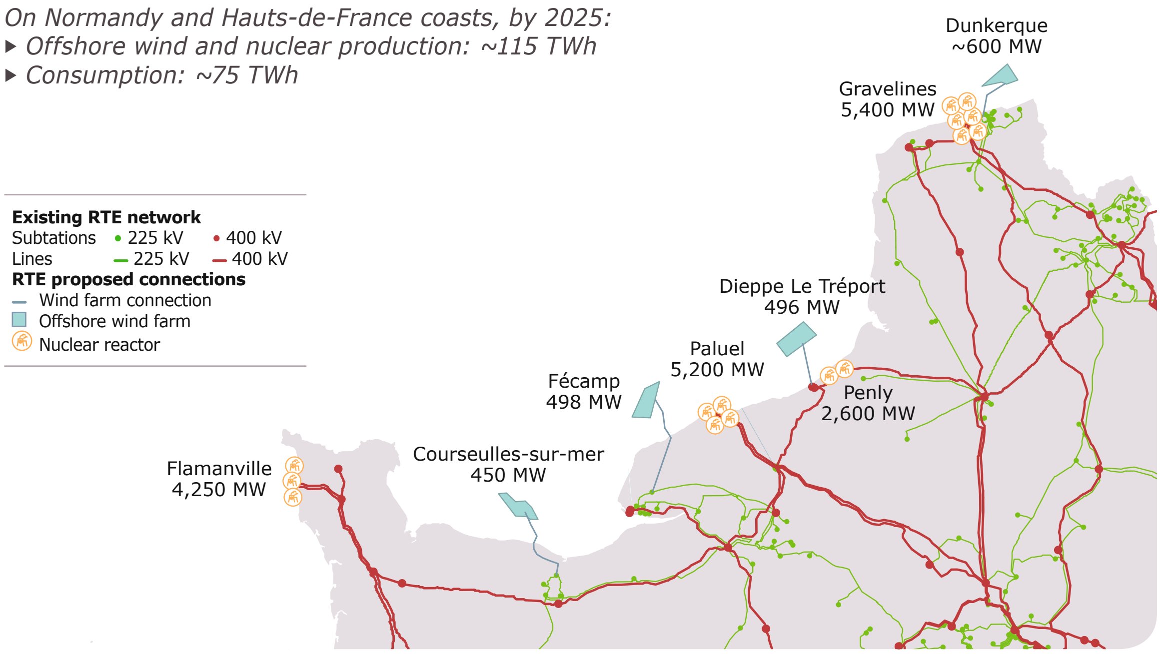
2) On the higher-voltage transmission network, the sooner it is known when the nuclear reactors are to close – which are scheduled to be decommissioned over the next few years under the multi-annual energy programme, the easier it will be to adapt the network;

3) For marine energies, coordinated planning for the offshore network and the onshore network has obvious economic and environmental benefits.

Since it takes a long time to approve and deliver network projects, decisions about changes to infrastructure are taken "with an uncertain future". Whatever approach is used to tackle this uncertainty, it will have a cost. Undertaking work on adapting the network in an as yet unknown context ("proactive" approach) can result in stranded costs; conversely, waiting until one has a clear overview of what the network's requirements are ("reactive" approach) can result in adaptations being implemented too late, thus temporarily increasing congestion costs. In the SDDR, neither of these two approaches is invariably preferable to the other, but a minimum set of adaptations is identified.

Beyond the various scenarios, the transition's practical feasibility is at play: it requires significant coordination between government, RTE and the regulator, as well as with all other stakeholders.

Figure 27. Structure of the network and nuclear and offshore wind farm production on the Normandy and Hauts-de-France coasts



On Normandy and Hauts-de-France coasts, by 2025:
- *Offshore wind and nuclear production: ~115 TWh*
- *Consumption: ~75 TWh*

These projects must be prepared and scheduled over the long term to guarantee that the whole industrial fabric involved in them will have the capabilities needed to complete them

As well as being important for meeting the energy policy targets set in the draft multi-annual energy programme, the SDDR serves as an industrial scheduling tool that involves RTE in its capacity as an operator and a wide panel of suppliers and subcontractors.

The principles detailed in the document have their role to play. The industrial strategy is based on (1) standardising equipment and long-term scheduling so as to keep costs down, (2) pooling infrastructure (for example, for connecting up offshore wind turbines), (3) giving preference to using onshore underground technology and (4) using digital technologies to further optimise existing powerlines and reduce the need to adapt the network.

Taking the opinions of the Minister, the energy regulator and the Environmental authority into account will ensure that the course suggested by RTE is shared, and that it can be amended if necessary. Once this course has been definitively decided upon, it will need to be possible to spread out and assess how well it is kept to in the long term. Otherwise, the expected savings will not be delivered.

The publication of the SDDR is also a way to increase the visibility of RTE's industrial ecosystem in terms of the network's long-term evolution and the underlying industrial plan.

1) From a technological perspective: the SDDR highlights the increase in requirements, as well as the evolution of their strength (for example, the preferred use of underground infrastructure), and makes it possible to prepare suppliers for the types of equipment that RTE will be looking for over the next few years (controllers, IT systems, etc.);

2) From an expertise perspective: several of the SDDR's sections require long-term knowledge of certain key technological areas, requiring special expertise. Clarifying the digital backbone's development requirements or what is needed for offshore connection means that training and recruitment needs can be prepared for in these areas;

3) From a resource perspective, the SDDR highlights supply and equipment and human resource issues (both within RTE and for stakeholders in the sector): availability of vessels for laying submarine cables, industrial production capabilities for these cables, maturity of industrial solutions in command-control systems, etc.

3.3 From an economic perspective

The SDDR clarifies the investment trajectories in the transmission system that are needed to implement the multi-annual energy programme

A retrospective analysis of investment spending in network infrastructure shows that it closely follows changes in the power mix.

In particular, structural investment in the higher-voltage transmission network went hand-in-hand with the expansion of France's nuclear power fleet in the 1980s and 1990s, and then the increase in power consumption. After a dip in the 2000s, investment spending in the power transmission network – driven by the increase in the number of interconnections, the integration of renewable energies and the gradual increase in spending on replacing network infrastructure – has continued to grow over the last few years.

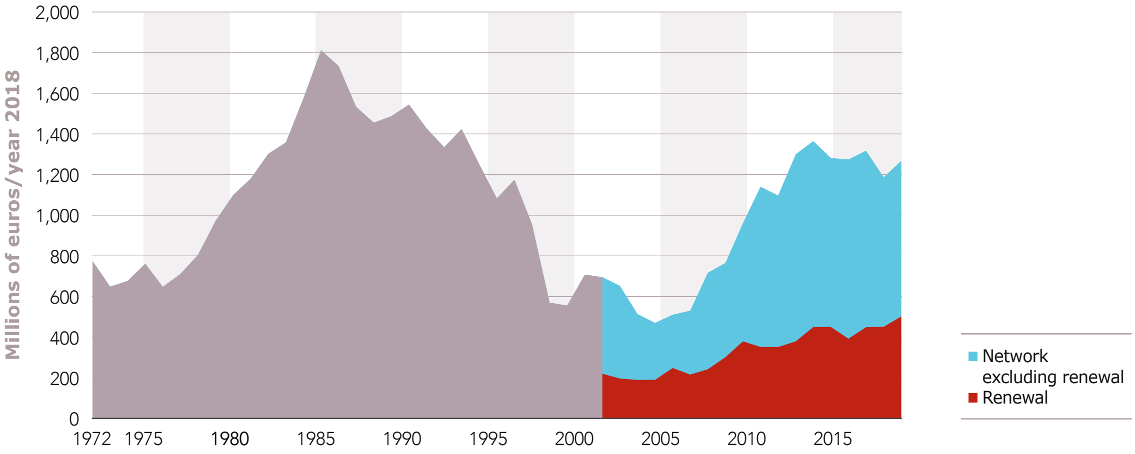
To support the energy transition, the investments listed in the SDDR have been valued at around €33 billion (gross) over 15 years (as opposed to €20 billion at the trend rate). This figure can be broken down into €13 billion for adaptation work (higher-voltage transmission network, subtransmission networks, connections), €8 billion for replacing the oldest infrastructure, €7 billion for connecting up marine energies, €3 billion for the digital backbone and €2 billion for crossborder interconnections (for France). The total earmarked for adapting the network is to be funded boththrough the TURPE (transmission system access tariff) and through the share paid by the generators under the regional connection programmes for renewable energies.

Today, at the trend rate, RTE is committing approximately €1.3 billion in investment every year for the items described in the SDDR; This rhythm of investment should increase annually by around €600 million starting in the next few years:

1) **this change can mainly be explained by the start of the works phase for connecting the first offshore wind power farms** (the first ones are scheduled to come into service in 2022, and starting in 2023, the pace will be increased, with more than one coming to service every year);

2) **excluding the maritime component, the volume of investments is increasing slightly, but most importantly, the content is changing: there is less network "development" for supplying regions, but more adaptation work to accommodate**

Figure 28. Increase/decrease in investment spending on the network (excluding IT and property)



renewable energies and more infrastructure renewal work and operations that involve renovating and adapting the oldest areas of the network.

These figures, which are admittedly high in absolute terms, need to be put into perspective and contextualised.

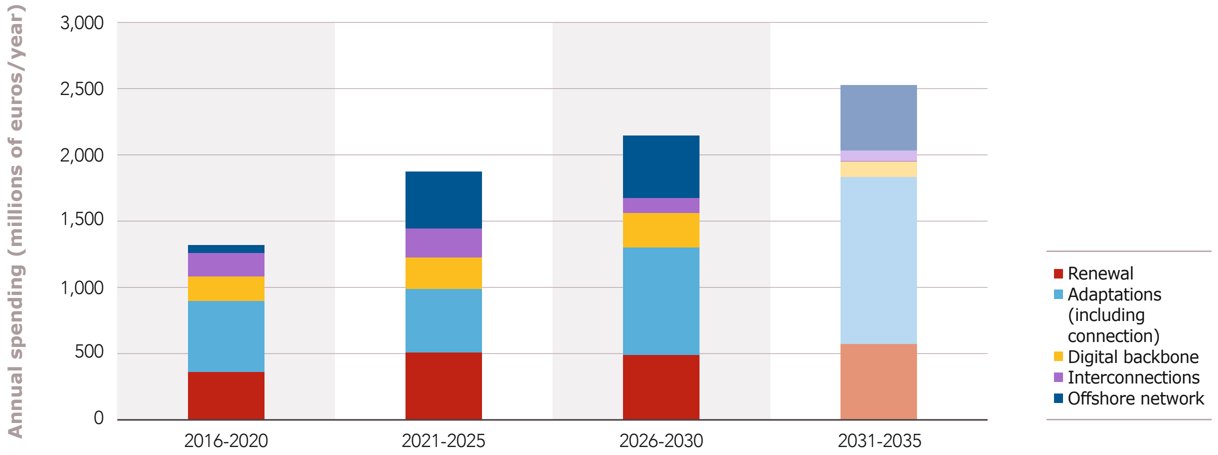
First of all, the investments needed for the network must be compared not only with the spending that is scheduled for transforming the energy mix as a whole (see page 50), but also with the spending – which is often greater – to which other European countries have committed for developing their networks (see page 49). They should also be compared to the spending which would be needed if the network's transformation was not required for the new production sites scheduled to be brought into service (see page 52), or if the work on the network needed to be accelerated at any time.

Also, the scope of the investment spending covered by RTE has recently increased. Although the French energy regulator had initially put the costs incurred by invitations to tender 1 and 2 for offshore wind power at nearly €41 billion over 20 years[4] (prior to the contracts being renegotiated between the project managers and the government), some of these costs – the costs involved in connecting up the infrastructure – are now to be covered by RTE via the TURPE (transmission system access tariff), and are no longer to be covered by the government's budget. This change, which means that RTE is now responsible for both delivering and financing these offshore connections, is therefore cost neutral for the community: **the corresponding increase in spending over the whole public transmission system is offset by a reduction in taxes levied by the government.**

Finally, this volume of investment, which is significantly higher than the current underlying volume, may seem high when considered globally, but it will be spread over a period of at least 15 years. Seen from the perspective of end users, the consequences of these additional investment needs will be mitigated. Indeed, because of the way in which the TURPE (the tariff for accessing the transmission system) – set by the French energy regulator – is put together, it includes the annually amortised instalment and the associated remuneration for the capital invested. Since these investments have long lives, they are amortised over long periods – around 30 to 40 years. This tends to keep the annual repayments down. Since interest rates are low, this growth in investment needs can be tackled with relative peace of mind.

All of this should lead to the share of the cost of transporting electricity relative to the overall cost of the power system remaining globally stable over the next few years.

Figure 29. Estimated investment spending on the public transmission system between now and 2035 (multi-annual energy programme scenario – SDDR reference trajectory)



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[4] French energy regulator, 2017, Deliberation of the French energy regulator of 13 July 2017 on assessing public service charges for energy for 2018

The SDDR has been optimised to limit the increase in investment needs, while ensuring that the targets set in the multi-annual energy programme can be met

The trajectories set forth in the SDDR are not the result of a preference for investment. On the contrary, the aim is to spend money in a way that is as effective as possible for the community, minimising the cost on the whole infrastructure's life cycle.

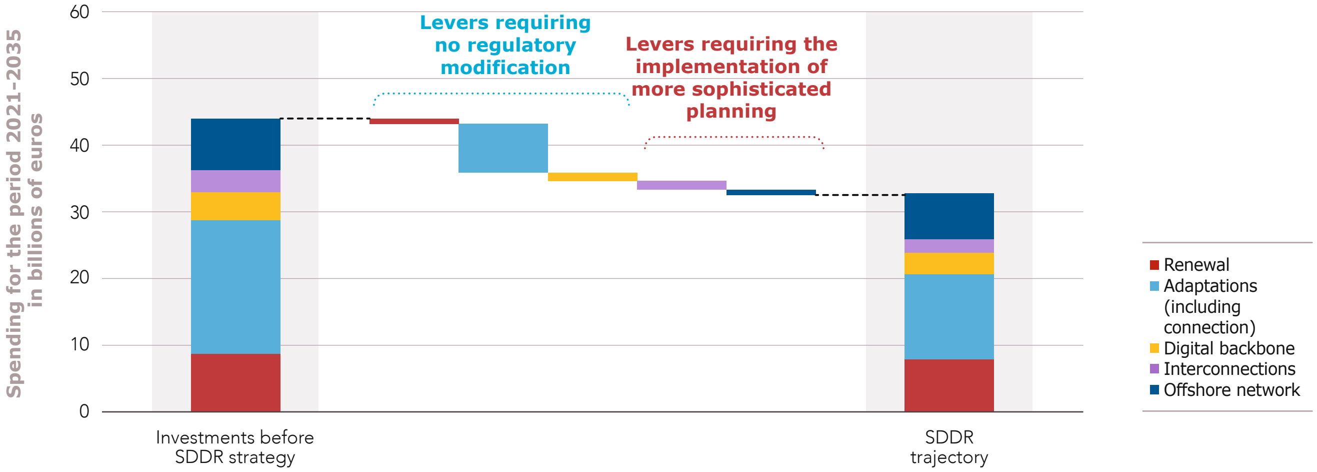
It is with this in mind, without any consideration given to the regulatory mechanisms which might result in investment spending being preferred to operating spending, that RTE has produced the SDDR. In particular, some analyses have shown that the balance between investment and maintenance spending needs to be rethought, with more money going on maintenance.

RTE is fully aware of the need to keep the costs of the energy transition down to ensure that it is accepted by people. As such, the SDDR's reference trajectory is built on a number of assumed principles, which will need to be translated into reality. In particular, these principles focus on ensuring that the network is properly sized, on spatial and temporal planning of the development of marine energies and on using digital technologies instead of implementing certain investments.

Implementing these principles is tantamount to using levers for optimisation and savings estimated to be worth more than €10 billion over the next 15 years. They are therefore of premium importance in the economic equation underpinning the public transmission system.

However, their implementation does not only depend on RTE. Although the most effective ones (particularly sizing optimisation for the onshore network) can be reached without any regulatory changes, they need to be properly understood by the public authorities and the various stakeholders operating in the sector: the principle of optimally sizing the network means accepting ad hoc modulations in production so as to avoid building infrastructure that would remain unused for most of the time. Others are based on more sophisticated planning, which incorporate thinking at complete project portfolio level (interconnections, connecting up offshore wind power farms, etc.). All of them help contain investment spending, but they are based on an acceptance of increased operating costs, particularly network congestion and maintenance costs: this increase, however, remains significantly lower than the reduction in spending that it creates, and therefore helps optimise the electricity transmission system's costs.

Figure 30. Estimated investment spending on the public transmission system between now and 2035 (multi-annual energy programme scenario)



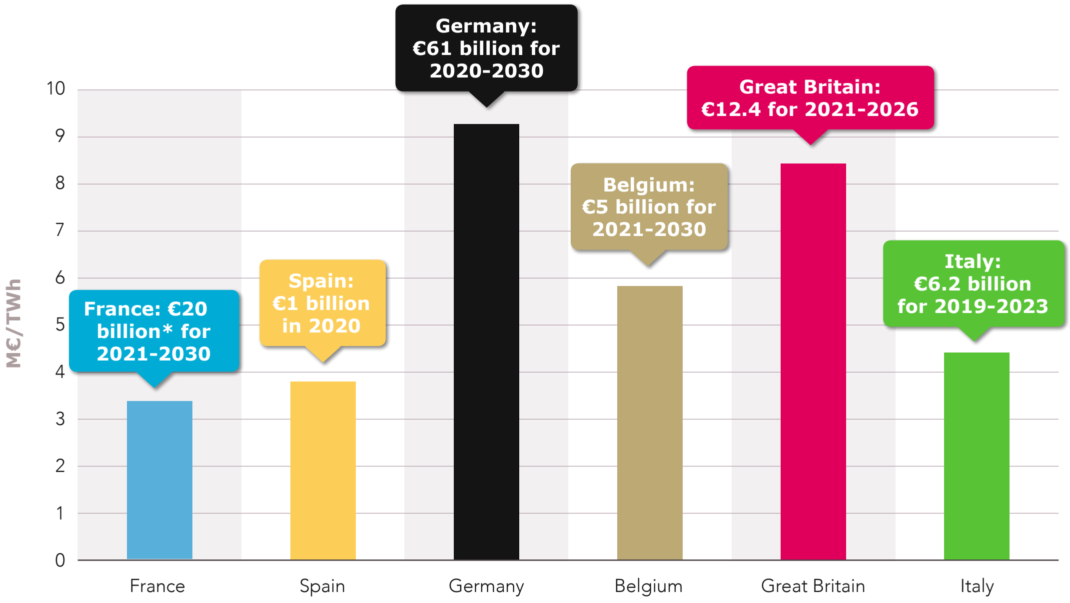
Compared with other countries: the investment spending presented in the SDDR is in the lower bracket

The network investments that are needed for the energy transition do not only concern France. Other European transmission system operators are having to tackle increases in investment spending – at levels that are often higher than those envisaged for France.

The German ten-year network development plan that was reviewed and published in 2019, for example, includes an investment programme worth some €61 billion – nearly three times what RTE is planning to spend over the same period. These high levels of spending have been made necessary by more rapid development of renewable energies (onshore and offshore) on the other side of the Rhine, by accumulated delays in adapting the network over the last few years which have led to extremely significant geographical imbalances and by greater use of underground direct current for the higher-voltage transmission network or for connecting up certain offshore wind farms.

Other European countries are also having to deal with significant investment needs, although they are slightly lower than those planned for Germany. When the total investments envisaged are compared with each country's electricity production, the amount to be spent under the SDDR is very much in the lower bracket: France is one of the countries requiring the least amount of investment.

Figure 31. Investments in the electricity transmission system in relation to annual electricity production



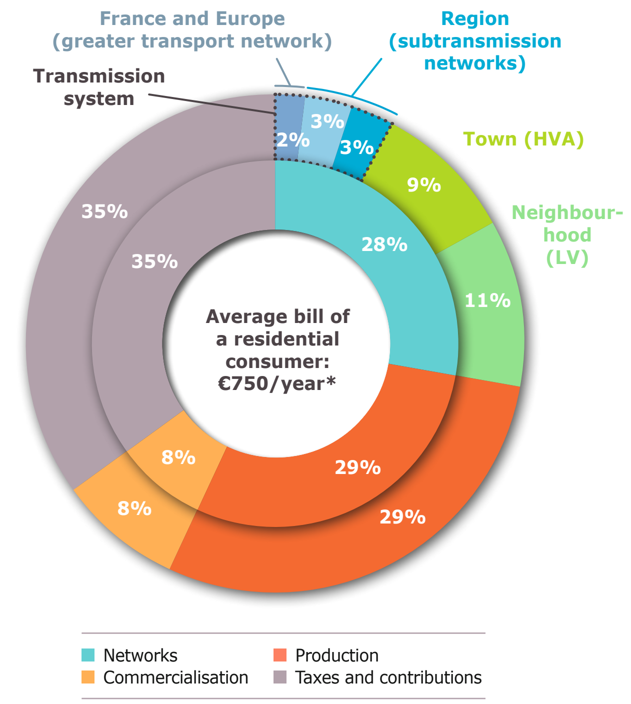
* For France, the spending condidered is the investment spending presented in the SDDR for the period 2021-2030

The share that the transmission system represents in the overall cost of the power system is still stable overall, close to 10%

Overall, the development of the generation sources (renewable energies and nuclear power in particular) requires investment of around €150-€200 billion over the next 15 years[5]. Investment spending in the electricity transmission network therefore only represents a limited share of the costs involved in transforming the mix. Furthermore, it can be paid off over a longer period of time (over 40 years for some network infrastructure, as opposed to 20 to 25 years for wind and solar assets and 10 years for ten-year investments in nuclear reactors).

Today, the share represented by the electricity transmission system in the system's annual costs is relatively low – around 10%. This share is even lower on consumers' energy bills (8%), since it is diluted by the effects of certain taxes (domestic tax on end electricity consumption, tax on end electricity consumption, value added tax, etc.) that consumers pay in addition to production and network costs. For individual consumers, the amount of their electricity bill that goes on the transmission system is around €60 per household per year, with the total average electricity bill standing at more than €750.

Figure 32. Breakdown of an energy bill for the average residential consumer (on the regulated sales tariff)



* *Based on data published by the French energy regulator for the composition of regulated sales tariffs: https://www.cre.fr/Pages-annexes/Open-Data*

Of this total, the very-high-voltage network (400 kV) represents an even smaller share (3%), but is where most of the savings are. Generally speaking, the more costly network components are for the lowest voltages. These scale effects demonstrate the economic benefits of the high- and extra-high-voltage network – that is the network that enables the generation fleet to be economically optimised on a large-scale and demand to increase – factors that helped electricity establish itself as a competitive form of energy in the 20th century.

An important lesson learned from the forward-looking work undertaken for the SDDR is that the share that the transmission system represents should remain stable overall for the period 2020-2035, close to 10% of the power system's total cost.

Although the financial transfer from the government's budget to the transmission system access tariff (TURPE), together with RTE assuming financial responsibility for connecting up offshore wind farms (approximately €7 billion over 15 years) will indeed increase the amounts covered by RTE under the TURPE, this transfer is cost-neutral overall for electricity bill payers.

These analyses are based on the wide-ranging programme to cost the various scenarios undertaken by RTE in 2017, which has provided a complete overview of their costs.

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[5] Assessment based on the economic costing exercise undertaken as part of the 2017 provisional long-term forecast plan (chapter 11.7)

Regarding the debate about the "real costs" of renewable energies: the transmission system's costs are very low in the multi-annual energy programme's scenario

People often reference a stubborn myth in the debate about the development of renewable energies for electricity: the myth about the "hidden costs of renewable energies", involved in integrating these energy sources into the electricity grid.

The production of the SDDR is a public initiative, undertaken in consultation with interested stakeholders, the hypotheses of which were submitted as part of a public dialogue process. Within this framework, the technical challenges associated with the transformations currently under way have been addressed, thus shedding light on these frequently-asked questions.

The work undertaken following the 2017 provisional long-term forecast plan had highlighted the need to think in terms of the system overall (comparing a whole scenario with another whole scenario) and the difficulty in allocating certain cost components to one or another source of energy. All Simplified approaches can nevertheless be used to specify orders of magnitude which can be compared with average power generation costs so as to identify ranges within which different technologies are competitive in accordance with a standardised method.

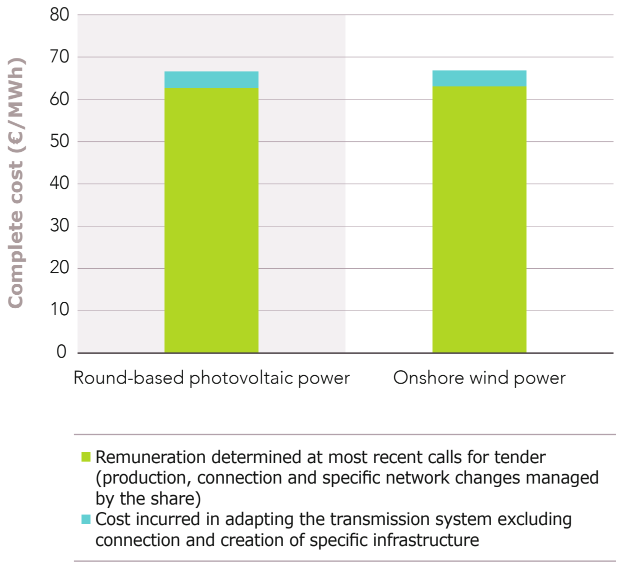
An initial category focuses on the costs of adapting the mix specifically associated with the development of renewable energies (sometimes called "back-up costs" by some stakeholders, as a reference to the thermal generating facilities that would be needed to offset the variable nature of wind or solar power): **the analyses in the provisional long-term forecast plan show that in scenarios such as the Volt and the *Ampere* – and even more so in the multi-annual energy programme's scenario – these costs are negligible in France given the power system's major balances.** In these scenarios, with a system that is extremely interconnected in Europe and a solid platform of manageable assets (nuclear, hydraulic, gas and combustion turbines) being maintained, the current security of supply criterion can indeed be honoured, without the need to build new thermal power plants, and by making use of existing power generation assets and flexibility, or assets and flexibility that have already been integrated into the multi-annual energy programme's trajectory.

The analyses conducted in the SDDR can be used to supplement these initial assessments and further assess the network costs associated with developing renewable energies.

In a simplified approach, even when one allocates all of the costs involved in adapting the network over the next 15 years for use with new renewable energy production facilities, the cost component allocated to the transmission system in the overall cost of onshore renewable energies (in addition to the share paid for by the generators) is an estimated €3 to €4 per MWh.

For offshore wind power farms, these network costs are more significant – around €15 to €20 per MWh, since they include offshore connections (a component which no longer appears in the purchase tariffs derived from new invitations to tender). However, even by adding the production cost of the project selected for the Dunkirk AO3 (€44/MWh) and a component for the expenses incurred on the network, the overall cost of offshore wind power comes out at around €60/MWh – which is very competitive compared with other energy sources.

Figure 33. Estimated complete costs of onshore wind power and ground-based photovoltaic solar power



Compared with the alternatives: network infrastructure is currently the most economical solution for pooling power generation resources

The solutions presented in the SDDR are designed to ensure that energy produced across the country is collected and supplied to consumers, in accordance with the standards expected for a country such as France, i.e. an excellent level of reliability.

The solutions for doing this are more varied than they were previously: they include optimising the performance of existing infrastructure (by instrumenting powerlines so that they can transport more current when the wind is stronger and when wind power production is as well, for example), building new infrastructure (substations and powerlines), using consumption flexibilities (demand-response mechanisms) or adding localised batteries or other energy storage systems.

RTE has undertaken a systematic analysis of these solutions in the SDDR. The proposed trajectories are based on the most economical of these solutions.

In particular, the strategy that involves adapting the network is based on the deployment of around a thousand active network management controllers over the next 15 years, so as to further optimise existing infrastructure. By using the flexibility of wind turbines and their ability to provide the network with services by reducing their production, this can increase – all things being equal elsewhere – the subtransmission networks' accommodation capacities. This is based on experiments currently being carried out in certain regions where wind power is being significantly developed, such as the Hauts-de-France region. This strategy, one of the prerequisites of which is the reinforcement of the digital backbone (IT systems, digitisation of command control systems at substations, bolstering of telecommunications lines at strategic substations), avoids the need for major investment in the subtransmission networks and will save some €7 billion over the period (which would have been billed to generators via shares in the regional connection programmes for renewable energy and would have ended up in the costs for supporting renewable energies).

These methods are highly appealing for tackling "moderate constraints" on the network, i.e. events which happen rarely and only for short periods of time. However, they are not appropriate for handling "structural constraints" (constraints that are frequent and last a long time).

For the structural constraints, the economic analyses show that reinforcing the network generally remains the most economical solution.

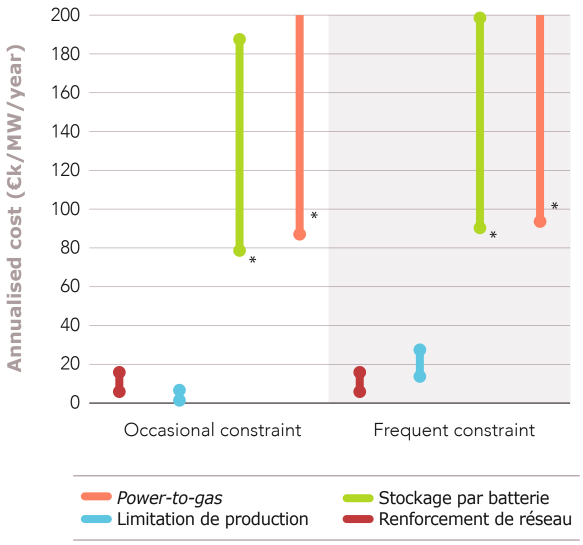
Without adapting the network, congestion costs (production being limited in certain zones and redispatching towards other generation sources) would increase at a rate of more than €1000 per year (a situation comparable to Germany today), and there would be an increase in greenhouse gas emissions. This spending should be compared with the average annual €500 million investment required while the network is adapted to the energy transition.

This competitivity is also attested in the long term compared with alternative techniques, such as installing battery storage systems close to production sites, the only role of which is to resolve constraints, or "power-to-gas".

These solutions, which are currently in the testing phase (the Ringo project for batteries or Jupiter1000 for power-to-gas) could be additional solutions by 2031-2035, provided that very specific conditions are met in terms of where they are located (near renewable energy production sites) and technical requirements are complied with (indexing of the operating profiles of these installations relative to flow configurations on the network, which are highly variable).

So, although transforming the network requires investment, this investment remains relatively limited across the system as a whole. The analyses presented in the SDDR show that the transmission system (included by incorporating the use of flexibilities on the subtransmission networks) is a pooling solution that is still very competitive in the scenarios studied. It can be used in particular to integrate variable renewable energies across a very wide geographical perimeter, thus reducing costs.

Figure 34. Economic comparison of the various solutions for managing constraints on the transmission system (2018 cost assumptions)



* In the low hypothesis, the battery storage and *power-to-gas* solutions are sized at 50% of maximum overrun capacity: additional production curtailment therefore needs to be implemented.

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FRENCH TRANSMISSION NETWORK DEVELOPMENT PLAN - MAIN RESULTS

2019 EDITION

French transmission network development plan

2019 EDITION

MAIN RESULTS - ENGLISH VERSION