Le réseau
de transport
d'électricité

R&D ROADMAP

FOR 2021-2024

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01 Introduction

The RTE Research & Development Department is innovating to achieve a successful energy and ecological transition. It accomplishes this by building solutions together with major stakeholders of diverse backgrounds: electrical engineering, material science, mechanical engineering, economics, digital technology, applied mathematics, eco-design, or even social sciences an humanities.

WHY DOES THE DEVELOPMENT OF THE ELECTRICITY AND ENERGY SYSTEM REQUIRE R&D WORK?

The power system is currently undergoing profound change generated by two key drivers: the energy transition on the one hand, and the uptake of digital technologies on the other. The first brings about the deployment of renewable energies whose behaviours, in terms of predictability, flexibility and electrical engineering response, is fundamentally different from those of conventional power stations. These new behaviours require significant adjustments to be made to our tools and decision-making methodologies, in order to guarantee safe operation in the decades ahead. As for digital technology, it has two major impacts: first it allows us to monitor our assets more accurately, helping us optimise their performance. Second, it enables much stronger interactions between various power system stakeholders (functionally and spatially), giving real-time access to increasing flexibility potential. Before these technologies can be implemented, economic analyses and demonstrator projects are required to establish their cost-benefit ratios.

WHY THIS ROADMAP?

Laying out the RTE roadmap for 2021 to 2024 forces us to set a course, identify challenges and define the conditions for success. It also provides an opportunity to publicly share our intentions in the hope of gathering feedback or even initiating partnerships. Part of the task will consist in deploying solutions previously developed and approved by the R&D department throughout the different operational processes. We must also continue to innovate in our own areas of expertise, steering our research in line with the environmental policy, that is the National Low Carbon Strategy (SNBC) in France or the Green Deal at European level. The changes required are far-reaching, time is running out, and R&D must take relevant action to ensure optimal solutions are implemented at the right time in the future. The objectives presented in this 2021-2024 roadmap are therefore intended to provide the building blocks needed for moving forwards serenely on the road to carbon neutrality by 2050, with interim markers along the way.

WHAT IMPROVEMENT CAN RTE R&D PROMISE?

Expectations differ with the considered timescale:

- **The 2025 timeline will deliver operational performance**: RTE **is deploying** across its operational units a suite of R&D solutions that are tried and tested: these are essentially decision-making support solutions for operators to help them operate an increasingly complex power system,
- **The 2030 timeline will deliver on the growing importance of renewable energies and the step change in addressing our ageing infrastructures**: Confronted with this increasing need for new power lines, R&D **is developing** solutions alongside the operational teams for an optimally designed network; they will capitalise on digital drivers to modify the operation, development, maintenance and renewal of the network,
- **The 2040-2050 timeline will deliver carbon neutrality**. With the National Low Carbon Strategy and the Green Deal, France and Europe have committed to moving towards carbon neutrality, the regeneration of biodiversity, and a circular economy. In order to meet this target, different futures are conceivable for the energy system, i.e., in terms of energy production, uses and networks. The R&D is designing techniques and tools to explore and assess possible scenarios; it is also **designing** the characteristics of the future infrastructures of the power network, by factoring in the environmental goals of the Green Deal at the design stage. The 2040-2050 timeline is the moment for eco-design.

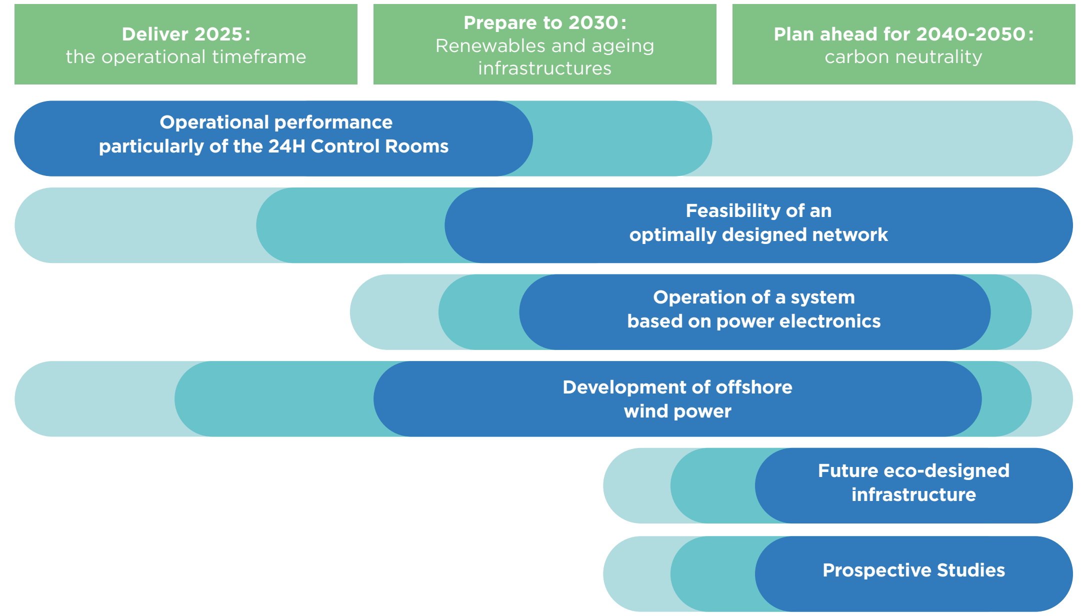
IS IT NOT DIFFICULT TO PLAN FOR 2050?

Although the National Low Carbon Strategy and the Green Deal set out clear objectives, there is indeed considerable uncertainty regarding their practical implementation and the course we should be charting.

This is why it is so important, as of now, to construct scenarios for these possible futures, evaluate their impact according to different criteria, and make an informed decision to implement certain options. In the context of energy infrastructures, in contrast to digital technology, these options are particularly binding as they involve assets with lifespans of 60 years or more. The solutions referred to in this 2021-2024 roadmap will clearly have to be devised for an uncertain future and incorporate a common core of "no regrets" solutions that will prove useful no matter what happens. To this end, a multicriteria evaluation grid (technical and economic performance, solidarity, environment, resource sobriety, resilience, etc.) should be used whenever possible to define and select the most appropriate and robust solutions.

02 The R&D goals

R&D contributes to 6 main goals set out in different timeframes, as illustrated below (the intensity of the colour illustrates the projected level of effort in each timeframe):



2.1 DELIVER 2025: THE OPERATIONAL TIMEFRAME

OPERATIONAL PERFORMANCE PARTICULARLY OF REAL-TIME MONITORING CONTROL ROOMS

Looking ahead to 2025, the prevailing purpose of R&D actions is operational performance. In the future RTE “24H Control Rooms”, the objective is to deploy new decision-making support tools for the operators dealing in real time with managing electricity flows, balancing supply and demand, and supervising electrical, computing and telecommunications equipment.

The primary performance improvements are obtained by enhancing the safety and quality of service, and through system management efficiencies, and through savings in both maintenance and investment savings.

Aside from these initial benefits, the tools devised by the R&D also help by automating a number of tedious tasks, thereby freeing up operator time for high added value tasks.

SCOOP (Schedule Optimisation of Operation Planning), the work scheduling support tool. The primary gain is the quality of scheduling: SCOOP helps find the best trade-off between the expected benefits of the work and the constraints that these works will bring to operations (de-energisation of installations).
The secondary gain is measured in terms of the time needed by an operator to build his schedule: efficient time management despite increased complexity (see the increasing variability of electricity flows linked to solar and wind power generation).

SETTING UP THE FUTURE 24H ROOMS

The massive integration of intermittent renewable energy sources, combined with the increasing need for replacement works driven by an ageing network, make it necessary to find optimised and more flexible operating modes, in particular by turning to digital solutions (controllers, sensors, etc.) and enhanced telecommunication systems. At the same time, the connection of offshore wind farms, and the development of interconnections, represent major industrial projects. RTE's industrial strategy relies on several fundamental needs: long-term scheduling for cost reduction, equipment standardisation, on the pooling of infrastructures (for the connection of offshore wind farms, for example) and finally the uptake of digital technologies, in order to go one step further and use existing power lines, reduce the need for network adaptation, and optimise the renewal of the oldest assets.

To be able to meet these challenges, the coordinated real-time monitoring of power flows, of equipment and of information systems, in a coordinated manner, becomes central to guaranteeing optimal performance. This is how the "24H rooms" project started.

By 2026, nine 24H rooms will make it possible to control and supervise power flows, and to oversee in real time the exchange of information on the operation and maintenance of the power and communciations networks. The planned developments will entail significant adaptation of operating modes at the national and regional levels. This will lead to changes in operational practices as well as and to the relocation of work from one employment area to another. This is why RTE management involves employees in the process of shaping this transformation, and offers individual support with their professional careers. This transformation goes beyond a simple industrial or technical adjustment, involving a complete overhaul of RTE's activities.

Figure: 3D model representation of 24H rooms, photo for illustration purposes only – Project

2.2 PREPARING FOR 2030: AGEING INFRASTRUCTURES AND AN INCREASING SHARE OF RENEWABLE ENERGY

FEASIBILITY OF AN OPTIMALLY DESIGNED NETWORK

By 2030, the combined effects of the integration of renewable energies and the ageing network infrastructure bring about a wave of new assets. Their development will need to be optimised in terms of volume and time, with the aim to limit financial, human and land resources, as well as the footprint on both environment and landscape. RTE's industrial strategy, formalised in the Ten Year Network Development Plan (TYNDP) and approved by the regulator (Energy Regulatory Committee ruling n°2020-200 dated 23 July 2020), is to achieve an optimally designed network. This strategy relies on two levers of action derived from R&D concepts.

The first lever of action aims to optimise the management of "assets", here referring to all the components of the network infrastructure. The objective is in particular to replace equipment according to measured or estimated performance, rather than at a prescribed predefined age, while continuing to meet the operational safety criteria. This entails joint optimisation of maintenance and replacement (see insert). More broadly, the asset management strategies must be chosen in order to offer the greatest efficiency in terms of services delivered and resources mobilised. Since these optimisations cannot be performed using generic desktop computer tools, the R&D is developing the Asset Management Support System (SAGA) chain of tools. These simulations provide objective assessments of the requirements for resources of all types, which is an essential component in establishing consolidated budgetary trajectories.

Paintwork, an example of a solution optimised between maintenance and replacement.
Is it better to repaint pylons or to let them age and replace them more frequently? SAGA-MONA digital simulation (MONA: Management and Optimisation Network Asset) reveals that the best strategy depends on the type of steel and on the degree of exposure to a seaside corrosive environment.

The second lever of action aims to avoid over-engineering the network in order to deal with extreme peaks in solar and wind power generation, which only occur for a few hours every year. The TYNDP indicates that a 0.3% curtailment of annual renewable energy production saves 7 billion euros of investment in network infrastructures over a period of 15 years. In order to guarantee dependable network operation, this curtailment must be automated reliably and with a short response time. With this in mind, the R&D has developed the concept of a zone controller (New Adaptive Zone Controller, NAZA) and is in the process of implementing the control architecture that will allow the operators in the power system operating centres to simultaneously supervise hundreds of controllers.

The renewable energy curtailment controllers also play a role in long-term studies.
The R&D is working to enable operators to supervise hundreds of controllers. These solutions must also be taken into account at the very onset of network structure development studies. The planning engineer must therefore dispose of tools that are capable of simulating them, in order to secure the benefits highlighted in the TYNDP.

OPERATION OF AN ELECTRICITY SYSTEM BASED ON POWER ELECTRONICS

2030 also sees the massive development of production and consumption connected by power electronics. This involves laptop chargers, electric vehicle charging units, and most importantly, their equivalents for solar panels and wind turbines. These items behave quite differently to conventional synchronous generators and loads such as older washing machines, or resistive heaters.

These new electrical behaviours impact the real-time stability of the power system[1], which is a key operating condition; it serves as the basis for all the higher-level operations such as managing power flows and balancing supply and demand.

(1) This applies to frequency and voltage stability, inertia, synchronism, etc.

As a consequence, the high penetration of power electronics requires a radical change in practices, tools and equipment[2] so as to have new solutions ahead of time that will maintain stability tomorrow, in real time, both in steady state and transient conditions. RTE's R&D has led the way in this field by putting the issue of power electronics on the agenda of academics, industry players and other network operators, knowing that the smallest power systems (small islands, Ireland, UK, Scandinavia) will be impacted before the European continental plate.

The challenge for RTE is to be ready in time. Without preparation, there is a risk of frequent onsets of severe technical failures (total or partial collapse of the network), or the need to implement preventive measures that are costly to society, for instance the continued maintenance of some of the older plants in operation.

Additionally, although the major changes along this axis will occur in 2030 and beyond, prompt action is needed to harness the potential of the these new decentralised flexible assets, and where appropriate to steer the design capacities of new entrants so they can provide the services required (see example below).

The contribution of electric vehicles to the network stability must be addressed of now, otherwise millions of vehicles will come off the assembly line without this capability, despite a potentially zero impact on manufacturing costs and ease of use.

(2) This applies to the stability study methods, the digital simulators used in these studies, the protection devices (breakers and associated automation systems), the system defence plan, the system restoration plan.

2.3 PLAN AHEAD FOR 2040-2050: CARBON NEUTRALITY

The Green Deal commits Europe to moving towards carbon neutrality, a circular economy, and the regeneration of biodiversity. This requires a significant restructuring of all economic sectors, and of the energy sector in particular, a large emitter of greenhouse gases.

The Green Deal addresses an "existential" threat. This term, chosen by the European Commission, highlights the magnitude of the problem. For instance, by 2070, between 1 and 3 billion people will be living in a hostile climate, depending on the course of climate action.

This is a formidable challenge and time is short. Indeed, the time required to restructure the major energy infrastructures, both the power generation and network infrastructures, and the time needed to change the manufacturers' product range, call for the prompt adoption of energy policy and industrial strategy guidelines. And making decisions requires first a vision of the future. What energy mixes should we aim for? What network architectures are possible? Which technologies should be implemented for this infrastructure? The RTE R&D is gearing itself up to help forge this vision, concentrating on the following interdependent areas:

— Forward planning

In a context of a comprehensive transition — and therefore of uncertainty regarding the new long-term political, societal, economic and environmental balances, forward planning lays the groundwork for possible future power systems. These studies involve the generation of hypotheses across a variety of fields, including the production mix, energy uses, and the network, through a coherent and scenario-based vision. The specific drivers of change that need to be examined include: the restructuring energy usages to support carbon neutrality, multi-energy coupling (see example opposite), the multiplication of decision-making levels (local, national, European), the environment, societal dynamics, the long-term local and European network architecture, and resilience to new disruptions (e.g.: a pandemic).

Biomass is sought after for reaching carbon neutrality, both directly for energy uses (direct or via fuels or gas) and for non-energy uses (construction, food supply, conservation of biodiversity). The distribution of biomass across these different uses has a heavy influence on the electrification of mobility.

— Development of offshore wind power

From 2020 to 2030, the first wind farms derived from the calls for tender issued between 2010 and 2020 will become operational. These projects are largely wind turbines that are erected in shallow waters (100 m at most) and are based on technologies that have been systematically tested on sites in the Baltic Sea. Numerous marine fauna impact studies have been carried out, some in partnership with the Energy Transition Institute France Énergie Marine. The increasing number of wind farms to be connected, combined with more energy to be exported, resulted in RTE being entrusted with the implementation of surface platforms for substations collecting and exporting power to the onshore network. These new installations consist of an internal high voltage alternating current substation positioned on a fixed structure anchored to the seabed.

After 2030, wind farms will be located even further away from the coast and reach even greater depths of water (more than 100 m), while the scarcity of viable landing points will call for power exports of up to 1 GW, rising in the future to 2 GW. The new challenges that will have to be addressed fall into three categories: 1) the supporting structure must float, be anchored to the seabed, and withstand the constraints of wind and swell; 2) the high-voltage (HV) and very-high-voltage (VHV) collection and export cables will have a submerged "floating" section and will be subject to greater dynamic stresses while having a degree of pliability to currents; 3) and lastly, the distances involved and power to be exported will mean resorting to alternating current (AC) to direct current (DC) conversions as well as the installation of HVDC (high voltage direct current) stations on the floating platforms.

The current research programme will therefore focus on the technical barriers to offshore floating substations, and on the other hand at the design of AC-dynamic and then DC-dynamic HV/VHV cables, power electronics equipment, and finally, on the mutual constraints of a floating mechanical structure and an HVDC station.

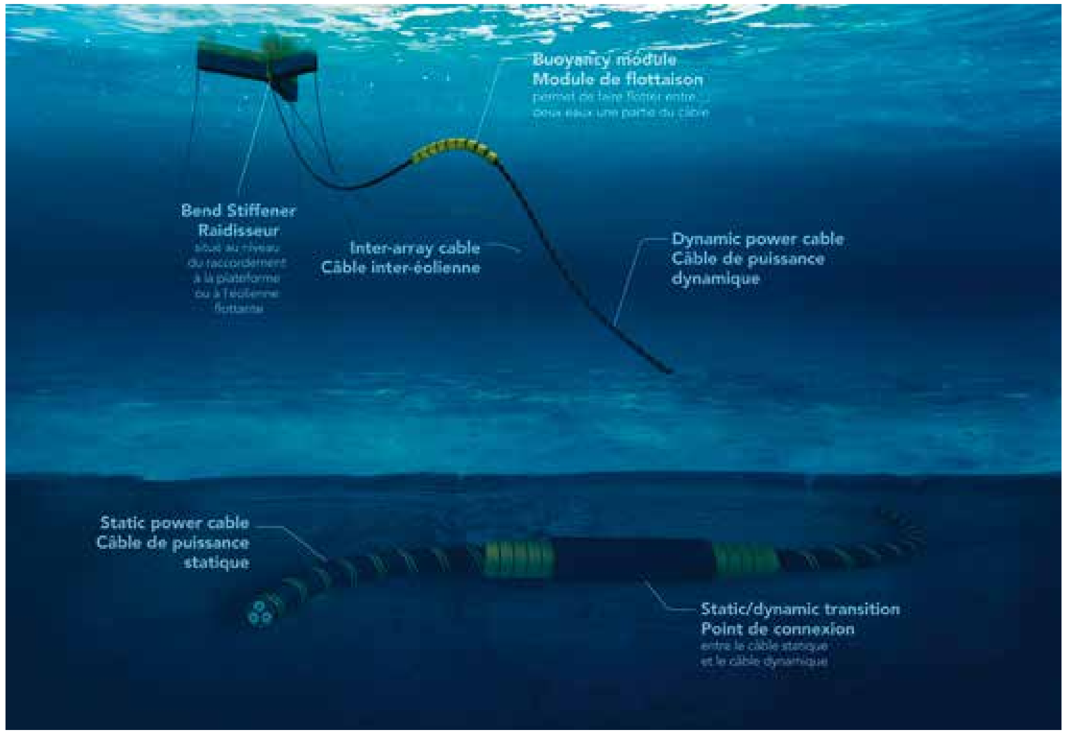


Figure: Floating wind turbine.

— A future eco-designed infrastructure

The ageing of the network and the integration of renewable energies provide an opportunity to roll out a new generation of network infrastructures, embedding new technical solutions that are consistent with the vision of the future.

Among other things we will need technical solutions for the new frontier of deep-sea offshore development.

More broadly, for all the future infrastructures, we need to prepare for the changes in environmental regulations heralded by the Green Deal, by factoring them in at the design stage, in the creation of the materials themselves. In this way, R&D will "eco-design" the future infrastructure.

Biomimetics is paving the way for radically new eco-design, for example:

- **Doing away with concrete in underground electrical connections** in sandy soil, by mobilising living calcifying organisms (BIOCALCIS© technology).
- **Suppressing the biofouling of floating cables**, in other words, their invasion by undesired plants, by applying a sharkskin inspired cable coating or by selectively encouraging plants that are conducive to buoyancy.

Through numerous partnerships, R&D is seeking to identify the technical barriers, and then to overcome them by means of design studies and demonstrators, *ultimately* supporting the emergence of an industrial offer that meets our needs.

Figure: Platform.

03

The R&D Programmes

Achieving the six goals presented above therefore requires input from a range of expertise: for example, the “feasibility of an optimally designed network” is based simultaneously on the implementation of controllers in the substations, therefore with a digital dimension at the heart of the infrastructures, on the capacity to model these devices in our technical-economic decision-making tools for long-term investment, and even on the detailed simulation of our asset management policy.

Another illustration: forward planning relies simultaneously on skills in developing technically realistic scenarios, and in amending them in response to input from the humanities and social sciences, and finally, requires tools that are capable of hour-by-hour simulation of power system operation in respect of supply and demand balance.

One could also mention offshore wind energy, which relies on equipment expertise (offshore platforms, dynamic cables), biodiversity (preservation of the marine environment) and even the stability of the system (contribution of wind power to the system services).

R&D Management have opted to organise this expertise into 6 cohesive functional programmes depicted below as “petals”; in the centre, a 7th programme covers the cross-cutting expertise that has a bearing on all activities.

Each of these programmes also incorporates a number of thematic roadmaps.

3.1 POWER SYSTEM STABILITY PROGRAMME

— Background

At the present time, the dynamics of the power system are mainly dictated by the physical behaviours of the generators in power plants. The different phenomena that can impact the stability of these dynamics, whose durations may vary between a few microseconds and a few seconds, are clearly identified and are analysed using methods, models and tools that are selected on the basis of in-depth knowledge of the system's operation.

The forthcoming changes to the energy sector, particularly the massive development of production and consumption connected by power electronics, will challenge the very basis of power system stability. The behaviour of the power system will no longer be dictated solely by well-known universal laws of physics but by laws of control derived from specifications. What phenomena should be examined to assess the stability of the system? What methods should be applied? What modelling of the network and components connected to it will be needed? How can the system's resilience to large-scale incidents be guaranteed?

The simulation tools will also have to be adapted: it is already clear that they will have to deliver greater flexibility and transparency, so as to meet the demands for analysis of large systems incorporating a wide range of sub-systems.

— Ambition

The ambition of the programme is to provide the scientific framework for analysis, the methods and the tools that will allow the operational teams to continue guaranteeing the sustainable stability of the power system, in the context of the energy transition, by focusing on two lines of action:

- the definition of stability in this new context and the changes required to continue identifying and controlling associated risks, and to maintain the resilience of the system, under the roadmap "Stability of a system undergoing radical change";
- the development of a new portfolio of simulation tools that will ensure continued high-quality network studies, is supported by the roadmap "Power System Simulation Tools".

3.1.1 THE STABILITY OF A POWER SYSTEM UNDERGOING RADICAL CHANGE

— Background

The widespread connection of power electronics interfaced equipment will profoundly change the dynamic behaviour of power systems, making it necessary to review the concept of stability, to define new requirements that must be met to control stability, and to rethink the way in which its resilience to large-scale events is guaranteed.

These conditions will be fulfilled:

- during the network development phase, through the technical requirements for connection, which will have to be updated within the next 10 years to anticipate the high penetration of power electronics that is expected to take place by 2030;
- during network operation, by identifying as early as possible the situations that could threaten the stability of the network, and by deploying the means to prevent or limit the associated consequences. These activities are based on methods, models and tools that will have to be renewed.

— Ambition

Define, supervise and control the stability of a power system with high penetration of power electronics, and guarantee its resilience.

— Objectives

Design of the future system and definition of requirements	The definitions of stability must be broadened by identifying the new phenomena that are likely to impact the stability of systems dominated by power electronics. Technical solutions to guarantee the stability of the future network will also be examined, in order to make them available to all the stakeholders and to propel them towards industrialisation at the lowest cost to society. Lastly, the final objective is to adapt the Grid codes to tomorrow's power system, which will require modifying their time domains profiles at the connection points like those currently used are inadequate to control the dynamics of a system dominated by the control laws of power electronics.
Monitoring of stability	Historically, stability has been managed in real time using procedures based on off-line simulations; these simulations may become inadequate due to the shift in the dynamics of the system and the intermittent supply of renewable energy which is causing the operating conditions to become increasingly uncertain. It is therefore necessary to work on closer-to-real-time methods to identify risky situations. Moreover, the methods used to verify compliance with the Grid codes will have to be renewed, which will also involve working on the inputs required and their availability.
Control of stability: models and levers of action	When a stability issue is identified, levers of action are required to return to acceptable operating conditions. Research must be carried out into methodologies for identifying these new levers of action. These methodologies will be based on simulations, as they are now, and will therefore be dependent on models. Models that are adapted to these new phenomena to be studied must thus be developed and validated.
Resilience – Defence and system restoration plans titution	The aim here is to rethink the defence and system restoration plans, which are designed to limit the consequences of severe incidents and to reduce the recovery time, so as to tap into the new opportunities arising from developments in the energy sector, especially the decentralized actions.

— Partnerships

Collaborate with the European TSOs (transmission system operators) and their academic networks on the new models/methods/Grid codes.

Establish a framework for R&D collaboration with ENEDIS, essential for major breakthroughs with the defence and system restoration plans, building on the decentralized actions.

Monitoring of oscillations

The power system is permanently subjected to disturbances of different orders of magnitude (load connections, opening of breakers, short circuits, etc.) which excite modes of oscillation between its components, in the same way as a bridge moves to accommodate road traffic or wind.

These oscillation modes may either be well damped (the amplitude of oscillations decreases very rapidly) or, at the other extreme, may be unstable (the oscillation amplitude increases). One of the focus areas of the roadmap is to work on the development of tools for real-time monitoring of oscillations to enable fast implementation of the measures needed to eliminate them.

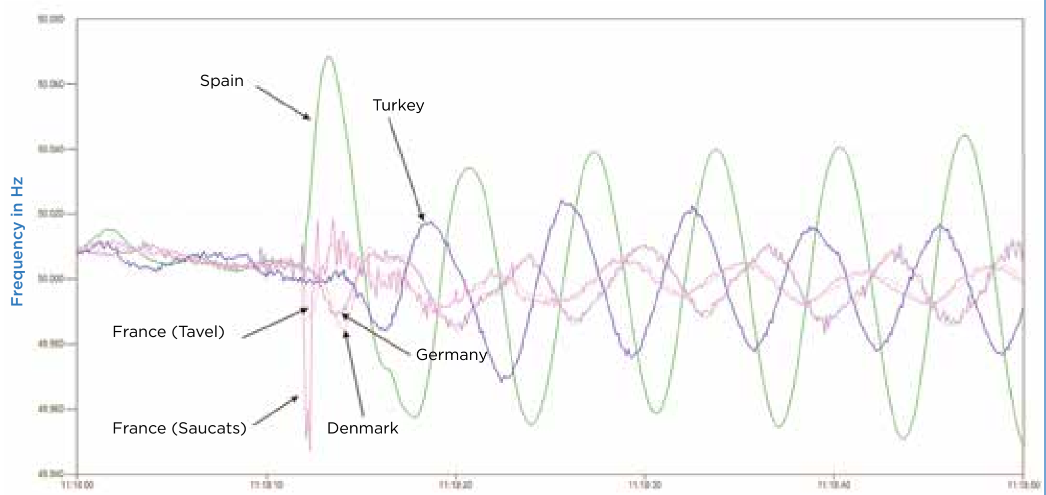
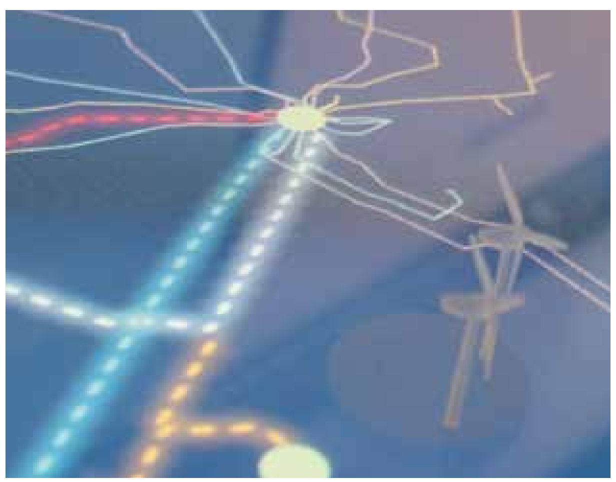


Figure: Oscillations on the European network on 1st December 2016 – The frequency in Turkey and Spain oscillates virtually out of phase with the frequency in Denmark and Germany (source: ENTSO-E).



3.1.2 POWER SYSTEM SIMULATION TOOLS

— Background

The assessment of network stability hinges on simulation. Yet, the changes to the power system will make present simulators less and less suitable:

- Simulations will be conducted on networks that are increasingly large, complex and elaborate, at the centre of specialism-based processes hampered by execution and decision-making time constraints: the flexibility, performance and quality of the simulation tools will all have to be aligned;
- The classical methods used in existing simulators will no longer be suitable: indeed, the present boundaries between the different phenomena impacting system stability will change or disappear owing to the high penetration of devices based on power electronics, or due to the different control levels installed in the system.

— Ambition

Develop a new portfolio of advanced and adaptive simulation tools, founded on open source and generic building blocks; it will allow high-quality network studies to be carried out, against a background of energy and digital transitions marked by rapid cycles of innovation and a wide range of new controllable equipment.

— Objectives

Replacement of simulation tools for long-term stability and transient stability	The new tool for long-term stability, that is to say, the study of phenomena with a duration ranging from a few microseconds to a few dozen seconds, has been tested and will be deployed in the winter of 2021/2022 ("Implementation" stage). The concept of the new transient stability simulator has been validated: the following stages will seek to develop all the required models and achieve validation before testing and deployment ("Industrialisation" stage).
Redefinition of simulation tools for balance status calculation and short-circuit management	A new steady-state calculation tool has been developed for more relevant and more innate factoring-in of the controllers supervising the system, and it has been tested for some cases: a prototype is available which will now be upgraded to support all the existing components, and is being considered in RTE and European network studies. In addition, work will be carried out to improve performance, by combining upstream research and industrial upgrading ("Demonstration" stage). The approach that will be adopted for short-circuit current calculations, which are key parameters for managing our infrastructures, is currently being defined, with several avenues for future research being explored ("Exploration" stage).
Consideration of new system components	Research actions must be undertaken to take full account of the new system components. Prototyping will then provide an opportunity to verify the relevance of the alternatives being considered. This exercise involves for example thinking about the simulation requirements of a system with high penetration of power electronics, or proper consideration of all the methods of control integrated in the system, particularly controllers (discrete-time control systems).
Release to open source and collaboration	RTE has committed itself to releasing its new portfolio of simulation tools by making them available on open source, and by using numerous building blocks which themselves are open source building blocks. The aim here is to make progress with the basic building blocks and to lead a community focused on simulators.

— Partnerships
An open source approach for simulators, and an accompanying community, in partnership with the Linux Energy Foundation. Pooling of shared functions by the TSOs (or European universities).

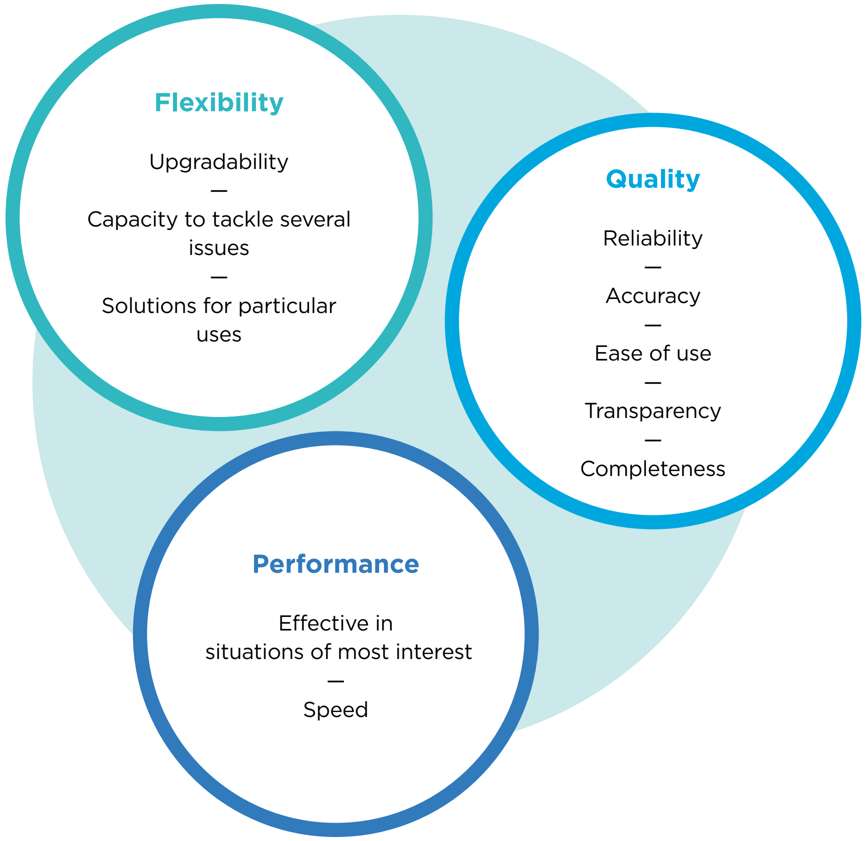


Figure: In addition to the classical concepts of quality and performance, the concept of flexibility is at the heart of the method adopted for developing a new portfolio of simulators, in order to simulate a power system that is to undergo rapid and radical change.

3.2 SYSTEM OPERATION PROGRAMME

— Background
The power system is becoming increasingly complex and less and less predictable, and its operation will have to change to overcome these escalating difficulties. An ever-growing volume of highly volatile data, numerous uncertainties surrounding network data such as power generation (including renewable energies) and consumption, substantial and fluctuating exchanges between the different market areas, a short timeframe in which RTE has exclusive control of the power system, the mass deployment of power electronics and controllers, more and more spikes in network activity... these are some of the aspects of this new context that must be addressed and for which we must provide new solutions.

— Ambition
In order to deal with this situation, RTE needs to provide the operators of the new 24H Control Rooms (supply-demand balancing/flows) with new solutions for managing this growing complexity, while containing operating costs and maintaining risk and security of supply at acceptable levels.

To this end, we will develop assistants designed to help the operators focus on priority tasks with high added value. The assistants will make it simpler to take large quantities of information into account by summarising it, they will anticipate adverse conditions, automate lower value tasks, build on good practices, etc. This objective will only be reached by reinforcing the prediction and understanding of the main factors impacting network operation (variations in consumption, production, topology, commercial transactions, etc.) in a drive to help operators identify the operating pathway best suited to the network's physical constraints, while integrating the automatic systems that will be dealing with some of the uncertainties and hazard conditions.

With this in mind, the "System Operation" programme will focus this research and development work on two key areas, the first aiming to devise, test and develop the operator assistants in the 24H Control Rooms linking supply-demand balance issues and network constraints, the second consisting in improving short-range forecasts (consumption, renewables, etc.) by adding a probabilistic dimension (confidence intervals) and finer space-time granularity for better guidance to the operators.

Figure: The National System Operation Centre (CNES) is a key player in electricity grid operation and supply-demand balance management.

3.2.1 GRID OPERATION 24H CONTROL ROOMS ASSISTANT

— Background

The power system is currently undergoing radical change, and has been doing so for a few years, in particular because of the deployment of renewable energies, as well as the widespread implementation of controllers.

These changes are making the task of operating the system more complex than before, and have given rise to various lines of research:

- establishment of a policy for probabilistic risk assessment,
- development of forecasting that differs from the current approach, based on the generation of the most probable situation, using more sophisticated calculation methods,
- interactions with and between operators, in a context where events are probabilistically estimated and where the time dimension is important,
- simplification of the work environment and proposals for enhanced ergonomics,
- assessment of the opportunities for system operation opened up by recent breakthroughs in AI.

— Ambition

Drawing on this work, the focus of this initiative, through the roadmap, will be to define and develop a set of tools and methods, to help the operators who perform network studies and operate the power system from D-1[3] to real time to take anticipatory decisions thanks to a suite of "smart assistants".

— Objectives

Better anticipation of network situations	Enable operators to better anticipate cases that are potentially problematic for network operation by developing better modelling of the uncertainties relating to injections (consumption, production, cross-border flows, controllers, flexibility, and distributed control systems) and of the short-term failures of installations (< 48hrs).
Improvement in forecasting	Determine the best operating pathway by trying to establish if there is a remedial action for constraints that are identified in advance, and if so, by putting the solution forward or giving the operator the option of implementing the solution or not.
Reinforcement of the two-way connection between human and machine	In order to convey the most relevant summary information at the right time and to the right recipient, take into consideration the choices made by the operators regarding proposed actions, and facilitate exchanges and coordination between the stakeholders in the different kind of 24H Control Rooms (Balancing/Flows, Equipment, and IT rooms).

(3) The day before for the following day: 24 hours in advance rather than on a rolling basis.

— Partnerships

Among the main partnerships for this roadmap, we can highlight our partnership with the Université d'Aix-la-Chapelle for the development of robust assessment methods for forecasting the status of the network, following on from the work carried out by the iTesla European project, and our partnership with Black Light Analytics for improved evaluation and forecasting of system dynamic constraints.

Figure: The OperatorFabric interface merges information flows from different tools into one single screen, displaying to operators the most relevant information at the most appropriate time.

3.2.2 SUPPLY-DEMAND BALANCING 24H CONTROL ROOMS ASSISTANT

— Background

The management of the supply and demand balance and its interactions with the network is going through a phase of fast, far-ranging and radical change. The establishment of European network codes has changed the principles governing this balancing, and has made the proactive and coordinated management of margins more difficult: multiplication of adjustment mechanism gates, reduced operating window, more and more possible interactions given network congestion, etc.

These changes are making supply-demand balance management more complex than before, and have given rise to these various lines of research:

- Define the changes in the existing methods and tools needed to support the advent of European platforms, of new cross-border exchange constraints, and the widespread entry of renewables market, while controlling their impact on network constraints,
- Put forward new tools (smart assistants) to support the ongoing changes to the supply and demand balance (extent of reserves, margins and diversified systems services) so as to guarantee optimal operation despite a reduced operating window caused by the increased frequency of adjustment gates,
- Redirect the alerts of the different supply-demand balancing processes/tools towards a streamlined and ergonomic interface in order to speed up the response to these alerts.

— Ambition

Drawing on this work, the focus of this initiative, through the roadmap, will be to define and develop a set of tools and methods to help the operators who balance the network in near real-time to take the best decisions in a reduced operating window thanks to a suite of "smart assistants".

— Objectives

Impact of European platforms on the network	Quantify the impact on the network of the activation of European supply and demand balancing platforms through different scenarios.
Development of smart assistants for supply-demand balance	Put forward new tools (smart assistants) or methods to support the ongoing changes to the supply-demand balance (extent of reserves, margins and diversified systems services) so as to guarantee optimal operation despite a reduced operating window caused by the increased frequency of adjustment gates.
Operator/smart assistant interaction	Facilitate interaction between the tools/assistants and the supply-demand-balance operators via a unified and ergonomic interface.

— Partnerships

As part of the European OSMOSE project, RTE is involved in the development of a demonstrator for close to real-time cross-border electricity exchanges between Italy and Slovenia that takes account of network constraints. This demonstrator offers an opportunity to investigate the growing interactions between the supply-demand balance and the network, in close partnership with other European transmission system operators (TERNA and ELES), energy producers (HSE, HDE, ENEL), and providers of IT solutions (EKC, Engineering).

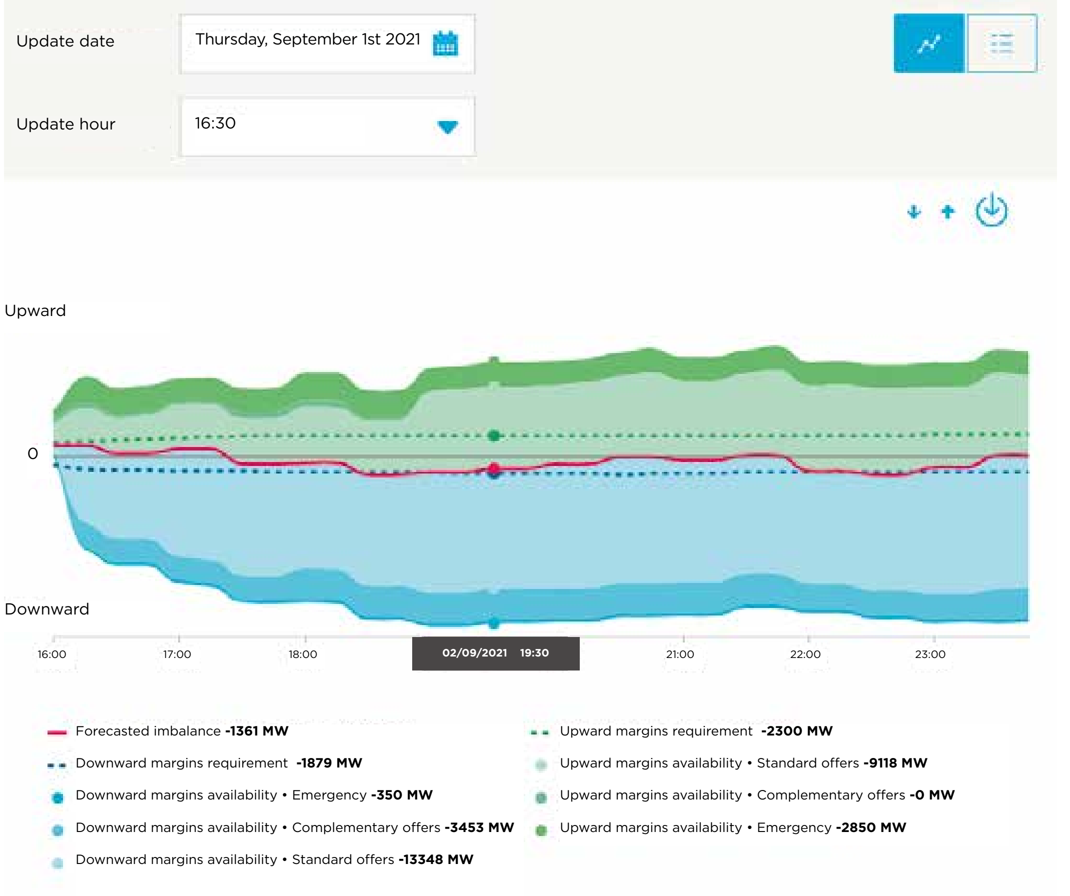


Figure: In order to guarantee a supply-demand balance despite the hazards that can disrupt it, RTE makes sure of the availability of power margins for the controllable loads via the MAUI tool, by automatically calculating every 30 minutes, 24/7, the margins that are required and available to the French power system, at all times, both upwards and downwards.

3.2.3 SHORT-TERM FORECASTS

— Background

The strong growth in renewable energies, intermittent generating sources, increases the need for network control. Indeed, the future zone controllers that will allow RTE to manage the network more closely will require local forecasting that is as pertinent, as accurate, and as up to date as possible. Similarly, the changes linked to the supply and demand balance (such as, for example, the transition from 24 to 96 gates per day, the more detailed time granularity of stakeholder programmes, in 15-minute or even 5-minute increments) will also broadly impact the requirements for forecast data.

— Ambition

By improving the quality of short-term forecasts for renewables and consumption as close to real time as possible, through the deployment of state-of-the-art machine learning methods, whilst exploring the possibility of using new data (weather products, market prices, etc.), RTE will benefit from higher quality forecasts by reducing the margins used and by staying within the limits of safe system operation.

Indeed, the tools used by forecasters are automatically upgraded, more frequently, to take advantage of all the data available in real time and to deliver forecasts in much more detailed time segments than is currently done. Lastly, the overhaul of some network preventive management processes will require the provision of reliable probabilistic forecasts (confidence intervals) that adapt at all times to the uncertainties of the projected situations.

Figure: Renewable Generation and Consumption forecasts are a key activity for RTE.

— Objectives

Improvement in consumption forecasts	Develop local consumption forecasting models for better data granularity by characterising the uncertainties and their space-time correlations.
Improvement in renewable energy forecasts	Improve the monitoring of the renewables fleets and in particular the observability of the photovoltaic industry through the real-time use of satellite imagery for more robust forecasting models, by anticipating weather prediction errors and identifying unavailabilities.
Development of probabilistic methods	From a more methodological point of view: development and roll-out of probabilistic forecasting models.

— Partnerships

Among the main partnerships for this roadmap, we can highlight, on the one hand, our partnership for the development of an open source code with Alliander (Dutch Distribution System Operator (DSO)) to enable the learning, operational deployment and monitoring of forecasting models (consumption, generation, etc.) and, on the other hand, our partnership with Armines OIE for improved observability and predictability of the photovoltaic industry through optimal use of satellite imagery or even through the use of "physical" models.

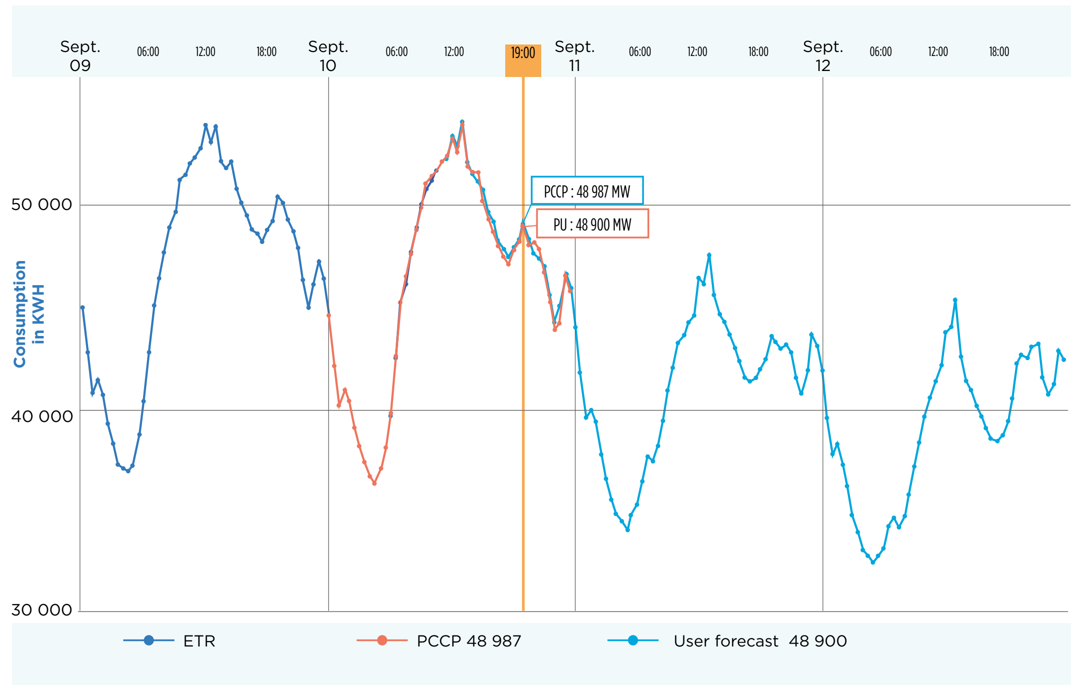


Figure: In order to anticipate possible supply-demand imbalances, the POPCORN model uses weather forecasts to predict French electricity consumption through machine learning methods (ETR = real-time estimation of consumption, PCCP = consumption forecasts under planned weather conditions, PU = user forecasts).

3.3 ASSET MANAGEMENT PROGRAMME

— Background

Over the past ten years, the issue of asset management has emerged in the European networks. The French network, the major portion of which was built in two stages after the Second World War, and then during the nuclear programme, is dogged by a growing technical debt: in light of the current trend, its average age is slowly but inexorably increasing, despite major investment. As indicated in the Ten-Year Network Development Plan (TYNDP) published in 2019, it is time to invest in the "everyday network". We are facing a surge of replacement operations, which will be difficult to deal with for technical, logistical, as well as economic reasons.

As an added challenge, the transmission network's assets are long-term investments (several decades) while the energy transition that is underway multiplies the uncertainties in shorter timelines. This applies as much to the structure of the generation mix as to the changes in consumption. As a result, the asset management strategies and their implementation must both be resilient to potentially very different futures.

At the same time, the opportunities presented by digital technologies and the establishment of "24H" equipment monitoring rooms offer new insights in the search for an overall optimum between operation and maintenance, on the one hand, and between maintenance, replacement and development, on the other hand, harnessing the distinctive nature of RTE as a "full TSO".

— Ambition

It is only a transformation of practices, and the changeover to asset management based on understanding the damage and estimating the risks, that will help RTE meet these challenges.

The "Asset Management" programme aims to provide RTE with innovative methods and tools to:

- Understand the condition of assets by means of monitoring, inspection and diagnostics, and predict asset condition through modelling and simulation. Among other things, the automation of inspections can significantly improve performance.
- Equip RTE with a coherent suite of decision-making tools, from the strategy for asset management to the scheduling of operations, with the aim of establishing the best trade-off between OPEX and CAPEX, technical-economic optimum and ability to deliver.
- Seek an overall optimum between maintenance and operation in the 24H rooms, based in particular on enhanced management of data, considered as an asset.

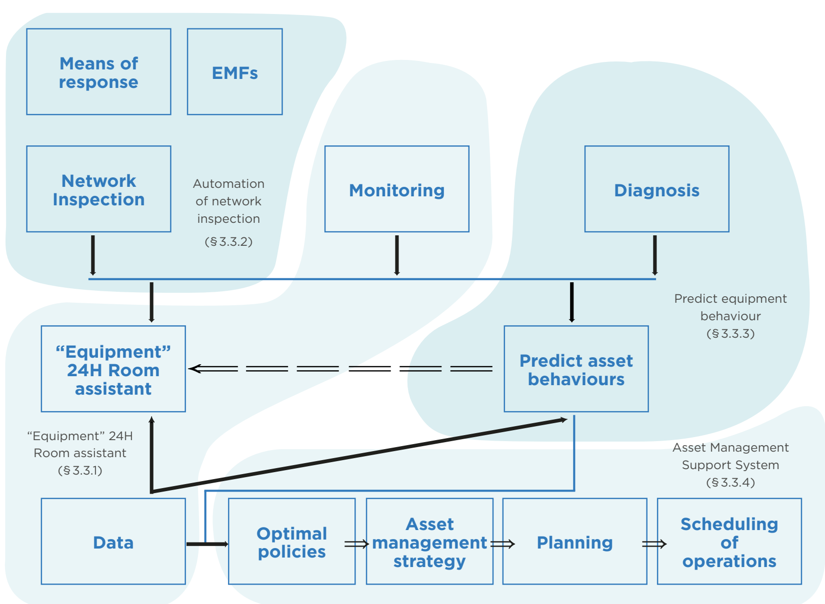


Figure: Overview of the Asset Management Programme.

3.3.1 EQUIPMENT SUPERVISION 24H ROOM ASSISTANT

— Background

In accordance with its business plan, RTE has taken the decision to set up, from 2024 onwards, a suite of centralised 24H rooms at the heart of an ecosystem for monitoring installations and for maintenance optimisation. And it is here that the project to "ramp-up monitoring", derived from past R&D work, will bring together additional information from monitoring of installations, enabling the predictive maintenance of a growing proportion of equipment. The future "equipment" 24H rooms address several challenges:

- Build on the "full TSO" nature of RTE and on the coordination between operational teams, between areas and between operation levels, to deliver trade-offs and safety in the interests of an overall optimum. One of the main challenges will be to build traditional operational baseline standards structured around different issues.
- Ensure continued control over relevant and auditable maintenance options based on a solid understanding of the condition of assets and a capacity to anticipate the consequences of these choices. In addition to reliable asset behaviour models, significant improvement in the completeness and accuracy of data is also essential, be it assets data, environmental data, or dynamic data.
- Bring these centralised rooms that cover an extended zone closer to the field: give equipment "a physical form" in the 24H rooms and provide support to operational teams via centralised expertise. The use of digital twins could prove to be a decisive lever of action.

— Ambition

Put forward a set of innovative methods and tools to develop the full potential of maintenance optimisation offered by the establishment of the new 24H equipment monitoring rooms. This calls, particularly in terms of data management, for improvements that will prove beneficial far beyond equipment monitoring.

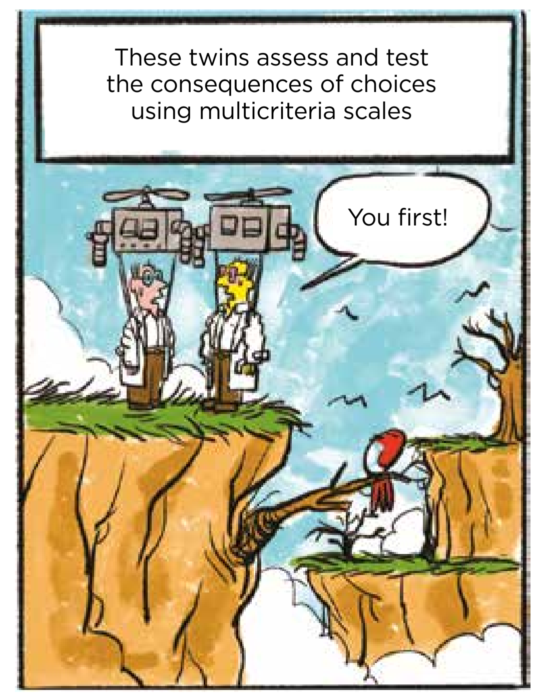
Digital twins: an essential tool to visualise, understand, forecast, and even take action.

A "twin" is a digital model of reality. It can be:

- **static** (such as a 3D representation of equipment),
- **dynamic** (such as a model of equipment status, updated through real-time measurements in the field),
- **prédictive** (in other words, enabling the simulation of equipment behaviours when called into service under different demand conditions),
- or, lastly, **active**, that is to say, able to intervene in the actual process.

It can also represent one single item of equipment (a transformer, for example) or an entire facility.

With regard to the 24H rooms, all the functions of digital twins will be examined, with a particular focus on the modelling of equipment.



— Objectives

Advanced monitoring	By spelling out the needs in terms of equipment health, with active monitoring of the state of knowledge in relation to a set of priority equipment, the objective is to suggest advanced maintenance functions when the 24H rooms are deployed. In addition to equipment health, we will also work on the ergonomics of decision-making systems by turning to cognitive science. R&D will continue its background task of investigating innovative monitoring systems according to need.
Promotion of "data" as an asset	B y considering data as an asset, subject to maintenance and "restoration", the aim is to develop innovative methods for automatic monitoring of data quality, such as a "status estimator" capitalising on the redundancy of available data. The other key area involves drawing up the baseline standards for data, which represents a longstanding challenge for RTE. An ontology-driven approach offers a promising way forward. This will result in a "concept car" digital twin, crossing different operational competences, structured around a limited number of standardised data models.
Synergies between 24H rooms	These synergies are divided into two areas of focus: • The search for an overall optimum between grid challenges (which lead to equipment being called into service at its operating limit) and equipment (risk of failure), applied for example for high voltage systems, or advanced functions for the management of outages based on a comprehensive view of risk. • Extending the advanced concepts developed for the flows rooms to the equipment monitoring rooms, concepts such as "hypervision".

— Partnership

Université de Genève (research into the use of ontologies in the development of data standards).

3.3.2 AUTOMATION OF GRID INSPECTIONS

— Background

RTE carries out regular inspections of the power transmission network, 100,000 km of overhead power lines (270,000 support structures), 6,000 km of underground cables and 2,700 substations. The aim is to check the condition of the equipment and of its surroundings: corrosion, condition of paintwork, distance from vegetation, hot spots, broken strands, etc., numerous problems that cannot be monitored remotely. At this point in time, these are generally visual inspections with the naked eye, from a helicopter or at ground level, or by climbing up the support structures, or even using the "remote eye" of a drone.

Over a number of years, RTE has been looking into the possibility of automating the inspection of overhead power lines, replacing the human eye and memory with sensors and with interpretation and comparison algorithms. Their capabilities are far superior, on a spectrum from ultraviolet to infrared to laser, with centimetre resolution. In addition, this would feed an enormous amount of high-quality structured data into the information system, something which is currently lacking. The automation of inspections is closely linked to the switch from helicopter to long-range drone.

Figure: Simulation of the flight hazards for a power line inspection.

Several barriers need to be removed before an industrial application can be considered:

- A switch from components that have now been proved as feasible (unmanned aerial vehicle – see box below – sensors, algorithms) to an integrated operational system, linked to the information system, functioning across an operating range (weather conditions, environment, etc.) that is sufficient for industrial use;
- Compliance with regulations for long-range drones that are both strict and under development (see box below).

Regulatory challenges and technical solutions.
The automated inspection of overhead power lines spanning tens of kilometres involves the use of so-called "long-range" drones, flying over long distances without a pilot. The regulations for this new technology (excluding military applications) are in the process of being drafted: they apply to aircraft that do not have passengers but risk crashing to the ground. Building on aeronautical experience gained through its Heliborne Operations Department, RTE is participating in this work with the Directorate General for Civil Aviation. At the same time, we need to examine both the means by which we can meet the safety requirements, as well as the evidence that these requirements are adequate, for example through simulation.

— Ambition

Put forward a solution for the automated inspection of the overhead network that is viable from an economic, industrial, and regulatory point of view. Explore ways of creating additional added value for this type of inspection, and of possibly extending its scope of application (substations, other inspection and work methods, particularly live work).

Figure: Network inspection robot test.

— **Objectives**

Inspection of overhead power lines	Reach an adequate level of operability and safety to initiate an industrial project for automated inspections that offer the same functions. Develop these new services (inspection by comparison, identification of other defects, automatic updating of data). The inspection by comparison, which involves assessing the changes in a defect or in vegetation between two inspections, paves the way for predictive maintenance.
Inspection of substations	Develop an initial automated inspection prototype, particularly for difficult conditions (converter stations for HVDC, etc.).
Methods of work	Develop systems to improve work conditions and the scope of live work.

— **Partnerships**

CEA, CNIM Airspace, ONERA.

For more information on the Diridrone: Diridrone tests, October 2020

Figure: Prototype of Diridrone during field trials in 2020
Length: 14.5 m Width: 4.5 m Weight: 150 kg Payload: 10 kg

3.3.3 PREDICTING EQUIPMENT BEHAVIOUR

— **Background**

In order to tackle the upcoming surge of asset replacement operations, we must transition from a policy grounded in an age of one-off replacement, to a policy based on actual assets damage, their individual probability of failure, and associated consequences. This damage, which depends on the assets past life, on its environment, on its operating regime, and on its maintenance, must be understood and reliability predicted. That is the aim of the roadmap.

There are many technical barriers, and making significant headway will take time. Indeed:

- The phenomena at work are multiple and potentially interactive. Aside from the complexity of the physical phenomena that need to be represented, the calculation capabilities for simulating them can be significant.
- The reconstruction of the asset's "living conditions" over several decades, essential for assessing accumulated damage, is far from easy (case history of winds, of current flows through the conductors, of the corrosiveness of the local environment, etc.).
- The experimental resources required to validate predictions (laboratory tests, sampling from the network) are scarce and expensive.

Thus far, out of the very wide range of different network assets, the R&D priority has been the conductors, key electricity transmission system components, whose internal damage due to multiple potential causes is neither repairable nor visible to the naked eye.

— **Ambition**

By combining experimental methods for multiphysics modelling and statistical analysis, deliver forecasting tools for the behaviour of critical and complex assets. Provide RTE with the testing and diagnostic resources, both digital and physical, that it needs to fulfil its missions. Well underway for overhead conductors, this ambition is due to be extended to other network components.

— **Objectives**

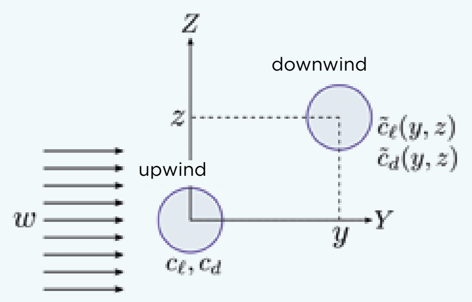
Overhead conductors and overhead lines	Successfully complete the work being carried out for conductor damage prediction, and ultimately, for support structure and foundation damage prediction: • by gradually extending the scope of application: variety of damage phenomena, of conductor designs, of fittings, of configurations (multiple bundles), etc. • by attaining adequately tested prediction capabilities and acceptable calculation costs to establish the asset management policies. In parallel, put forward an internal diagnostics system that is applicable to all types of conductors and damage.
Substations	Expand our understanding of behaviours through multiphysics modelling to a group of critical and complex components: breakers, wound components including transformers, low voltage cables, auxiliaries, etc.
Education and knowledge-sharing[4]	Publish a reference manual summarising the work carried out on conductors. Capitalise on the ecosystem created by previous research to establish a chair in physics dedicated to overhead power lines, involving several laboratories.

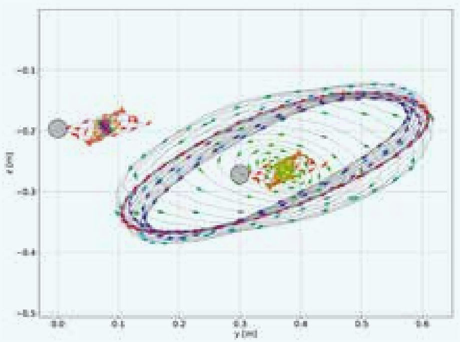
(4) Aside from the positive aspects of knowledge-sharing, publishing in leading scientific journals ensures that RTE's future decisions are founded on scientifically validated work. Therefore, wherever possible, this is an important objective.

Videos are available to find out more about the OLLA[5] Project: the OLLA project. Regarding overhead power lines diagnostics: test bench for diagnostic systems.

— Partnerships
École Normale Supérieure Paris Saclay, CEA, Université de Technologie de Compiègne, LETSCAN, INERIS.

Ageing of multi-bundle conductors

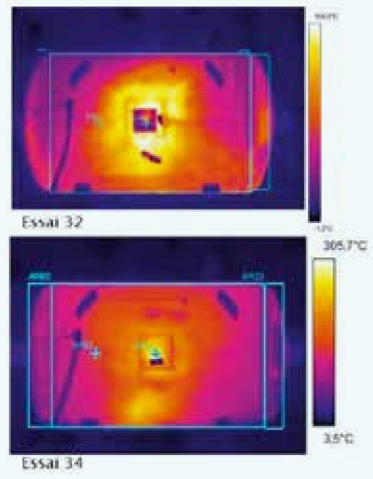




Simulation of subspan oscillations for a bundle conductor. It is clear that the "downwind" cable oscillations are caused by the drag of the "upwind" cable. Work must now be carried out to assess the resulting fatigue damage dynamics and work out accumulated damage according to wind conditions. (Eurobios / OLLA Project)

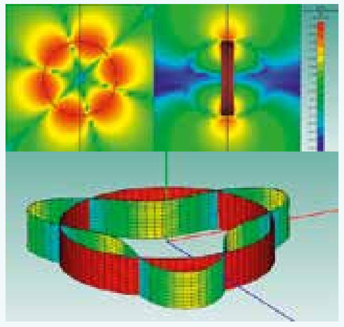
Underground cables

Thermal imaging simulation of an electrical fault in an underground duct to replicate thermal and mechanical effects. (Picture INERIS)



Behaviour of wound components

Multiphysics modelling (electrical-vibro-acoustic) of an induction coil. This model led to the design of less noisy coils (UTC – RTE patent).



(5) Overhead Lines Lifespan Assessment

3.3.4 ASSET MANAGEMENT SUPPORT SYSTEMS

— Background
The Ten-Year Network Development Plan (TYNDP) has underlined the need to invest in the "everyday network", whose technical debt is on an upward trend. Addressing the build-up of operations involved raises various difficulties that can only be overcome by a change in practices (see illustration below):

- A substantial increase in resources devoted to asset management must be based on an auditable risk assessment and on a demonstrated capacity to deliver. What is more, the proposed strategy will have to demonstrate resilience to unknowns associated with the energy transition.
- The changeover from a strategy rooted in an age of replacement and acceptable risk, both previously determined, to a strategy based on minimising risk with respect to reliability theory. Among other things, this requires the establishment of a common "baseline of consequences".
- The optimisation of methods for deploying asset management strategies that ensure compliance with technical constraints (ability to perform withdrawals across the network) and resource constraints, while aligning with other operations involving assets (development projects).

Both now and in the long term, this will rely to a large extent on a core set of high-quality structured data and on robust tools.

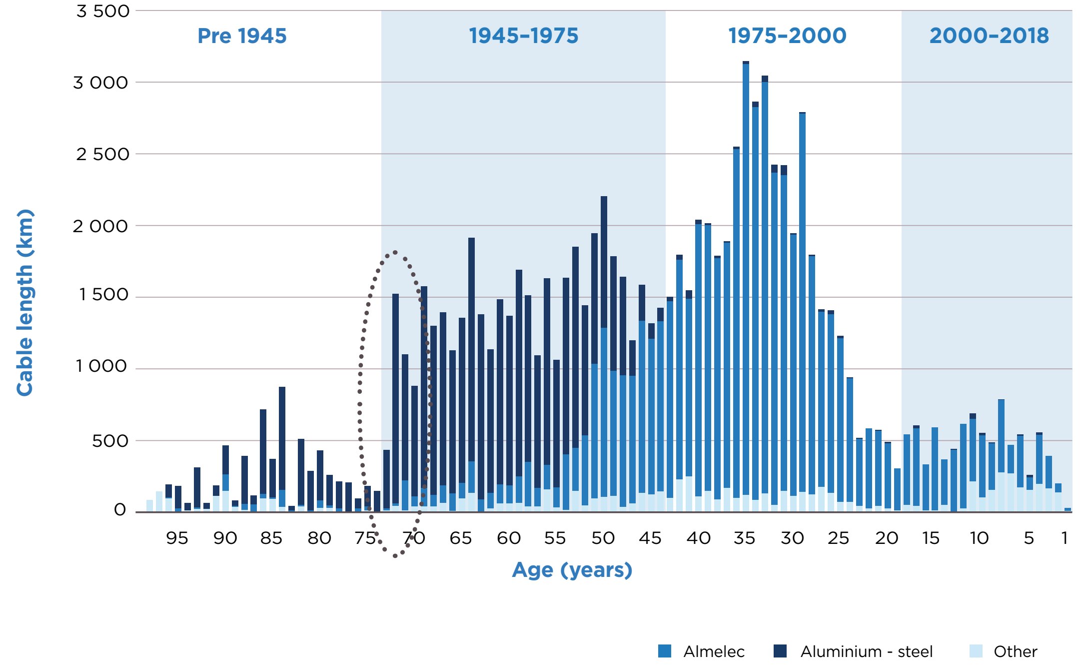


Figure: Age structure of overhead conductors.

— Ambition

Provide RTE with a coherent suite of tools and methods, that are at the industrial prototype stage at the minimum, and that will deliver "optimal" and auditable choices on timeframes ranging from the overall asset management strategy to the detailed scheduling of operations.

— Objectives

Steering asset management	Ensure that RTE can put forward the best possible asset management strategy, and resources allocated to maintaining and renewing the network. This entails the establishment of survival laws for the equipment in various conditions (maintainability, reparability, covariates), the establishment of a common baseline for the consequences of failure, the enhancement of holistic simulation techniques already used for the TYNDP.
Roll-out of asset management policies	Arrive at operational prototypes for the stages of planning (distribution of operations over the years, over a period of four to eight years) and scheduling (entering operations into a detailed schedule for a period of one to two years). These two stages increasingly involve detailed knowledge of constraints and of regional equipment.
Education and knowledge-sharing[6]	Publish work on optimised policies and share the software library in open source, to promote knowledge-sharing.

Risk is estimated in terms of non-distributed energy, each boxplot representing the risk distribution for the withdrawal of the installation on a given week (there are 52 boxes), each red dot representing a network situation. This data can be used to build a schedule of operations that minimises overall risk under resource constraints (particularly human resources).

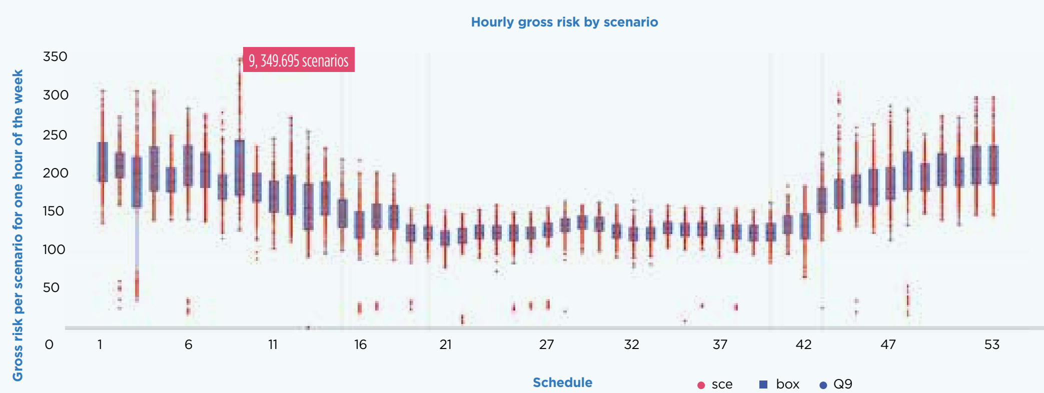


Figure: Distribution of risk related to the withdrawal of an installation.

(6) Aside from the positive aspects of knowledge-sharing, publishing in leading scientific journals ensures that RTE's future decisions are founded on scientifically validated work. Therefore, wherever possible, this is an important objective.

3.4 PROGRAMME FOR A CYBER-PHYSICAL AND ECO-DESIGNED FUTURE FOR NETWORK INFRASTRUCTURES

— Background

This programme follows on from the "Development of the network infrastructure" programme that ran over the period 2016-2020. The technical devices that are examined amount to the **essential and permanent basic** elements of the electrical power transmission network: lines and cables, substations, power electronics and direct current facilities, the protection-automation-and-control systems of the substations, and the system control architecture. Each element represents a research topic in its own right.

The term "eco-design" describes a method for the design and development of these future infrastructures that factors in environmental impact criteria (CO2 footprint, use of scarce materials, and impact on biodiversity) as well as technical and economic performance criteria.

The term "cyber-physical" applies more specifically to the topics of "control architecture", "protection-automation-and-control", and "power electronics and direct current". It spotlights the increased entanglement of the network's physical and digital infrastructures, in particular with regard to the control (timeframe, location, laws of control) of their different functions.

The topic of "lines and cables" encompasses the overhead lines, underground and subsea cables, the conductors as well as all the hardware that make up the different types of connections (pylon, foundation, insulators, anchoring devices).

The topic of "substations" covers outdoor substations (air insulated substations), indoor substations (gas insulated substation) and now also offshore substations (floating or on fixed platforms), for electro-technical components as well as for structural components (fences, buildings, new autonomous equipment and tools).

— Ambition

The programme aims, on the one hand, to analyse and develop the network infrastructure elements that have been identified as a source of restrictions and, on the other hand, to bring these technologies to full fruition by means of simulations, mock-ups and systems installed in fully representative environments. This work must be undertaken as part of RTE projects or in consortium with other French and European partners. Lastly, the objective is to incorporate all or part of this work in technical baselines for standardisation, and in the technical specifications of future industrial deployments by RTE.

3.4.1 CONTROL ARCHITECTURE FOR A HYBRID CYBER-PHYSICAL SYSTEM

— Background

Control of the power system hinges on a triple-layer model: protection (an automatic action, for example) close to the monitored installation, such as a power line or a transformer, automation-and-control for actions coordinated by software, such as local controllers in the substation (a first consolidation point), optimisation through network operation by the dispatcher, and a set of analysis software or actions such as controller actions or secondary regulation, requiring a more comprehensive overview and aiming chiefly to control the macroscopic parameters of the power system (voltage, supply and demand balance, management of current flows). This triple-layer model can be applied both to functions deployed at a local level and to others at a centralised level:

- At a local level, through automated systems and protection systems which fulfil simple, safe and rapid functions, based on local information, and are essentially designed to protect people and property,
- At a centralised level, through automated and other systems which enable actions that are coordinated across the entire system, with complex algorithms, slower response times, and the need to gather information from all the network components.

The growth in decentralised generation facilities, storage and power electronics, much faster operating dynamics, and limited predictability, combine to make control of the system all the more complex. The current control architecture will not make it possible to capitalise on all the means of intervention (referred to as flexibilities) made available by the hundreds of controllers.

— Ambition

Through this work, RTE is seeking to provide its various operational teams with the methods and tools they need to fulfil their functions, in this context of technological change. Consequently, the software and-automation-and-control IT teams, the engineering teams, the operation and maintenance teams, will be fully equipped to meet the challenges of a power system intertwining tangible objects and systems, simulation-modelled objects and systems, protection software, automation-and-control software, and optimisation software. This system of systems is referred to as a hybrid cyber-physical system (or CPS).

The ambition of R&D is in particular to assess the value to RTE of power network control architectures that are more decentralised that those currently used, on a scope that extends beyond that of controllers overseeing power flows, and to identify or create the tools and methods to design or validate them.

— Objectives

Modelling	Examine the modelling of an overall architecture for control: • Modelling of an architecture for a centralised/decentralised system with coordination of the layers of action Protection – Control – Optimisation, incorporating the telecommunications systems and protocols needed for these actions. • Mechanisms for collaboration between the different entities of an adaptive and collaborative system.
Design and validation	Study the design and validation of cyber-physical systems (CPS) (methods, tools, combined simulation of electricity network/controllers/telecommunications networks).
Potential implementation	Envision the implementation process and required infrastructures: telecommunications networks - analysis and synthesis applications, run locally or as close as possible to the monitored or controlled process, i.e., edge computing, transmission of information to customers, factoring in concerns about IT security relating to data exchange and an estimation of the ecological footprint of these data transfers.
Use cases	Examine more specifically examples of decentralised implementation (controllers, local management of voltage, optimal pathway for operating the zones, etc.) through the application of the MPC model (Model Predictive Control)[7] by a controller solving the constraints. The task is then to coordinate the actions of the different controllers to achieve multi-zone control. Lastly, the feasibility and advantages/drawbacks of a distributed vs. centralised technical architecture will be investigated.

— Partnerships

In order to meet the challenges of open and flexible digitization, RTE has teamed up with an industrial consortium proposed by the institute for technological research SystemX whose activities are focused on the hybridization of Artificial Intelligence, the learning from the operational teams, and physical models, to speed up the calculations required for augmented simulation.

(7) The MPC model designed by RTE's R&D examines at each time iteration how to remove a maximum power flow constraint on a line for a given geographical zone. It identifies and selects the most effective mitigation depending on the known time constraints, out of all the levers of flexibility which the algorithm knows of for the zone, i.e., actions with batteries, commands to modify production or open a breaker. The controller then sends the commands.

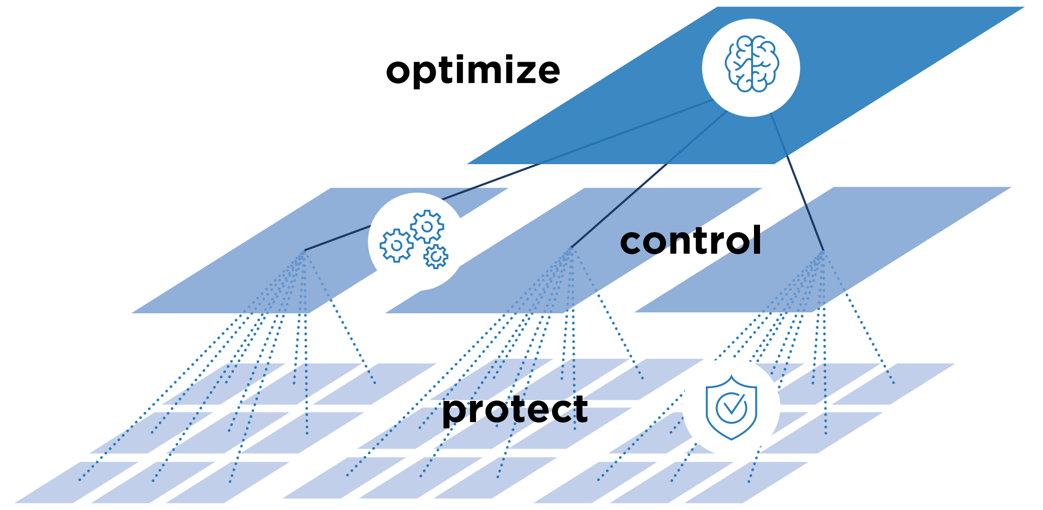


Figure: Triple-layer modelling of a control architecture.

3.4.2 PROTECTION–AUTOMATION-AND-CONTROL

— Background

The digitization of equipment has gradually and profoundly modified the protection-automation-and-control facilities of the 2,700 substations owned by RTE. This forms the basis of the SMART ELECTRE and R#SPACE industrial projects to replace substation protection–automation-and-control systems. This upturn in digitization and telecommunications has resulted in a proliferation of electronic devices, whose supply and interoperability are becoming critical for the company.

— Ambition

As with the work carried out in the telecommunications and car industries, virtualization technologies applied to real-time systems should be transferable to the protection–automation-and-control systems of electrical facilities. The aim is to replace physical equipment with independent software modules that run on a soft-ware platform and on "off-the-shelf" equipment.

Virtualization is a real technological breakthrough, which must deliver an economic payoff at the time of purchase, along with a significant reduction in equipment required, a simplification in the engineering for associated works,and a generalisation of remote diagnostics, remote administration and remote maintenance.In the medium term, the "Protection Automation and Control" roadmap must demonstrate the feasibility of a virtualized and open source solution for substation systems, under existing protection plans. In the long term, the ambition is to review these plans so as to improve their technical outcomes – i.e., safety, cyber-security and reliability. Furthermore, the roadmap reassesses the auxiliary power supply systems for substations so to take into account developments in storage and power electronics, and to incorporate RTE's environmental footprint optimisation, in the context of new protection automation and control architectures.

— Objectives

Open virtualization of substation PAC functions	Development on a platform of a virtualized demonstrator for the protection-automation-and-control system of a 225 kV / 63 kV substation, in a virtualized solution under manufacturer ownership. Investigation for the development of an open source software platform that is controlled by RTE and is able to integrate multi-vendor application modules (for the purposes of Project R#Space).
Revision of protection plans	Re-examine the protection plans, taking into consideration the increasing market penetration of decentralised generation facilities and the new technological opportunities, virtualization in particular.
Review substation auxiliary supply systems	Re-assess the requirements and technical constraints of substations (harmonics, etc.), develop state of the art solutions for the auxiliary supplies and validate preferred architectures. This is based on a study entrusted to CEA-Tech.

— Partnerships

RTE, the Grenoble Engineering and Management School, and G2Elab, are joining forces to explore the development, on a commodity server, of the virtualization of a prototype for differential protection against insulation failures on the transmission network, that does not require an external synchronisation source (for example, a Global Navigation System like GPS or GALLILEO), thereby avoiding any uncontrolled dependency.

RTE and SCHNEIDER ELECTRIC France are working together on the virtualization of a protection-automation-and-control system for a high-voltage substation. The solution offers an interface for integrating specific algorithms developed by RTE or third parties.

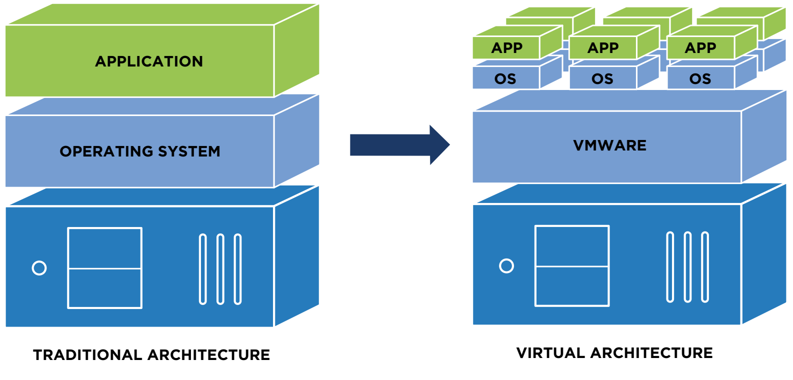


Figure: Virtualisation model.

3.4.3 POWER ELECTRONICS AND DIRECT CURRENT

— Background

The deployment across the electricity system of equipment based on power electronics will speed up in the coming years. This acceleration is prompted by the widespread entry of renewables into the markets, by the strong development of direct current interconnections, and more broadly, by the digitization of the economy. Indeed, the TYNDP foresees that half of the network development investments in the next 10 years will be allocated to HVDC connections. Yet, these connections, as with renewables, generally interface with the network through power electronics. To that one must add the new types of consumers: electric vehicles, datacentres, storage.

Alongside this unprecedented proliferation of active devices, the interactions between alternating and direct current networks are growing. The system is therefore becoming more complex, with increasing risks in terms of equipment service life: for example, the risk of resonance in cables. In addition, the field of direct current and power electronics is still a new one, undergoing a technological shift, and led by the digital transition.

— Ambition

This roadmap attempts to provide a partial response to these new challenges through two ambitions. The first is to support day-to-day operation and address the key issues set out in its business plan, for example by striving to limit the risk of interactions caused by the proliferation of power electronics equipment. The second, which delivers on a longer-term policy, aims to anticipate deep-seated changes and shed light on RTE's strategy, for example in relation to direct current connections.

— Objectives

DC connection proposals and DC networks	Feasibility studies for a direct current connection offer to industry customers (producers, consumers, storage). This would make it possible to pool the AC/DC converters that customers are currently responsible for, and to increase the overall efficiency of the system.
Interactions and interoperability of an AC/DC hybrid system	Continue the effort to study the methodological and modelling aspects that are specific to power electronics components.
New opportunities provided by power electronics equipment	Identification of the specific functions or capabilities of innovative components based on power electronics and associated equipment, followed by validation through small-scale mock-ups (solid state transformer, DC/DC transformer). For example, the validation of new functions offered by a superconducting fault current limiter in DC systems.

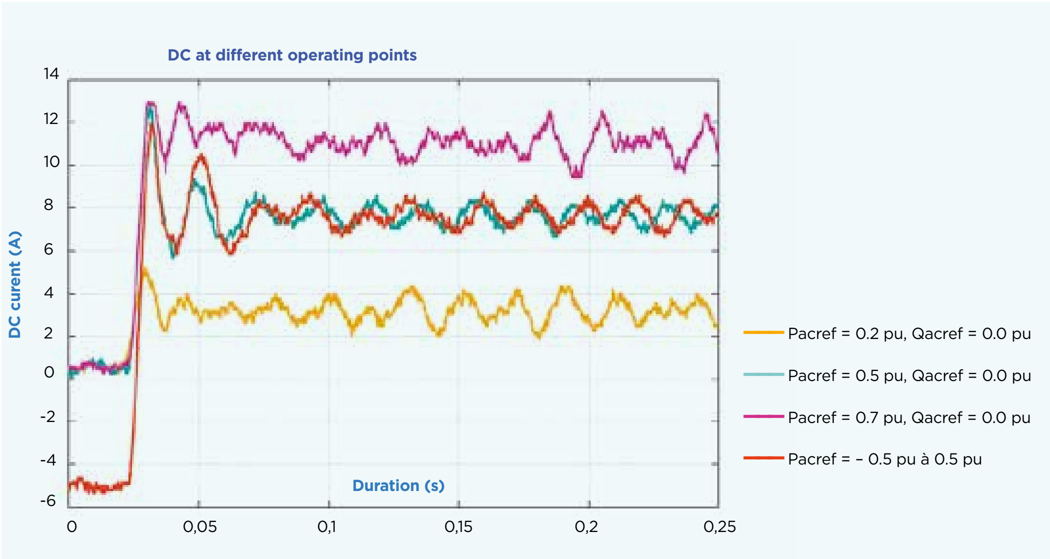
— Partnerships

RTE has partnered with Arts et Métiers, Centrale Lille, and the Lille Electrotechnical and Power Electronics Laboratory (L2EP) to work on AC and DC network interactions and on interoperability. This project is expected to last 5 years (2017-2021), and an extension is planned.

RTE and the Supergrid Institute (Lyon) have signed a partnership agreement on the subject of power electronics.

RTE and Universitat Politècnica de Catalunya (UPC) have signed a partnership agreement to work together on the innovative concept of an alternating-direct converter that combines several voltage levels on the DC side.

RTE has signed a partnership agreement (August 2020 – August 2024) with the Catholic University of Leuven (KU Leuven) to study the implementation of "grid forming" type controls for a direct current (HVDC) connection in bipolar configuration.



A MMC arms
B Arm inductance
C Global control card
D AC-side filter
E Sub-module
F BCA control card

Figure: Modelling and comparison with a mock-up by Arts et Métiers, Centrale Lille and L2EP (Lille).

3.4.4 THE FUTURE OF CONNECTION INFRASTRUCTURES

— Background

The electricity transmission network, made up of 100,000 km of overhead power lines (OPL) and 6,000 km of underground cables (UC), is continuously evolving. It changes to connect new customers and new producers to a power supply, to establish interconnections, including subsea cables (SSC), but also to gradually replace infrastructures built in the last century[8]. DC technology represents a new offer that is growing, particularly for interconnections.

These installations, with a service life of approximately 80 years, shape landscapes and regional planning: by their nature, they have societal consequences and, given the ground coverage involved, could offer a tremendous opportunity to be a source of biodiversity regeneration.

— Ambition

Beyond energy efficiency and economic performance, the question is how we can build or renew our electricity connections in the future while factoring in all the environmental considerations and challenges facing society: multifunctionality, shared uses with third parties, limitation of our contribution to the greenhouse gas effect, resource efficiency in relation to non-fossil mineral resources, restoration of biodiversity? Is it possible to move towards power connections that are 100% recyclable, carbon neutral, with a positive environmental footprint and shared uses?

The ambition of R&D is to develop concepts for new generation electrical, environmental and societal linkages and thus overcome the main obstacles: dependence on suppliers, financial constraints and technical performance.

— Objectives

Design of New Generation Green Connections	Identification of areas for improvement based on OHL and UC life cycle analyses in the context of a high-voltage network. Assessment of our understanding of interactions with seabeds and marine life with France Énergie Marine. Innovations in these areas for improvement will include eco-design and biomimetics initiatives (for example, materials with fewer greenhouse gas emissions and less impact on biodiversity).
Electrical components	Enhance the energy efficiency of electrical connections through innovation in the field of electrical components, seeking in particular a reduction of the noise produced through the corona effect and a reduction of electrical losses.
Tools, methods and materials	Innovate the tools, methods and materials that make up the hardware supporting each electrical connection so that it can be operated at optimum performance over the long term. For example, test the biocalcification solution for sandy soil, to increase the heat dissipation effect and mechanical strength, as a replacement for excavations for underground connections using concrete.

— Partnerships

CEEBIOS – European Centre of Excellence for Biomimetics) in Senlis. Thanks to biomimetics, living organisms will be a source of inspiration for these future electrical infrastructure components, which continue to be the subject of R&D in light of these challenges.
Soletanche Bachy: a partnership was launched at the end of 2020 for the assessment of the proof of concept for the BIOCALCIS® process as a substitute for concrete-based solutions for RTE underground electrical connections.
France Energies Marines: the partnership with this research institute is furthering the study of the interactions between the marine sphere and the technical means necessary for transmitting power from offshore wind farms.

(8) see the 2019 TYNDP ten years network development plan scheme

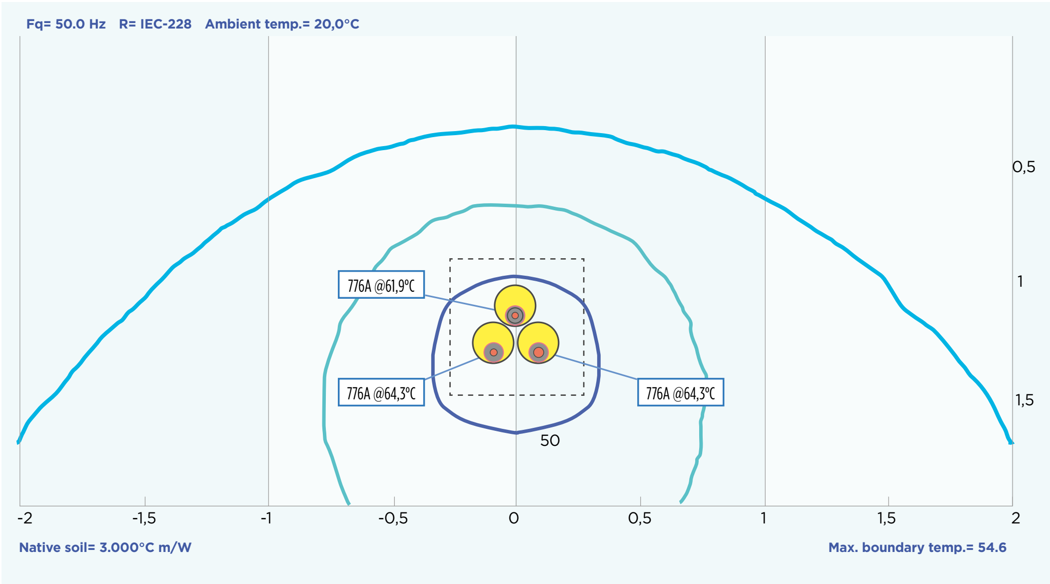


Figure: HDPE (high-density polyethylene) tubes coated with BIOCALCIS®.

3.4.5 THE FUTURE OF SUBSTATION INFRASTRUCTURES

— Background

The substation is a permanent and integral component in the operation of the electricity network: it directs power flows according to the system's operating requirements, and transforms and controls voltage levels. Its role as a node in power transmission has grown over time, from node (hub) to provider of measurement data of all kinds (power states, alarms, monitoring of ageing, etc.).

Conventionally designed as outdoor air-insulated substations (insulation properties of ambient air) or indoor gas-insulated substations, the ongoing development of offshore windfarms is prompting the development of offshore substations (above water and secured to the seabed, then floating in deep water, and even submerged) for collection of power and transmission to the onshore network.

— Ambition

The substation is a focus for certain environmental and societal challenges regarding sustainable development: limiting the contribution to greenhouse gases (caused by SF6 gas in particular), restoring biodiversity, and even reducing the consumption of non-fossil mineral resources.

New technologies and innovative design principles are being considered for all the different types of substation, outdoor, indoor, and offshore.

— Objectives

Electrical components	Examine the introduction of new technologies, first through bench tests then test them on a representative site. For example, low greenhouse gas 225 kV and 400 kV breakers, and instrument transformers without oil or greenhouse gas effects. For offshore substations, and the floating substations in particular, the movement and acceleration of electrical components will be studied, as part of the work being carried out on the articulated mooring of dynamic cables.
Infrastructure and installation components	Examine the introduction of new materials and new technologies in substations with the objective of achieving a positive effect on the environment. For example: control greenhouse gas leaks, look into paint-free framework, low-carbon materials, and carbon storage for circulation routes, sheaths and fencing. For offshore substations, the mooring fixtures will be studied.

Figure: GRIMAUX 63 kV substation: pilot for RTE's first low greenhouse gas insulated substation, commissioned in June 2019.

— Partnerships

CEEBIOS – European Centre of Excellence for Biomimetics) in Senlis.

France Energies Marines: the partnership with this research institute is furthering the study of the interactions between the marine sphere and the technical means necessary for transmitting power from offshore wind farms.

3.5 PROGRAMME FOR THE ENVIRONMENT, SOCIETY AND PROSPECTIVE STUDIES

In a commitment to help RTE and the national public authorities, steering the future of the power grid and system, this program aims to develop a comprehensive understanding of energy embracing technico-economic, social and environmental dimensions, in a world undergoing profound change.

— Background

"An environmental perspective"

The Green Deal commits Europe to moving towards carbon neutrality, the regeneration of biodiversity, and a circular economy. These challenges will increasingly bring about strong economic and regulatory changes, which have to be anticipated, given the long service life of power infrastructures: 20, 40, 60 years or even longer for transport infrastructures. Pylons, conductors, nuclear power plants, wind turbines and photovoltaic panels must be qualified not only in terms of power, energy and euros, but also with regard to greenhouse gases, tons of unrecycled materials, toxic releases, non-indigenous land cover, biodiversity destruction or regeneration, etc.

"A social perspective"

The electricity network is also a social system: an accepted pooling of resources (e.g.: financial) and impacts (e.g.: landscapes) that enable to achieve economies of scale for the benefit of all. Therefore, the energy transition is not purely a technical operation, it affects this social equilibrium, engaging local residents in the acceptance of new infrastructures (production and transport), consumers in issues related to resource efficiency and flexibility in energy uses, as well as new local investors and even individual investors.

"A changing world"

Tackling climate change and the collapse of biodiversity will require changes that are all the more far-reaching as the likelihood of a significant decoupling of economic growth from environmental footprint is speculative[9]. The changes will affect production and consumption patterns, and more broadly, lifestyles and aspirations, and ultimately the energy that permeates them.

Furthermore, society will have to adapt itself to the already unavoidable consequences of these trends, particularly a potential global exodus[10] with all its social and geopolitical implications. The future of the energy sector must therefore be contextualised and designed for a world that is very different to today's.

— Ambition

The five roadmaps of this programme form part of this effort at anticipation. They are cross-cutting, interfacing with a broad range of other R&D topics and RTE specialisms:

- **Grid and biodiversity**: objectively assess the relationships between network and biodiversity, use this knowledge to work towards materials and practices that regenerate biodiversity;
- **Energy, grid and society**: understand the dynamics of the relationships between energy, network and all of society's stakeholders;
- **Eco-design, environmental and resilience analyses**: objectively assess environmental impacts on the environment and on resilience, and factor these in at the design stage;
- **Future of the energy system**: ensure that RTE is able to analyse the entire European energy system, so as to anticipate the possible futures of the French electricity system;
- **Governance and regulation in tune with society**: put forward structural changes to the governance of the transmission system and electricity system (including market designs) so as to incorporate regional, societal and energy policy dynamics, whilst maintaining the safety and efficiency of the system.

(9) "Globally, growth has not been decoupled from resource consumption and environmental pressures and is not likely to become so". Agence Européenne de l'Environnement, publication consultée le 3/6/21.
(10) By 2070, 1 to 3 billion human beings will be living in a hostile climate, that is to say, outside of the "climate niche" conditions that have served humanity for the past 6,000 years. In the worst-case scenario, one third of the world's population will be exposed to a mean annual temperature of more than 29°C, a situation currently found in only in 0.8% of the global land surface, mostly concentrated in the Sahara. «Future of the human climate niche» PNAS May 26, 2020 117 (21) 11350-11355.

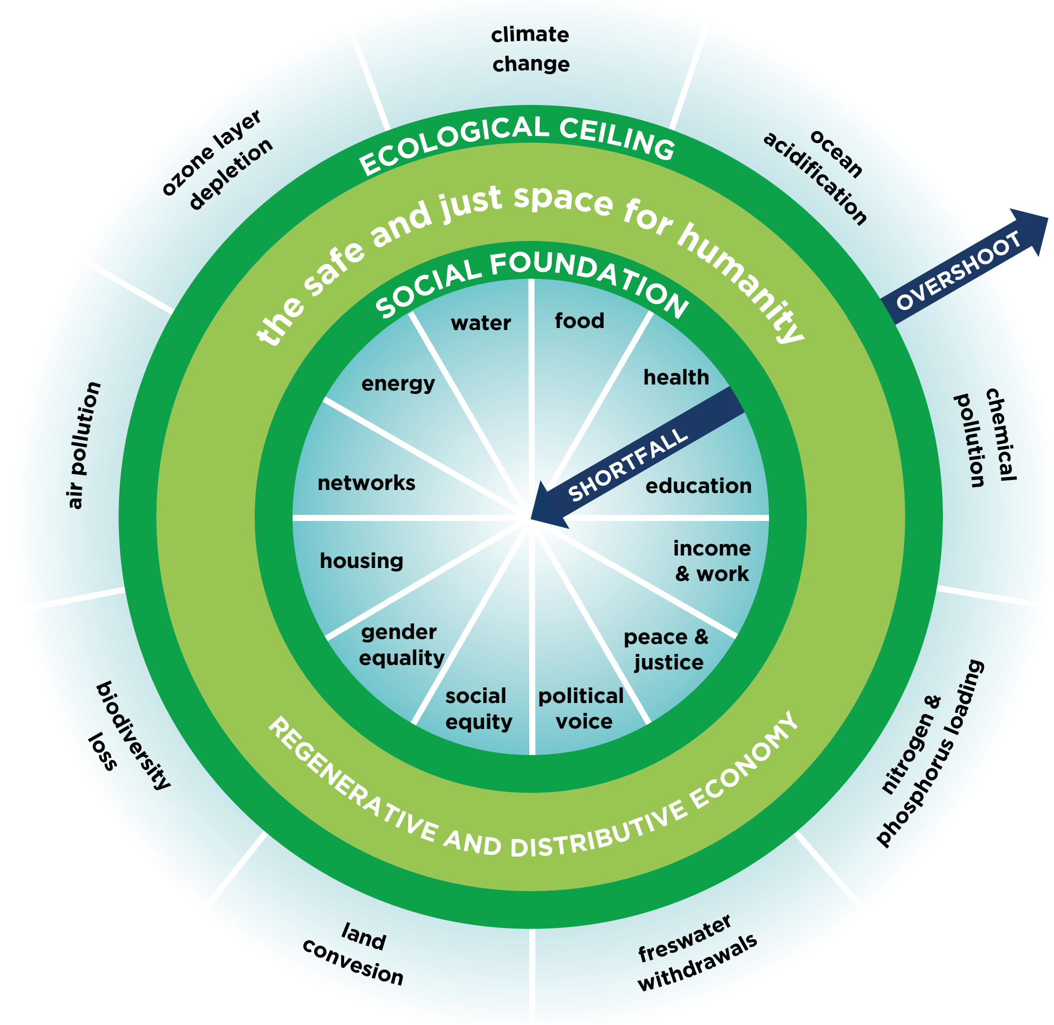


Figure: The "Doughnut Economics" model developed by Kate Raworth illustrates the boundaries that must be taken into account for a lasting environmentally and societally balanced economy. It underpins our framework for the analysis of possible futures for the energy system.

3.5.1 ECO-DESIGN, ENVIRONMENTAL AND RESILIENCE ANALYSES

— Background

In the face of threats qualified as "existential" by the European Commission, the Green Deal commits Europe to a multifaceted transition to carbon neutrality, the regeneration of biodiversity, and a circular economy. These "externalities" are expected to gradually bring about more and more economic and regulatory outcomes. In addition, the damage to the climate and the collapse of biodiversity are already partly irreversible, which is giving rise to new hazards and an ever-growing need for resilience.

The aim is therefore to methodize decision-making based on a renewed understanding of the notion of value, encompassing not only conventional technical-economic criteria but also environmental, social and resilience criteria. In addition, progress with these criteria will be all the more significant and all the less expensive if they are taken into consideration at the design stage, be it in the design of equipment or in the design of the future energy mix in future-oriented studies. Thus, the aim is to generalise eco-design.

— Ambition

This roadmap aspires to provide RTE with methods and tools to measure the environmental, social and resilience impact of our activities, supplementing existing technical-economic analyses, and, on the basis of these diagnostics, to offer solutions for concrete action and delivery of eco-designs.

— Objectives

Environmental analyses	**Develop solutions for life cycle environmental impact assessments for the infrastructures of the power networks and electricity system, up to European level.** Life cycle analysis (LCA) is relatively advanced for manufactured products. But further research in LCA and other methods is needed for complex systems (electricity, energy), for societal evaluations (employment, human rights, etc.), and even for more interactive and extended studies. Progress must also be made with data, both in terms of completeness and transparency, and in terms of structuring and governance.
Raw materials criticality analyses	**Develop decision-making methods and tools to address the risks linked to raw materials**: supplies, environmental impacts, duty of vigilance, circular use; in keeping with the work on material intensity modelling of scenarios for the transition of the electricity system.
Societal analysis	**Develop solutions for life cycle social impact assessments for the for the infrastructures of the power networks and electricity system, up to European level**. Assist in the selection and design of relevant indicators to quantify the social impacts of RTE at different regional and local levels.
Resilience analysis	**Explore methods (e.g.: stress tests) for identifying grid and system vulnerabilities in the face of new risk drivers,** particularly environmental drivers (e.g.: climate) and social drivers, to offer a different perspective on equipment and electrical engineering operating risks.
Eco-design	**Test and demonstrate the feasibility of solutions and methodologies inspired by nature (biomimetics) and the principles of a circular economy.**

— Partnerships

To achieve its goals, this roadmap mobilises a number of academic partners (Mines ParisTech OIE, BRGM, EcoSD, ADEME, Ceebios, etc.), industrial partners (suppliers, recyclers, etc.), as well as specialised consultancy firms (MicroHumus, etc.) for the purposes of both modelling and analysis, and testing innovative eco-designed solutions.

With particular reference to the field of marine renewable energies (MRE), a number of multi-stakeholder partnerships fall under France Énergies Marines.

Partnerships with our TSO counterparts already provide an opportunity for sharing good practices and must be strengthened in order to develop standardisation and interact together with our suppliers.

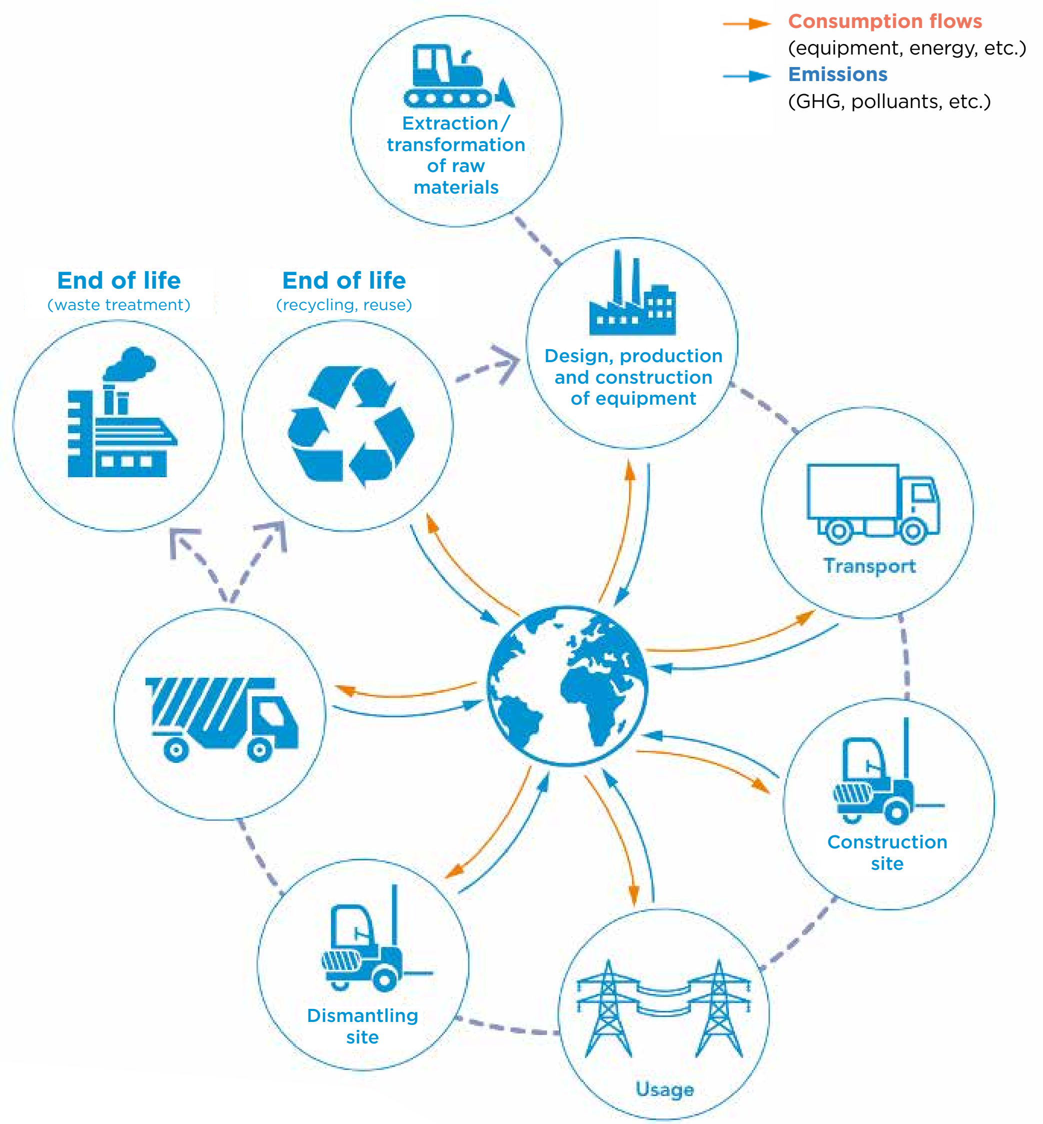


Figure: The life cycle of RTE activities, from cradle to grave.

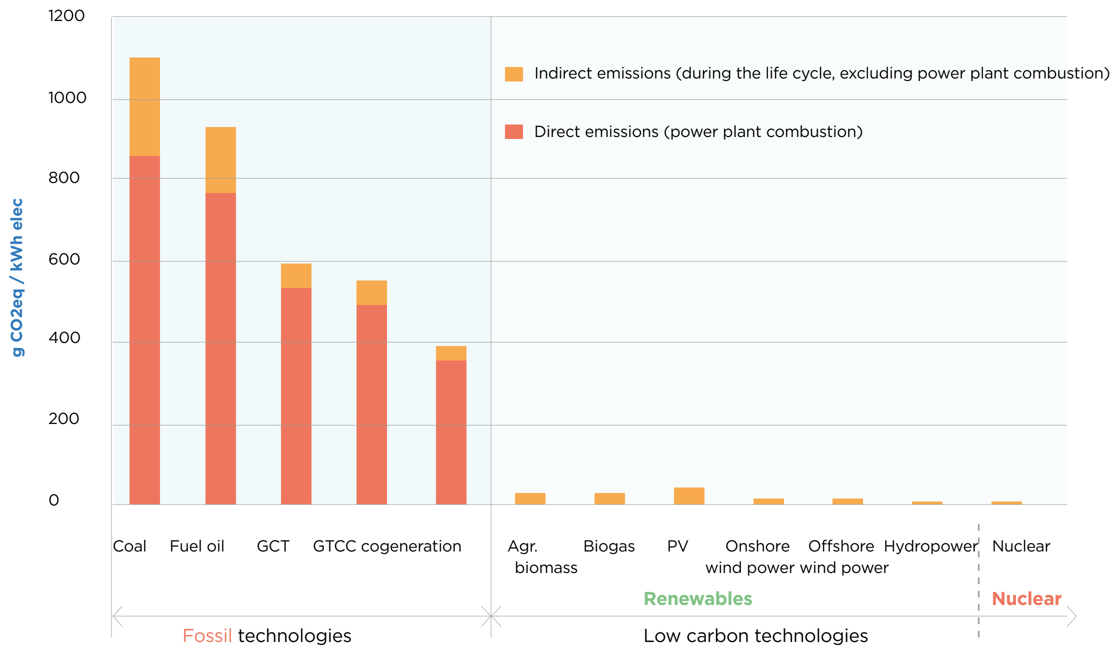


Figure: Carbon emission factors in 2020. Excerpt from the document produced in the context of the GT6 Environnement event on 13/7/2021 as part of the "Scenarios for 2050" exercise led by RTE.

3.5.2 GRID AND BIODIVERSITY: UNDERSTAND AND REGENERATE

— Background

A growing number of scientific studies confirm that current biodiversity extinction rates are more than 100 times greater than those that prevailed throughout the geological history of the planet (source IPBES[11]). Against this background of biodiversity collapse, the relationship between electricity infrastructures and living organisms is of increasing importance.

The high and very high voltage transmission network permeates France with its 100,000 km of overhead lines, 275,000 pylons, 6,000 km of underground cables and 2,700 substations. It extends to the subsea environment with 1,500 km of power connection projects for offshore wind farms and substations. This footprint has consequences for biodiversity that must be assessed and addressed, with the aim of achieving a positive coexistence.

— Ambition

The ambition of this roadmap is to improve RTE's ability to:

- understand the interactions between the infrastructure and landscapes, living natural systems and living organisms, by applying rigorous scientific methods;
- harness this knowledge to develop network solutions that will minimise the negative impacts and will contribute to biodiversity regeneration, which is one of the objectives that the Green Deal is committed to achieving.

— Objectives

Access to and installation of electricity infrastructures	New methodologies for impact studies and biological inventories, particularly in marine environments, which are necessary at a minimum prior to any works, and even during operation. They relate to the effects of noise, air and water pollution, and degradation of the quality of soils and waters.
Infrastructure presence in the landscape and infrastructure maintenance (including vegetation cutback)	This covers the "resource effect" of pylons, which can serve as perching and resting places, as well as breeding grounds. This covers the working strips which, depending on vegetation management practices and on interactions with town planning and stakeholders, can become barriers and cause fragmentation, but also serve as welcoming spaces and corridors. This also covers onshore substations (and vegetation management methods) and the future offshore substations, likely to generate a "reef effect" contributing to the regeneration of marine biodiversity. Taken together, could these elements allow the power network to take on the additional role of ecological corridor, including in agricultural settings, creating a positive relationship not only with biodiversity but also with stakeholders, and regions and localities?
Impact of power transmission on biodiversity	With particular emphasis on marine biodiversity, this applies, beyond the impact of the presence of equipment and its maintenance, to the specific effects of the transmission of power: electromagnetic and electrostatic fields, noise and vibration.

(11) IPBES (2019): Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. E. S. Brondizio, J. Settele, S. Díaz, and H. T. Ngo (editors). IPBES secretariat, Bonn, Germany.

— Parnerships

This roadmap hinges on a large number of contractors (specialised consultancy firms) and external scientific partners (institutes for ecological transition, universities, research centres) experts in the field of biodiversity. With regard to the marine environment in particular, research is pooled in research consortia bringing together France Énergies Marines and other bodies such as the Pôles Mer marine science and technology clusters.

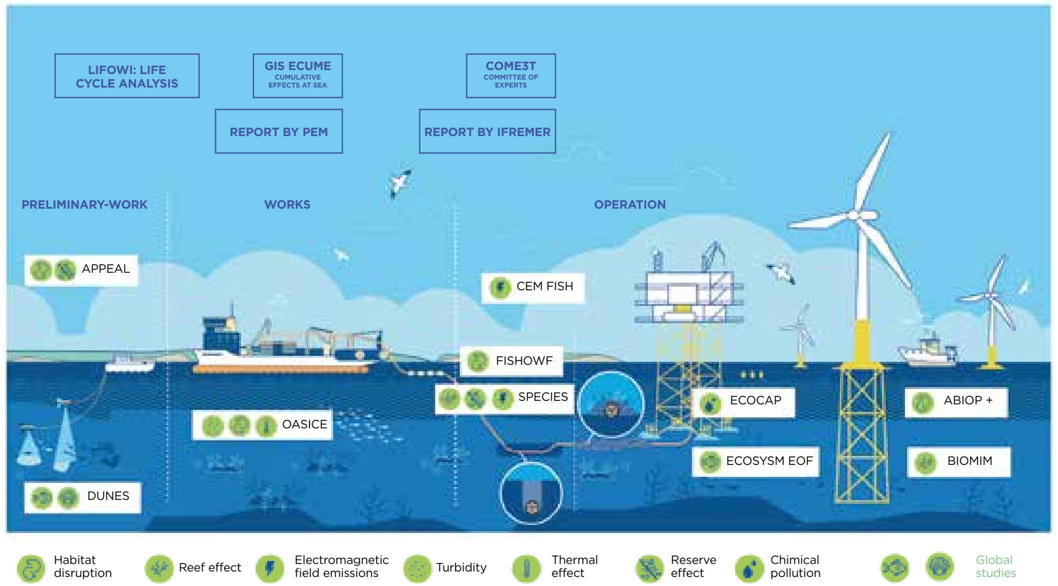


Figure: Overview of marine biodiversity impact studies.

3.5.3 GOVERNANCE AND REGULATION IN TUNE WITH SOCIETY

— Background

The electricity transmission public service is the legacy of decisions taken at national level, for the purpose of ensuring that the entire nation has access to electricity under optimum technical and economic conditions. In the early 2000s, a European dimension was added to these national criteria. The ongoing energy transition calls into question this top-down approach. Five main drivers have led us to reconsider the governance and regulation of the electricity system:

1. The increasing questioning of centralised decisions;
2. The end of the technical uniqueness of the solution provided by the electricity transmission network, following the development of storage and digital technologies;
3. The rise of local communities skills in the field of energy, combined with the citizen and community initiatives enabled by the Clean-Energy-Package;

4. The highly ambitious energy transition objectives set for 2030 (– 55% GHG emissions);
5. Emerging doubts on the current model's capacity to ensure the long-term security of supply.

— Ambition

Put forward proposals to the public authorities for structural changes to the regulation and governance of electricity transmission, possibly of the power system as a whole, with a view to:

- guaranteeing the TSO's core public service missions with regard to the operating safety of networks and security of supply;
- integrating the new regional, societal, environmental and energy policy dynamics.

— Objectives

Disclosure and coordination of scarcity in a system with zero marginal costs of production	We expect the market to identify scarcity and coordinate stakeholders, to ensure optimal operation of the existing fleet in the short term, and to guide investment in the medium to long term. This basic function of the market becomes ineffective in a zero marginal cost system, in which value lies more in power and flexibility than in energy. The energy transition requires redesigning the market model and regulation.
Diversification of the electricity product	The regulation of electricity and of its markets is based on the assumption that electricity is a fungible, undisguisable product. Technological, regulatory and societal developments can prompt the addition of attributes to the electricity product: the choice of a differentiated security level for each consumer, localisation, energy source, energy communities, etc.
New organisation of electricity transmission and of the transmission system operator	What developments are possible for RTE, as well as for associated regulation in the broadest sense (the tariff, in particular), assuming radical changes in circumstances resulting from the drivers of change listed above?
Subsidiarity and responsibility	The aim of this activity – connected to the above activities – is to work with the external ecosystem on an acceptable compromise between subsidiarity and responsibility at different decision-making levels, from a local to a European level.
Triple bottom line accounting, measuring financial, environmental and social performance	In the wake of the work by Schneider and Kering, explore the possibility of explicitly incorporating social and environmental externalities into RTE's accounting practice and *ultimately* into its regulatory practice.

— Partnerships

This roadmap mobilises a broad range of external partners as regards both their specialisms and their positioning on the value chain, with a wide spectrum of levels of maturity of topics, ranging from academic subjects well upstream, down to subjects that are close to the industrial deployment phase. Without aiming to be exhaustive, the following existing partnerships illustrate the mix of cooperation: Paris Dauphine University in relation to a chair on European electricity markets and a chair on regulation mechanisms; MinesParisTech with regard to a chair on corporate theory and with regard to work on solidarity in power supply in an innovation-intensive environment; Toulouse School of Economics on the question of tariffs; CEA on the subject of electric vehicles and associated trials; CentraleSupelec for topics linked to the optimal use of interconnections. Partnerships with triple bottom line accounting practitioners are in the process of being drawn up. Furthermore, exchanges and joint work are being developed with some of RTE's European counterparts in relation to several topics covered in the roadmap.

Figure: This page published by the French energy transition association CLER illustrates the call for a less "top-down" governance of energy (*"Civil society has its say on French energy choices"*).

3.5.4 ENERGY, GRID AND SOCIETY

— Background

The energy transition raises questions about the manner in which modern societies are transformed by the challenges associated with the decarbonisation of energy, how the practices and lifestyles of stakeholders will evolve, along with their methods for mobilisation and organisation. These questions can be asked at different levels, from the most global to the most local. As a result, in the past few years, energy has become an area of study in its own right in humanities and social studies, in order to analyse the political and social implications of energy.

— Ambition

The ambition of this roadmap is to capture and characterise the societal, regional and political transformations and dynamics affecting the energy sector. It must also provide the methods for reporting these in forward-looking studies, guided by a robust and testable scientific approach.

— Objectives

New consumer, user and lifestyle profiles	The aim is to overcome the limitations of the *homo economicus* mindset, when it comes to current or emerging energy practices, and more broadly, to the lifestyles and collective organisations that underlie them. This should make it possible to quantify new or planned practices for achieving a successful energy transition, such as resource efficiency or flexible uses, as well as their interplay with other challenges like housing, transport, food, etc.
Shared resources, energy communities and local resource mobilisation	New players depart from the historical supply scheme, and experiment, for example, energy communities, or new forms of political, legal and economic organisation. This approach seeks to explore new rationales for actions, their motivation and structuring.
Energy decentralisation, regional strategies, and the role of the network	Inherently regionally differentiated, renewable energies contribute to the energy decentralisation process, reinforced by political decentralisation (e.g.: the law for a New Territorial Organisation of the Republic, NOTRE). This approach seeks to examine the underlying processes and the implications, particularly the resultant regional restructuring, in which the role of the grids may be called into question.
Public service, common good, and solidarity	The concepts of public service and common good are socio-political and historical constructs. This area of focus aims to explore the manner in which the prevailing concept of public energy service can be challenged by current societal developments, as well as by the instruments that convey it (pricing and principle of equalisation, for example).

— Partnerships

In order to cover all these topics, this roadmap mobilises a wide range of disciplines (sociology, history, economics, law, planning, political science, anthropology, geopolitics, etc.) at different levels of action, from macro-level (Europe) to extreme micro-level (individual) and multiple intermediate levels (regions, communities, etc.) and timescales (past, present, future).

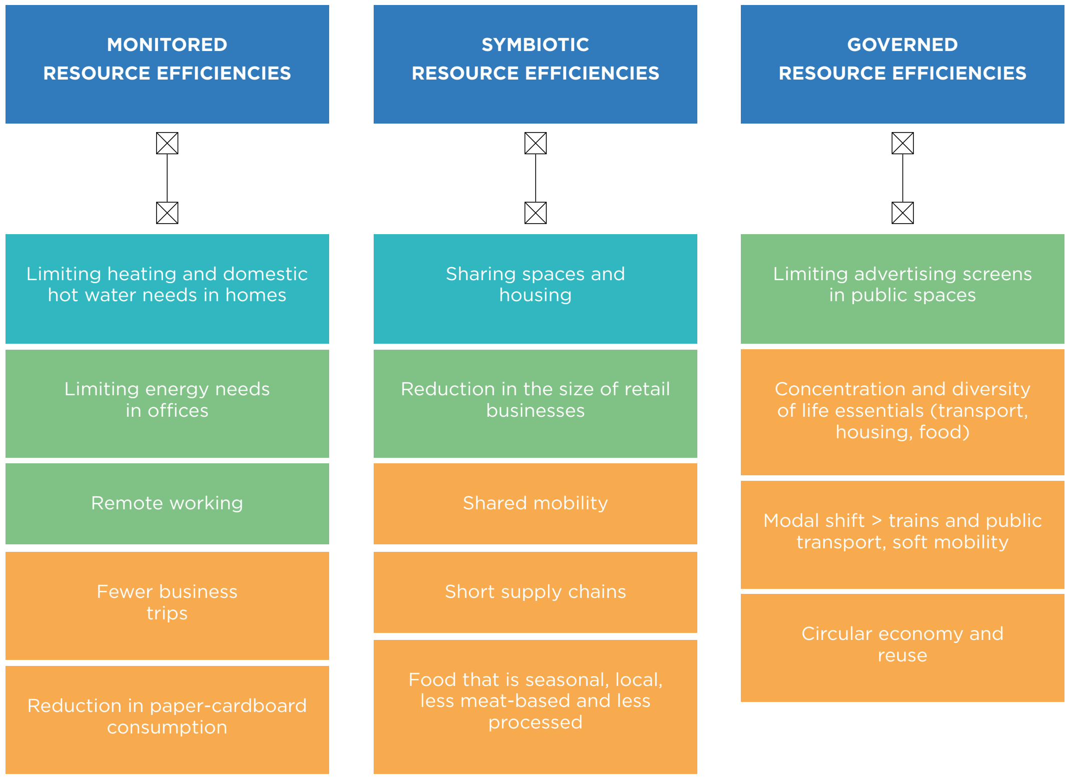


Figure: Resource efficiency potential identified in the "Scenarios for 2050" exercise led by RTE, debated during the "Societal dynamics" Working Group event on 7/1/21. Three standard models of resource efficiency were selected in the research carried out by Guérineau and Mayer, 2021 (joint work by R&D and RTE).

3.5.5 FUTURES OF THE ENERGY SYSTEM

— Background

Understanding energy in the long-term requires to overcome two main barriers:

- Carbon neutrality requires significant restructuring of the energy system, in particular with a 50% reduction in overall energy consumption by 2050, and the decarbonisation of uses (which at the present time are 70% powered by fossil fuels). This forward planning exercise must go beyond the current trend in uses and beyond the reasoning applied exclusively to electricity, so as to investigate how to meet global energy needs, taking into account all the energy deposits, carriers and uses.
- The technical-economic analysis including CO2 emissions is not enough. In the general context set out in the introduction to the programme, it is important to factor in the other environmental considerations (e.g.: biodiversity), societal considerations (e.g.: acceptability of wind farms, of flexibility, of resource efficiency), regional considerations (e.g.: local employment) and geostrategic considerations (e.g.: resilience of supply chains).

— Ambition

Ensure that RTE is in a position to analyse the complete European energy system, so as to accurately anticipate the possible futures of the French electricity system.

A multi-energy outlook: the example of mobility

At present, mobility is almost entirely fuelled by fossil energy sources. What level of electricity consumption should we expect for mobility? This will depend on changes in requirements and behaviours (urban planning, individual versus collective mobility, growth or stagnation in soft mobility, etc). This will depend on the technological options (electrochemical batteries, hydrogen cells, biomass fuels). And lastly, this will depend on the availability of biomass for energy uses.

— Objectives

Tools, methods and data for energy analysis	The objective is to explore European energy balances that have been restructured to reach carbon neutrality, as illustrated in the Sankey diagram (figure), in which each arrow is an unknown yet to be quantified. This requires modelling the different pieces of the puzzle: future energy sources, carriers and uses. Regarding uses in particular, in order to move away from current technological choices and make a connection with behaviours and needs, it is necessary to model "useful energies", that is to say, final energy requirements (mechanical needs, heating needs, etc.) per unit of service delivered.
Tools, methods, and data for assessing the economic, social and environmental footprint of the energy system: moving towards "three-way LCA"	The aim is to apply breakdown approaches typical of life cycle environmental assessment, to the social dimension (especially employment) and to the economical dimension. The economic aim is to anticipate long-term economic costs better by working on the drivers of these costs, (quantities of raw material, of labour, etc.).
Modelling and studies of the system as a whole	The aim is the technical-economic simulation of energy system operations (hourly granularity, representation of hazards, installed capacity adjustments, use of different means of generation, storage, interconnections, etc.), incorporating, in particular, system resilience indicators such as the resilience to common mode, technical and organisational hazards; as well as the local dimension, through analyses at different levels.

— **Partnerships**

Various partnerships have been established to capture all the elements in this roadmap. These include the chair in Modelling for Forward Planning and Sustainable Development, for the modelling of the electricity system, and CEA for the modelling of heating networks.

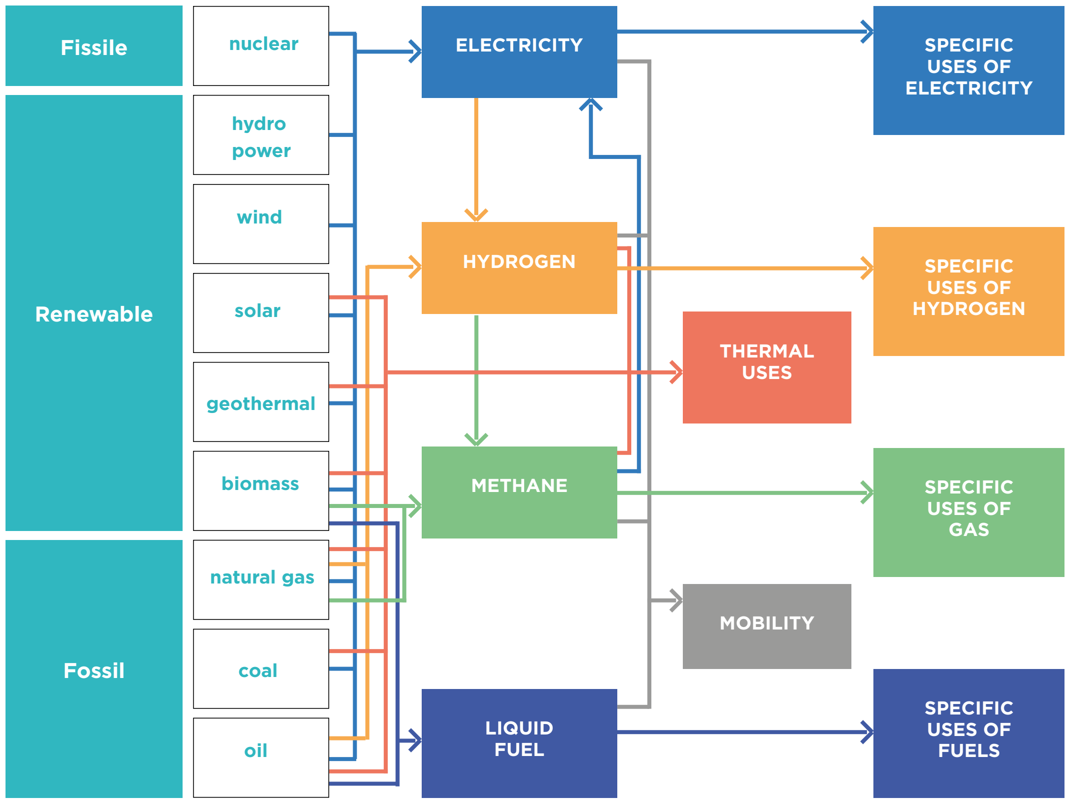


Figure: The modelling must enable the assessment of a complete restructuring of the energy system, of sources, carriers and uses.

3.6 PROGRAMME FOR CLIMATE, AND LONG TERM POWER SYSTEM ADEQUACY AND PLANNING

The French and European electricity system was built over the years, based on high power generation facilities and increasingly interconnected transmission networks, this architecture being the most technically and economically appropriate for pooling resources and guaranteeing network security.

The energy transition, and more broadly the ecological transition, initiated at European level is giving rise to significant developments and disruptions in the electricity system: changes in decentralised generation units, changes in consumption patterns (flexibilities, electric vehicles, etc.), changes in the energy system (multi-energy system), storage, the growing share of electricity in final energy consumption, etc. Furthermore, the environment and society are undergoing profound changes whose processes are speeding up: availability of resources, climate change, societal challenges to production and consumption patterns, etc. We can see that the changes in the electricity system tend to increase dependence on weather conditions. The effects of climate change are having a growing influence on some of the parameters (generation units, consumption) of the electricity mix, which must be taken into consideration: cold snaps, heatwaves, generating capacity output of hydropower and wind power, etc. What is more, these weather conditions also have implications for our network infrastructure: capacity to withstand extreme temperatures, flooding, landslides, etc. Extreme situations therefore play a key role in the design of the electricity system and our network: design studies must be able to incorporate different weather condition scenarios and their frequency, including for infrequent events.

In order to guarantee appropriate and efficient future investments, RTE must anticipate these transformations with the intention of reviewing and adapting the methods and tools currently implemented in future-oriented studies and network development studies (renewal, optimisation of existing equipment, construction of new infrastructures). Indeed, these transformations modify the current network development strategies and provide new insights.

The integration of new technologies (renewables, storage, small modular reactors, etc.) and the ageing of the network are giving rise to a pressing need for a new network and, aside from increased inputs, open up a debate on new network architectures.

What will be the impact on the network's structure of offshore networks and of the Green Deal objective of 450 GW of offshore wind farms by 2050? How can multi-energies and flexibilities be taken into account in the development of the network? What are the new electricity transport needs? What levels of resilience and reliability will be expected from the future network? What will be the impact of climate change on the design and operation of the power system?

With that in mind, the "Climate, and long term power system adequacy and planning" Programme will have three R&D areas of focus. The first area of focus aims to document and quantify the impacts of the climate on the French and European electricity system and infrastructures. The second area of focus seeks to develop the models and tools for RTE's adequacy and network investment studies, and thus assist public decision makers regarding energy planning (adequacy report, TYNDP, etc.). And lastly, the third area of focus aims to develop a long-term vision of network development, combining the forecasts for the energy system with technological solutions, so as to assess the various possible network architectures, and equip the operational teams with the methods and tools needed to single out optimal development.

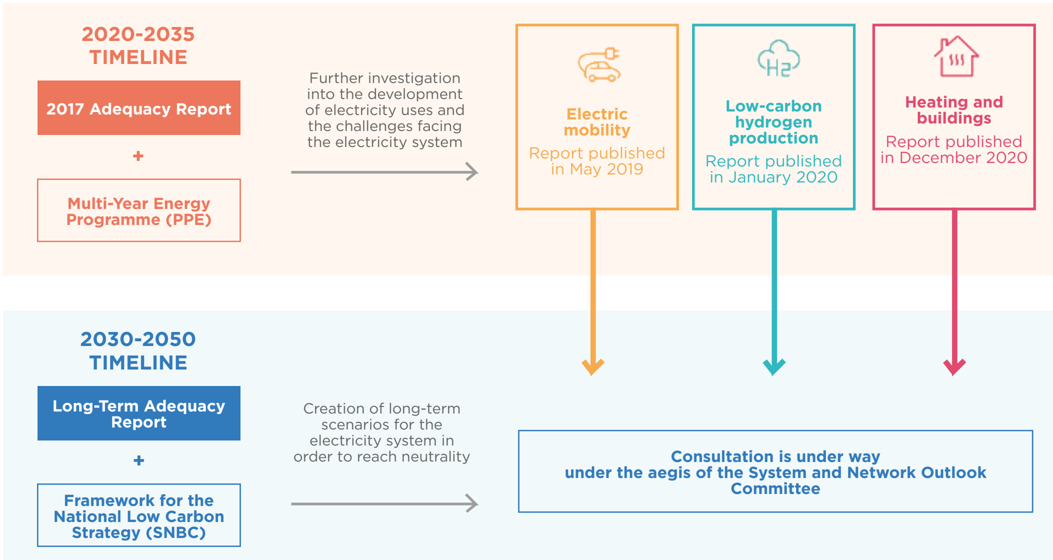


Figure: R&D adapts the methods and tools used in future-oriented studies to inform public decision-making.

3.6.1 CLIMATE, WEATHER AND IMPACTS ON THE POWER SYSTEM

— Background

The observed, planned, and foreseeable developments in the electricity system are inclined to increase dependence on weather conditions. The effects of climate change will have a considerable influence on some electricity mix parameters, which must be taken into consideration: cold snaps, heatwaves, hydropower, and wind power generating capacity, etc. RTE is required without fail to have sound knowledge of changing weather conditions and of long-term changes in climate in order to embed the broad spectrum of weather conditions and their frequencies, including infrequent events, into its **supply-demand balance** monitoring activities, on the one hand, and into the **resilience of its infrastructures**, on the other hand.

In order to guarantee efficient and adequate levels of future investment, RTE must understand, anticipate and analyse its network's dependence on the current and future climate, so as to take full account of associated uncertainties.

— Ambition

The objective of this roadmap is to provide RTE with the relevant knowledge, methods, tools and data relating to the current and future climate, the resulting impacts on the French and European network and, more broadly, on the entire power system, in the context of the widest possible knowledge-sharing at European level, in the interest of consistency (since our networks are interconnected, we must ensure a harmonised approach to resilience) and efficiency (why not join forces if we have similar requirements).

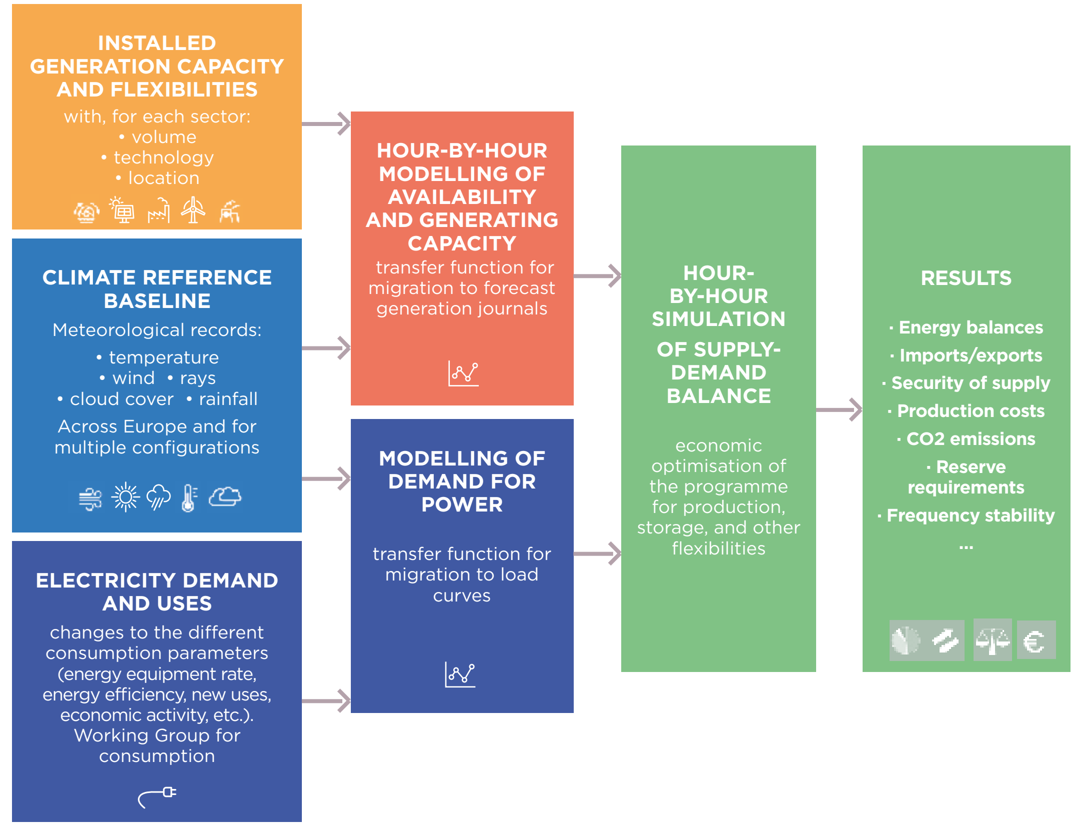


Figure: Basis of adequacy simulation using climate data to model consumption and renewable energy production.

— Objectives

Upgrade of climate databases	Update the climate databases and derived data relating to energy (transfer functions for migration to consumption and renewable energy production) to make them state of the art, taking advantage of the European ecosystem of weather services that offers lasting solutions.
Industrialisation of long-term forecast data	Develop an internal reference platform for the implementation of transfer functions and facilitate the provision of weather-related generation and consumption data in internal long-term research studies.
Analyse the impacts of weather on network infrastructures	Reduce the impacts of climate change on network infrastructures by contributing to the Resilience RTE's plan and feeding the results of external projects into the plan.
Long-term consumption forecasts	Incorporate the new consumption modelling issues (electromobility, multi-energy systems, new flexibilities, etc.) as well as new approaches to modelling for residential and tertiary sector consumption.

By definition, this roadmap cuts across different teams: R&D itself, maintenance, engineering, operation, and forward planning, in particular. It also delivers cross-functional coordination: spotlighting the question of weather, of climate, and of the long-term assumptions associated with them, promoting the emergence of a “climate community” within RTE.

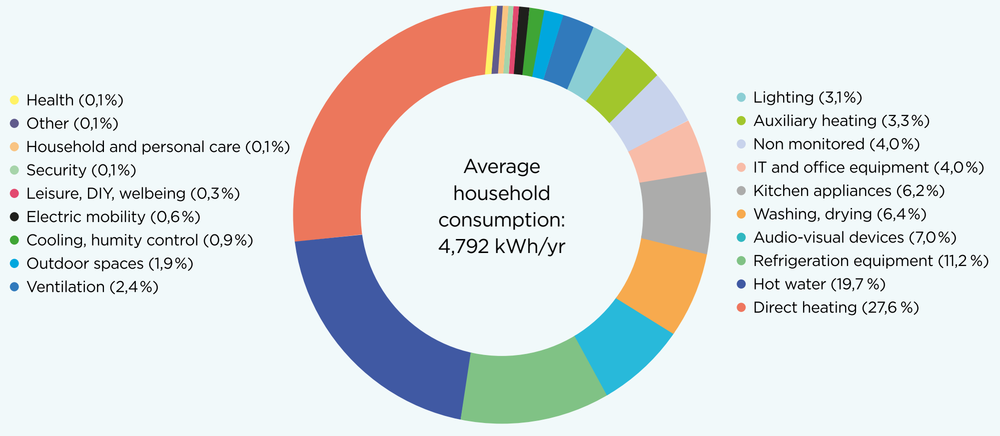


Figure: Distribution of the electricity consumption of an average household by type of use.

— Partnerships

Aside from the longstanding natural partnership with Météo-France, the objectives envisage a rational diversification towards French partners, including the Institut Pierre Simon Laplace for its foothold in the international climate community, and the École des Mines for its extensive expertise at the interface of weather, climate and energy, as well as an opening-up to the world (RTE has therefore recently become a member of the World Energy & Meteorology Council) in a bid to develop relations with several key industry partners in Europe, specifically through European research projects.

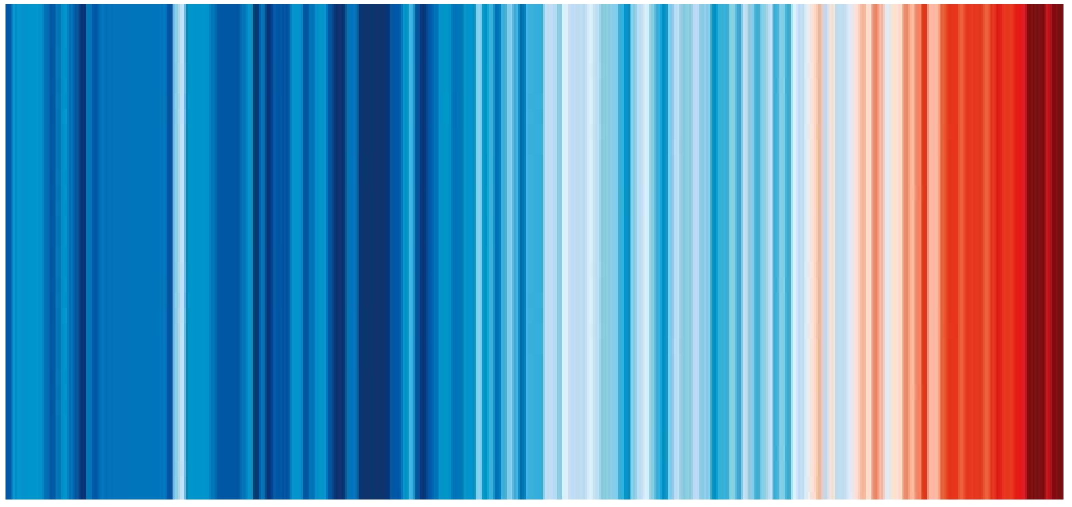


Figure: Mean temperatures in France from 1899 to 2020.

3.6.2 SYSTEM EXPANSION

— Background

The electricity system is facing many challenges at a turning point where RTE must:

- **adapt** to the changing context: the emergence of largely decentralised and fluctuating renewable energy production, new forms of consumption such as electric mobility, increased interactions with other energy sources and hydrogen in particular, the plan for strengthened interconnections, restructuring and pooling opportunities in the course of renewing network assets, Europe’s Green Deal targets for 2050;
- **get the maximum potential** out of the different structural and flexible solutions that are available, and whose range is expanding: network solutions such as dynamic line rating and new controllers, as well as solutions offered by methods for storage and demand control;
- **determine** future investments in the network against a backdrop of great uncertainty, modelled by a variety of possible scenarios.

— Ambition

Faced with these challenges, R&D is rallying around to speed up the process for improving the methods, policies, tools and data used, and to address the new issues in-depth, applying a cross-cutting perspective and a forward-looking approach, supported by research partnerships. The objective for the coming decade is for RTE to be better able to make and justify possible decisions regarding the operational development of the network to support the current energy transition – reduction in environmental impact, resilience, and expected quality of service at controlled cost, etc. This will require significant changes to some practices with the aim of adapting to a public network usage that is shifting fast with the current disruptions to the energy system, and of anticipating network developments through forecasting, in accordance with the scenarios set out in the Adequacy Report for 2050. The conclusions of this work will be used and summarised in future Ten Year Network Development Plans.

Sector restructuring

In some sectors under review, researchers are dealing with an increase in the possible combinations of strategies for asset constraints or other asset management issues. The opportunity then arises to undertake an in-depth restructuring of the sector.

A prototype was developed and then deployed in January 2021 to enhance the analyses performed by operational engineers, and to ensure that their decisions are objective (classification of the least costly strategies and spelling out of the strategies).

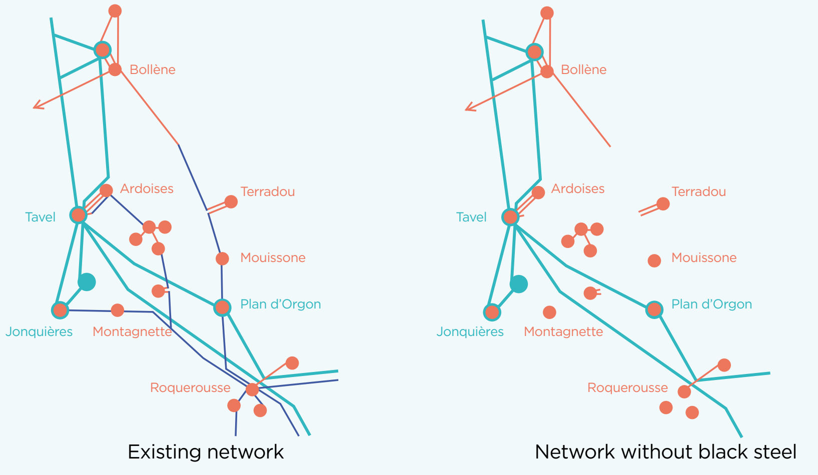


Figure: Example of area restructuring (in this case, elimination of black steel).

— Objectives

Change in decision-making processes with the management of hazards and uncertainties	Apply innovative solutions to overcome the difficulties linked to the implementation of policies and methodologies, using a multi-situation process to manage hazards and take better account of future scenarios that are increasingly changeable and subject to uncertainty.
Exploration of new network architectures: from local to global	The boom in decentralised renewable generation promotes the emergence of local ways of thinking in a spirit of reduced dependency. R&D's research into a local-global system explored the topic of levels of system balance, without however studying the network aspects. In this context of great uncertainty as to the more or less centralised nature of the future electricity system, the objective is to assess possible network infrastructures in terms of infrastructure and cost, and to answer a number of questions, including: What use is a transmission network in a scenario of "balanced regions" in respect of annual energy or of power at a much more local level? What are the options for the transmission of offshore wind power from the North Sea to the rest of Europe?
Model system operation in network development studies	The development of flexibilities gives rise to changes in electricity system operation and provides new opportunities that can be incorporated into the development of the network, with a view to finding the right balance between flexible solutions and structural solutions.

3.6.3 MODELLING OF LONG-TERM ADEQUACY

— Background

Assessing the adequacy of a given generating fleet with projected consumption, factoring in the hazards that may come into play, both weather hazards and hazards that are specific to the electricity system, is essential for any power system operator, so as to guarantee the supply of electricity (winter/summer seasonal changes) and inform public decision-making with regard to energy planning (adequacy report, TYNDP, etc.). The effects of the energy and ecological transition, the new interconnections, European regulations (Clean Energy Package), improved technologies, shifts in lifestyles that influence energy uses (flexibilities, reserves, batteries, power-to-X, environmental indicators, etc.) all increase the need for medium- and long-term probabilistic studies using methods, models and tools still to be developed.

— Ambition

The aim of the roadmap is to continue to meet the need for models and tools for RTE's supply-demand balance and network investment studies, to improve them, and to move them in the direction of industrial developments available to all. In doing so, this roadmap seeks to ensure that the operational teams continue to be equipped in their effort to ensure consistency between national and European studies, be they supply-demand balance or investment studies.

Changes in energy balances in France (in TWh)

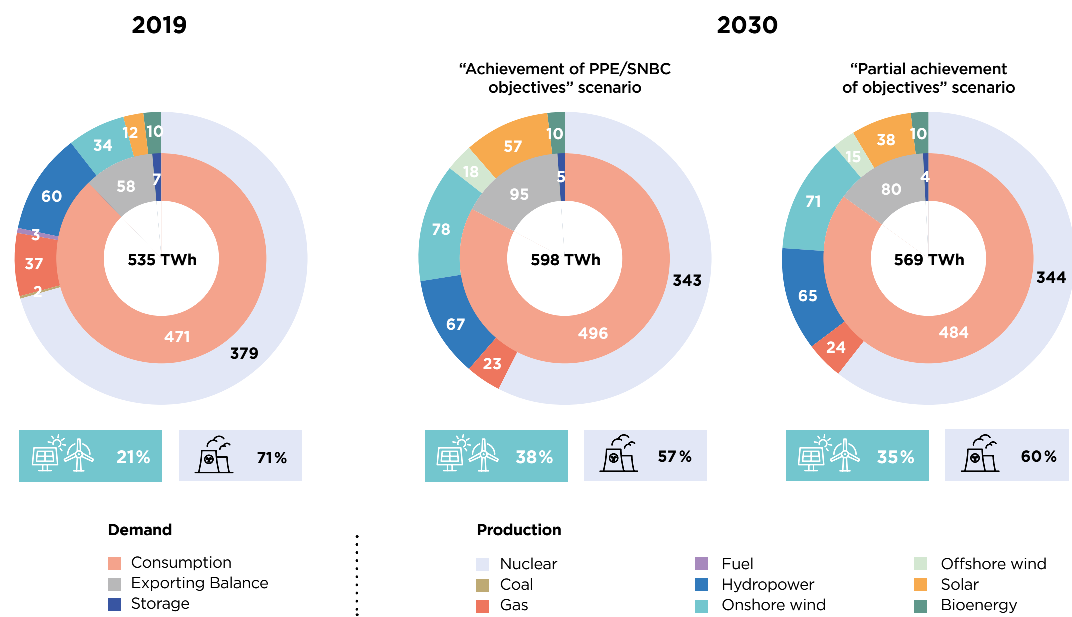


Figure: Changes in energy balances in France, as modelled by the Antares software.

— Objectives

Changes in the modelling of the electricity network's assets	Meeting the challenges of the energy transition requires high-quality research studies, using modelling that is as close as possible to reality for renewables, thermal units, batteries, and all the new installations that are currently not taken into account or are inadequately taken into account by the Antares software (developments in the nuclear fleet, hydroelectric fleet, maintenance of thermal units, multi-energy systems, etc.).
Enhancement of the network investment module Antares expansion	Incorporate innovative AI concepts and machine learning into the optimisation algorithms for economically optimal generating capacity and network capacity.
Reinvestment in models for supply-demand balance studies; creation of a new tool adapted to changes in the energy landscape	Develop a new tool for supply-demand balance and network investment research studies, combining different energy carriers, in order to respond to changes in the national and European energy landscape..

3.7 CROSS-CUTTING R&D ACTIVITIES

This programme incorporates two cross-cutting roadmaps that are intended to feed into all six functional programmes presented previously.

3.7.1 DIGITAL SOLUTIONS TO OBSERVE, FORECAST AND DECIDE

— Background

The question of "digitalisation" is ever present in our developed societies. Some claim that data is the new fuel driving our economies (https://www.economist.com/briefing/2017/05/06/data-is-giving-rise-to-a-new-economy) and others that effective data management may be the solution for building more efficient and resilient systems[12]. In addition, understanding the impact of digital technology on our electricity systems is a key issue for the coming decade. The question is in two parts. First, "How does "digital technology" alter the processes governing the production and consumption of electricity, or indeed of energy"? Second, "How can we use digital technology to better[13] manage and develop the electricity system"? We will only address the issues relating to the core business of RTE, and the question of "digitalisation" of support functions does not fall within the scope of this roadmap.

Our traditional approach has been to build a physical system (infrastructures) and subsequently to add increasingly digital and complex layers of management. At the present time, the availability of immense data processing computing power and of broad communication bandwidths at significantly lower cost[14], is leading to the mass deployment of digital solutions, from embedded solutions (smart sensors, IoT, etc.) to GAFA clouds. These solutions will play a key role in the operation of the system, its efficiency, but also its resilience. We must rethink the idea that the system is a system of cyber-physical systems, and come up with a design blending physical and digital layers.

The objective is to understand the different facets of this digitalisation that will impact the entire value chain as well as our ecosystem: from the system's architecture, and even its governance (local/global, peer2peer, Europe/nation/region/town/neighbourhood/etc.), its development, its maintenance, and its operation. The potential negative effects of this digitalisation must also be subject to a cost-benefit analysis, but equally, calibrated through comparisons with the digitalisation of other sectors: entertainment, social networking, e-commerce, etc. There is a wide range of digital solutions with very different characteristics. Questions of sovereignty and cyber-security are also clearly major issues for a Critical Infrastructure Operator.

If we look at the history of technology timeline presented in the Encyclopaedia Britannica, (https://www.britannica.com/story/history-of-technology-timeline), it is striking that two of the last milestones relate to data management in complex systems: CRISPR-Cas9 for gene editing and AI with the success of AlphaGo.

This trend will undoubtedly continue and the convergence between nanotechnology, biotechnology, computing and cognitive science (NBIC) will probably intensify. These areas will also cross-pollinate by sharing concepts relating to data management. We must understand these trends and try to influence them in order to make the "best possible" use of them for electricity systems, and to mitigate or prevent possible negative effects.

(12) "Another lesson we can learn from living organisms is better management of information. In an ecosystem, information flows continuously and in every direction: through food chains, hormones, and other chemical vectors, or else through other forms of sensory communication, whether intentional or not. When grazed by gazelles, acacia trees release pheromones that are detected by other acacia trees in the vicinity, which then increase their toxin levels to repel grazers". T. Chekchak, http://blog-isige.mines-paristech.fr/2020/05/05/le-bio-mimetisme-outil-de-resilience-locale-face-a-la-crise-sanitaire/"
(13) The question of what is "better" links up with multicriteria performance, which must also be defined.
(14) These costs arguably do not sufficiently reflect many negative externalities.

— Ambition

This roadmap deals with the exploration of emerging digital and algorithmic solutions for the management of a critical system of systems such as power system; it cuts across other R&D activities, particularly in relation to subjects requiring modelling and simulation. There are several objectives:

- The digital twin[15]: the aim is to develop modelling and simulation capabilities that cut across different operational issues. This experimental topic could have several spin-off effects.

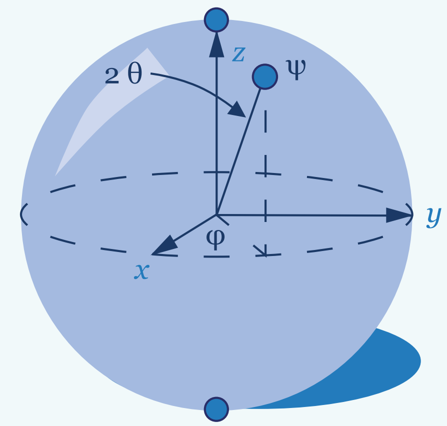
- Monitoring of "digital technology and algorithms", covering all the following layers: (1) hardware, (2) communication and architecture, (3) services, (4) programming languages, (5) algorithms, and (6) testing/validation/certification.

- Optimisation: this branch of applied mathematics plays an important role in our digital strategies. The aim is to channel and make use of the latest expertise to assist in RTE's decision-making.

(15) The digital twin is a dynamic virtual representation of a real-world physical object, system, or process. The digital twin uses data collected in real-time, simulation, and machine learning to understand, forecast and make better decisions.

Quantum calculator

It uses the quantum properties of matter, such as superposition (an infinitely small particle can be in an undetermined state before measurement) and entanglement, to perform calculations for several data states at the same time. In contrast to a conventional computer based on transistors that uses binary data (encoded by bits, with a value of 0 or 1), a quantum computer uses qubits whose quantum state can have several values at the same time. In theory, a 4-qubit quantum computer performs calculations 16 times faster than a 4-bit conventional computer: the computational power of a quantum computer doubles with every additional qubit!



— Objectives

Roadmap "Digital Solutions to Observe, Forecast and Decide"	Digital twin	The order and choice of subjects is yet to be confirmed: • Prototyping of a digital twin architecture, • Heatwave resilience study, • LCA of asset management options, • Objective assessment of RTE's overall requirements for resources for TURPE7 tariffs.
	Optimisation	• Integrate the best tools: the "modeller" serving to redirect to commercial and open source "solvers". • Develop a prototype that simulates the strong interaction between the supply-demand balance and the network, with modelling and factoring in of uncertainties, mitigations and controllers. • RTE optimisation community: training, assistance with modelling, support to projects. • Steer scientific research through hypotheses and challenges.
	Digital technology and algorithms	• "Passive" monitoring: monitor academic institutions; • "Active" monitoring: steer academic institutions towards new categories of problems or applications; • "Proactive" monitoring: engage in research on specific cases for predetermined applications. This is about "proof of concept" without being on the critical path of a R&D project more focused on "operational issues"; this is therefore more of a techno-push approach.
	AI	Steer scientific research through hypotheses and challenges in relation to the issues facing the electricity system.

3.7.2 OPEN R&D

— Background

The transformative goals set out in the CAP R&D Project will only be achieved through greater cooperation with a broader ecosystem of partners. Given the diversity of activities to be carried out, the complexities and uncertainties that each one involves, it will indeed be essential to pool resources and effortwith other stakeholders, to save time by reusing and sharing results, and to bring together the numerous skills that RTE cannot build alone. The “Open R&D” roadmap sets out to meet this challenge by designing and establishing innovative, effective and attractive collaboration methods and frameworks for governance, in order to develop the multi-stakeholder partnerships needed for the different projects.

This roadmap builds on the efforts carried out in the past years on standardisation, partnership development, and open collaboration. It is guided for example by the open source initiative initiated in 2018, which led to the creation of LF Energy, an open source foundation established in partnership with the Linux Foundation, focused on the needs of electricity systems and the challenges of energy transition.

LF ENERGY

STRATEGIC MEMBER

Figure: As at end August 2021, the Linux Foundation Energy (LF Energy), created on the initiative of RTE and focused on electricity system needs and energy transition challenges, had a total of 44 members and was home to 12 projects (www.lfenergy.org)

— Ambition

The new ways of working together to be imagined, experimented and promoted within the scope of this roadmap should ideally be designed for:

- optimum pooling of resources and efforts with other stakeholders;
- increased opportunities for reusing external results, in return for increased dissemination of the results obtained by RTE;
- seamless partnerships with innovative parties, sharing convergent interests and providing complementary skills and know-how;
- faster implementation of collaboration frameworks, avoiding lengthy contractual and administrative processes;
- better coordination with the ecosystem contributing to improved interoperability and integration beyond company walls;
- greater momentum for additive innovation, beneficial to the performance of RTE and other stakeholders in the ecosystem (French, European and international companies and institutions interacting with RTE);
- the mitigation of the risks inherent in the innovation process by increased diversity of viewpoints and pooling of efforts;
- better resource efficiency (ie sobriety) from sharing and reuse;
- greater resilience, by avoiding closed partnerships.

To meet these ambitions, the areas covered by the “Open R&D” roadmap are:

- standardisation;
- open source for software development;
- the development of partnerships and consortia and open innovation;
- open data for R&D activities;
- membership of and contribution to technical societies.

— Objectives

Standardisation	The main objectives of the work of standardisation activities are: • feeding the technical reference documents with the outcome of R&D activities and the future needs of RTE, • ensuring that relevant standards are available in a timely manner for the specification of future industrial applications, • maintaining insightful technical exchanges with our suppliers. Priority is given to two areas: • digitalisation standards, • environmental standards.
Creation of an ecosystem of partners for the co-development of open source software	The purpose is to develop a committed productive and fit for purpose ecosystem of partners, particularly in relation to the LF Energy foundation. It also entails supporting software projects with important industrial stake, to identify opportunities for open source collaboration and materialize them where appropriate.
Identification, experimentation and validation of new software development practices for open source collaboration	This activity encompasses: • internal coordination, education at all levels of the company, the sharing of best practices, feedback analysis; • the transformation of internal software development activities, which includes adapting the adaptation of skills, training and software procurement processes, as well as identifying and trying out new tooling.
Closer alignment between standardisation and open source	The intended objective is to have a greater impact on standards, with less effort, leveraging strength of open source collaborations. In turn, open source projects should be able to save time and resources by building on the standardisation work carried out.
Partnerships and open innovation	The primary objective is to support RTE’s R&D projects to identify, build and run partnerships. It also seeks to design and experiment new models of cooperation based on open innovation.
Open Data	The objective is to identify areas in which an open data approach would be conducive to the development of R&D partnerships and open innovation, and subsequently define the practical arrangements, bringing other stakeholders on board where appropriate.

— Partnerships

Partnership development efforts will focus on:

• expanding the ecosystem engaged with LF Energy and more specifically in relation with the software projects relevant to RTE;

• establishing and strengthening frameworks for cooperation with the DSOs (distribution system operators)/ (like the STAR[16] partnership with Enedis in France, for example, and the LF Energy projects in Europe);

• and more broadly, providing support to the other Cap R&D roadmaps with the organisation of partnerships and open innovation.

(16) The STAR (System for Traceability of Activations of Renewables) project, based on blockchain technology, is designed to make it easier to harness the flexibilities in renewable generation, by automating and increasing the reliability of data-processing and traceability across the whole chain, from considering the conditions for flexibility to valuing the execution.

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