Study on strategic perspectives of energy

Summary of the study

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I. Executive summary – Medium and long-term trends in the energy sector

A dozen prospective "theses" have emerged from this work. They describe a largely remodeled energy sector, under the combined effects of technological evolutions and public politics in response to climatic and social stakes.

These "theses" are obviously formulated with the expected level of humility given the medium to long-term prospects (2030 and 2050-time horizons) explored here. They constitute our best estimate of the energy sector's transformation in the face of a deeply uncertain future, and they rely on a thorough analysis of the key trends that the sector is experiencing (see "Monographs"). They were submitted to a sounding board of international energy experts, which demonstrated that while some of these theses are relatively consensual, others are more controversial (see Presentation of the Sounding Board Results document). Each of these theses was more thoroughly explored in a dedicated document (see "Theses" documents), which exposes both motives to believe in its realization and reasons to doubt it.

All twelve theses are synthetically formulated below:

1. **[Final energy demand]** – Energy consumption will decrease in Europe
   Although final energy demand will increase globally, driven by growing demand in developing countries, it will strongly decrease in Europe and in France, including for natural gas, as a result of energy efficiency policies. In Europe and in France, power demand will decrease, or at most increase slightly despite important substitutions of end uses (mobility and heat) towards this energy.

2. **[Power systems]** – Due to improved cost-competitiveness of renewable power sources, power systems will "naturally" become almost decarbonized
   Worldwide, a majority of newly developed power generation capacities will be renewable. In developed countries, very low carbon power systems (>80% carbon-free power sources) will generalize before 2050 at the latest. These decarbonized power systems will be competitive (as compared to fossil-fuel systems) in interconnected area, as in non-interconnected areas where competitiveness will be reached sooner, thanks to both lower production costs of electricity and intermittent generation enabling technologies.

3. **[Power networks]** – The need for networks will grow, even though their utilization rates will decrease
   The energy transition will greatly impact the power grids' overall equilibrium, generating both significant needs for extensive networks (to integrate a growing fraction of renewable production et benefit from a reduced intermittency in said production) and lower grid utilization rates (due to self-consumption and distributed generation). Increasingly decentralized power production will cause a drop in apparent demand from the transmission networks' point of view, but the need for interconnections will rise, to benefit from geographic and climatic compensation effects on intermittent renewable generation. These opposing dynamics create a risk of stranded assets.

4. **[Power grids planning]** – In order to prevent grid-related costs from soaring, coordinating generation and transmission (and perhaps distribution) investments will become an increasingly imperious necessity
   The shift to a high level of renewable integration will lead to an entire redesign of the power systems and networks, requiring a holistic reflection to optimize system-wide investments in generation capacities and transmission (and perhaps distribution) networks. Congestion issues observed in systems where generation assets are located far from consumption centers (e.g. offshore wind farms in northern Germany, solar and wind power generation in northern and

western China for industrial consumption centers in the East and South) are testament to the importance of the stakes.

5. **[Flexibility]** – The deployment of new flexibility tools, in response to renewable generation integration issues, will change both the nature of power grids themselves and their operations.
   Flexibility requirements will increase and will be mostly met through decentralized tools (storage, demand response, electric vehicle batteries, decentralized production) requiring the aggregation of numerous points; the distribution system operator will then become responsible for the active management of the network and the organization of local flexibility markets. The coordination between TSOs and DSOs in the operation and optimization of flexibility tools (global optimization vs local optimization) will become a critical issue.

6. **[Electricity storage]** – As a flexibility tool, battery storage will become an essential part of the power system
   Electricity storage, especially with electric vehicle batteries, will play a key role in enabling the proper functioning of low-carbon power systems with a high penetration of variable renewable energy. A decrease in battery costs, similar to the one experienced by solar PV systems, will drive this trend.

7. **[Micro-grids]** – The top-down hierarchical structure of large networks will evolve towards a decentralized model articulating patches of micro-grids.
   The combination of distributed renewable generation and colocalized battery storage will allow micro-grids, which will enable neighborhoods to locally source their power supply, to grow and be profitable in places where the economic and regulatory conditions make their development possible. In geographical areas affected by extreme weather events, such as the US, they will be deployed for their value in terms of resilience, even if they imply a premium as compared to grid electricity. In developing countries where the power grid is not fully developed yet, electrification will rely on micro-grids that will progressively become interconnected. Except in specific cases (isolated systems, lack of reliable networks, rural electrification in Africa during development phases), these micro-grids will still be connected to the main network, to benefit from demand/generation optimization.

8. **[The role of wholesale electricity markets]** – The ability of wholesale markets to send relevant price signals could be called into question. The market design will have to be adapted to introduce or reintroduce price signals or long-term contracts.

   The paradigm of wholesale electricity markets (flexible generation for a non-flexible demand) will progressively be overhauled: power production is becoming more rigid (with increasing volumes of unavoidable renewable power) while the active management of demand is making it more and more flexible. Storage capacities will improve the flexibility of both demand and generation.
   Production volumes at zero marginal cost will weigh in on wholesale prices, potentially questioning their ability to ensure full investment costs coverage (long-term marginal costs).
   Under these conditions, wholesale markets could no longer be used as a relevant long-term investment price signal – even if recent examples demonstrate that investments in large renewable infrastructures based on market price signals are not impossible. On the other hand, the development of flexibility tools like storage and demand-response could reinforce the relevance of market prices. The wholesale market will in any case continue to be used to optimize dispatching according to economic criteria.

9. **[Gas systems]** – In Europe, gas infrastructures will continue to play an important role, in particular as enablers of the energy transition

In Europe, gas infrastructures will continue to play an important role thanks to various drivers: a shift towards “green” gas, the growth of its utilization for mobility, a still important contribution of gas to meet winter peak demand in addition to low-carbon electricity. However, decreasing demand for natural gas will prevent new infrastructure investments from being considered, except for security of supply concerns or to enable biomethane grid-injection (reverse flow plants, etc.).

10. **[Hydrogen]** – In the long term, a hydrogen economy could emerge
    In the long-term and provided a decrease in technology costs, hydrogen could emerge as a prominent vector in energy systems, enabling energy storage and importation from geographical areas with low renewable production costs (e.g. Chile, Mexico, Australia or the Middle East for solar PV) to large consumption centers. Hydrogen could provide a relevant solution to specific requirements on certain mobility segments, and most of all to the massive decarbonization of power and gas systems, in conjunction with renewable power generation.

11. **[Consumers and suppliers]** – Emerging technologies will allow consumers to take control of their energy supply and consumption
    Many alternatives to the “classic supplier” will be available to consumers for their energy supply. Self-producing private individuals or SMEs will grow in numbers, reaching several millions in each large European country. They will be able to procure electricity via peer-to-peer platforms (using blockchain technology for example), allowing them to choose their supply of energy from identified and localized sources (short circuit logic) and/or to sell their own excess production. For larger companies, long-term power purchase agreements signed directly with renewable energy producers will spread on a large scale in all developed countries. Innovative demand management solutions (Big Data, IoT, smart-metering, Artificial Intelligence) will provide private as well as corporate consumers with new opportunities to control their consumption.

12. **[Pace of change in the industry]** – Driven by innovative technologies and social as well as environmental stakes, the pace of change in an industry traditionally characterized by a high degree of inertia will accelerate considerably
    Cost reductions (PV, batteries) and technical improvements (size and power of new-generation offshore wind turbines) in various renewable technologies have considerably accelerated in the past few years. Information technologies (blockchain, big data, IoT, smart metering, Artificial Intelligence) add to this trend as they establish themselves in the sector. These dynamics are actively reshaping, at an unprecedented pace, an infrastructure-rich industry characterized by long time constants, which results in potential risks of stranded assets.

II. Reflection paths for the regulator

This study provided some perspective on the work of the regulator by setting a medium and long-term horizon. Twelve issues were chosen to propose national (and perhaps European) level regulatory approaches, to adapt to a rapidly changing sector:

1. **In France as in Europe, adjusting regulatory approaches to account for a faster deployment pace of innovative technologies (storage, flexibility, metering, data, …) and their impacts on operators**

   It is essential that system operators holding a monopoly be incentivized by regulatory frameworks, especially tariff-related, to innovate and use all available modern technologies to continuously improve their performance in terms of costs and quality of service. Although regulatory approaches have evolved in the past few years, with the generalization of incentive regulation, additional changes to implement will need to be evaluated, for operators to be properly incentivized to adapt to continuous and fast-paced rather than incremental change.

2. **Generalizing framed experiments to answer the complexity of emerging market design issues, through approaches such as the « regulatory sandbox »**

   Beyond the overall objective mentioned above, highly complex emerging questions will have to be dealt with and should be anticipated as early as today: aggregating and valuing millions of distributed flexibility sources for the electric system, optimizing the charge and discharge of millions of electric vehicles, coordinating TSO and DSO activities to better integrate renewable energy into the grid and to better use of flexibility sources available for various needs, etc. Regulatory activities will increasingly need to make room for framed experiments to deal with this new complexity, using approaches such as the “regulatory sandbox”.

3. **Deploying a regulatory framework allowing for improved coordination between new generation capacities deployment and network development**

   The energy transition and the consequent changes (rapid deployment of renewable intermittent capacities, improved energy efficiency, self-consumption development, etc.) constitute a challenge for network operators, as they might bring into question their historical balance. Network operators could be faced with new types of investments (for example to deal with reverse power flows from the distribution grid to the transmission grid, and to develop interconnections to better integrate massive intermittent renewable generation, provided it is justified by a cost-benefit analysis), while the net withdrawals by downstream networks could decrease.

   Such an equation could result in an increase in grid utilization tariffs. In this context, the optimization of network investments should be carefully examined. The lack of coordination between new generation capacities deployment and network development can be the source of significant extra costs, as the example of Germany demonstrates: congestion management costs have soared in the past few years (~1 Bn€/yr) in the country, where the development of renewable capacities is more advanced than in France.

   Consequently, the regulator will need, on the one hand, to reinforce transparency on the cost of the energy transition for networks, and on the other hand to improve the coordination between generation and network development, to optimize the overall cost of the energy transition.

4. **Exercising caution in new gas system investments (except those related to security of supply or green gas development), to avoid stranded costs if low gas demand scenarios were to realize**

   Given the current trends affecting natural gas in Europe (energy efficiency, substitutions of end-uses towards electricity, uncertainty over the role of natural gas in the electricity mix), some gas

infrastructures in Europe face a long-term risk of strongly diminishing use rates. This drop raises the question of natural gas solutions competitiveness (with lower demand resulting in rising unit costs of transport and distribution from each customer's point of view), and of the risk of stranded assets. This situation commends an elevated level of caution as far as new investments are concerned (except for investments related to security concerns, modernization of existing infrastructure or green gas development, e.g. reverse flow infrastructure), to avoid the appearance of new stranded costs, should low gas demand scenarios come true.

5. **Improving the quality of economic signals conveyed to economic actors, to avoid long-term and costly repercussions of faulty mechanisms**

   These economic signals can either be market prices or tariffs. They can include fiscal components, which are outside the scope of the regulator. Conception errors on these signals, preventing them from reflecting the reality of costs – including capital and risk remuneration – can result in investment decisions by economic actors which are sub-optimal for the community, with potential long-term repercussions.

6. **Applying these principles to the case of self-consumption**

   The case of self-consumption can illustrate the issue. Although still emerging in France, it is already an established trend in many developed country (residential self-consumption in particular), and one that should grow rapidly in France and abroad. This development raises the issue of fairly reflecting the costs avoided or generated by the self-consumer, especially in terms of grid access tariff structure and/or sales tariffs, as well as taxation terms. As of today, the regulatory framework should avoid future (and potentially significant) developments be based on faulty or biased economic signals, which would generate over costs for the electric system as a whole. It should also reconcile encouraging self-consumption development with principles of equity and national solidarity, to limit the transfer of value between consumers, especially in favor of wealthier ones.

7. **Ensuring that the market configuration produces relevant long-term economic signals for investments.**

   The shift towards a majority of electricity produced at zero marginal cost could destabilize and render unpredictable the spot market price – even though recent examples demonstrate that investments in large renewable infrastructures based on market price signals are not impossible. While these technologies become more profitable, thus justifying a growing share in the energy mix, reflection over the appropriate market design must continue, to facilitate the emergence of long-term price signals allowing producers, suppliers and consumers to hedge price risk. These assurances will allow for secure funding of new investments in generation, in the industry, and in innovating energy efficiency solutions for consumers.

8. **Facilitating the emergence of incentive mechanisms other than subsidies, relying as much as possible on market-based mechanisms, to encourage renewable energy development**

   Given the new competitiveness of renewable technologies, appropriate incentive mechanisms (e.g. facilitating corporate PPA, prioritizing auctions – vs. subsidies with no capacity limit – with requirements reflecting the overall cost of energy integration if need be), should be substituted to subsidies, which could become irrelevant, in order to ensure the best economic efficiency.

9. **Setting up a governance allowing for coordination between TSO and DSO operations when mobilizing distributed flexibility resources**

   Distributed flexibility tools (storage, demand-response, EV batteries, distributed generation) will play an important part in the management of growing flexibility needs resulting from the energy

transition. Distribution system operators will increasingly need to actively manage the grid, and perhaps to organize local flexibility markets. However, these distributed resources will also be able to meet the national-level needs of the power system, through their large-scale aggregation.

In that context, coordinating TSOs and DSOs in the operation of flexibility resources (global optimization vs local optimization) will become a critical issue for the regulator, that could require the implementation of adequate governance.

10. Improving the coordination between operators and actors of the electric and gas systems, to facilitate an overall approach to the development and operation of the energy system

In all likelihood, gas will continue to play an important role in the energy transition and in the future energy system. Gas itself will be greener, in the shape of biomethane or gas synthesized from renewable electricity (Power-to-Gas). Gas infrastructures represent a necessary potential for the supply of winter peak demand. Gas-fired power plants remain an unparalleled source of flexibility for the power system.

In the context of a changing energy system, in which interactions between gas and electricity will grow increasingly varied and complex, the regulator will need to reinforce the coordination between actors of the electric and gas systems, and to promote a holistic approach to the energy system.

11. Allowing for distributed storage development

Confronted with the potential of distributed storage, the regulatory framework should make its development possible wherever it can create value. Unless it is technically impossible, distributed storage and in particular EV batteries must be able to access all segments of the electricity value chain: wholesale markets (futures, intra-day, and balancing markets), grid services (frequency regulation, congestion management), capacity markets, etc.

12. Ensuring consumer trust in the context of a rapidly evolving sector

The regulatory framework should contribute to avoiding risks of negative perception by certain consumers, in the context of new technological deployment (Linky) or of new processes in the sector (crowd-funding of renewable capacities, demand-response, etc.). These changes cannot be synonymous of price volatility, economic loss, risk on personal data, etc. To that effect, the energy regulator should make sure to bring about, in any way possible, a collaborating approach with other regulators involved in the energy transition (ANSSI, CNIL, etc.).

III. Appendices

A. Background and objectives of the study

The energy sector is undergoing major upheavals in Europe and around the world as a result of two real revolutions. On the one hand, the energy transition changes the landscape of electricity generation and modifies the generation mix. The need to reduce CO2 emissions leads to limiting the share of fossil fuels, while the consequences of the Fukushima accident weigh on the economic fundamentals of nuclear production. At the same time, intermittent renewables, as well as energy storage technologies, are seeing their production costs drop dramatically. On the other hand, the digital revolution is transforming all the components of the energy sector. The multiplication of available data, thanks in particular to the roll-out of smart meters, goes hand in hand with the exponential development of the processing capacity of this data. The ways to operate and maintain networks, the understanding of consumer behavior and expectations, and the ability to control equipment intelligently, are profoundly altered.

These major developments create a particularly uncertain future and challenge the functioning of the energy markets.

In this context, the objective of this study was to analyze, in Europe and worldwide, the changes taking place in the energy sector to better know and anticipate foreseeable medium and long-term changes. The work carried-out was in particular aimed at confronting observable trends in France with that observable abroad, in and outside Europe.

Various sources of information were used to carry out the analysis, and specifically:

- A review of recent literature on all segments of the energy sector (with a European and global prism) and an analysis of recent communication from private and public actors in the sector.
- The consultation of over 80 qualified individuals from the energy sector – *French, European, and from around the world* – who were asked to share their personal opinion on the topics explored **(the "Sounding Board").**
- Feedback and information collected from about 30 international private and public actors interviewed during **two study missions carried out in California (USA) and China**.
- E-CUBE Strategy Consultants' knowledge base and expertise, as well as specific analysis carried out within the scope of this study (based on publicly available sources).
- The knowledge base and expertise provided by the French Energy Regulator departments involved in this study.

The purpose of publishing the results of this work and prospective analysis is to provide public authorities, and more generally actors of the energy sector, with decision-support information on potential long-term trends.

Key messages emerging from this study are presented in the summary included hereafter. The full study is constituted of several deliverables, listed and presented in paragraph III.

B. Methodology

The first phase of the study focused on structuring the key sectorial dynamics around nine topics, ensuring a full coverage of the value chain:

1. Power mix (competitiveness of renewable generation technologies and consequences on power systems)
2. Electricity storage
3. Power networks
4. Suppliers and energy services
5. Final energy demand
6. Gas infrastructures
7. Gas and power systems coupling
8. The consumer in the energy transition
9. Greenhouse gas emissions and carbon pricing mechanisms

Each of these topics is the object of a **monograph,** which describes the working dynamics and compiles the most up-to-date information and data (costs, deployment levels, etc.), thus providing a situational analysis as well as medium and long-term prospects for these topics. Prolonging the observed trends into medium and long-term prospects, whenever possible, has essentially been an exercise of finding consensus where it existed, and defining areas of uncertainty in order to shed light on the scope of possibilities. Case studies from different countries complete and illustrate these monographs.

The work conducted to write these monographs drove the project team to formulate **"theses"** regarding the key changes that may take place the energy sector in the medium and long-term. These "theses" are obviously formulated with the expected level of humility given the medium to long-term prospects explored here: in the face of a deeply uncertain future, they constitute our best estimate of the energy sector's coming transformation.

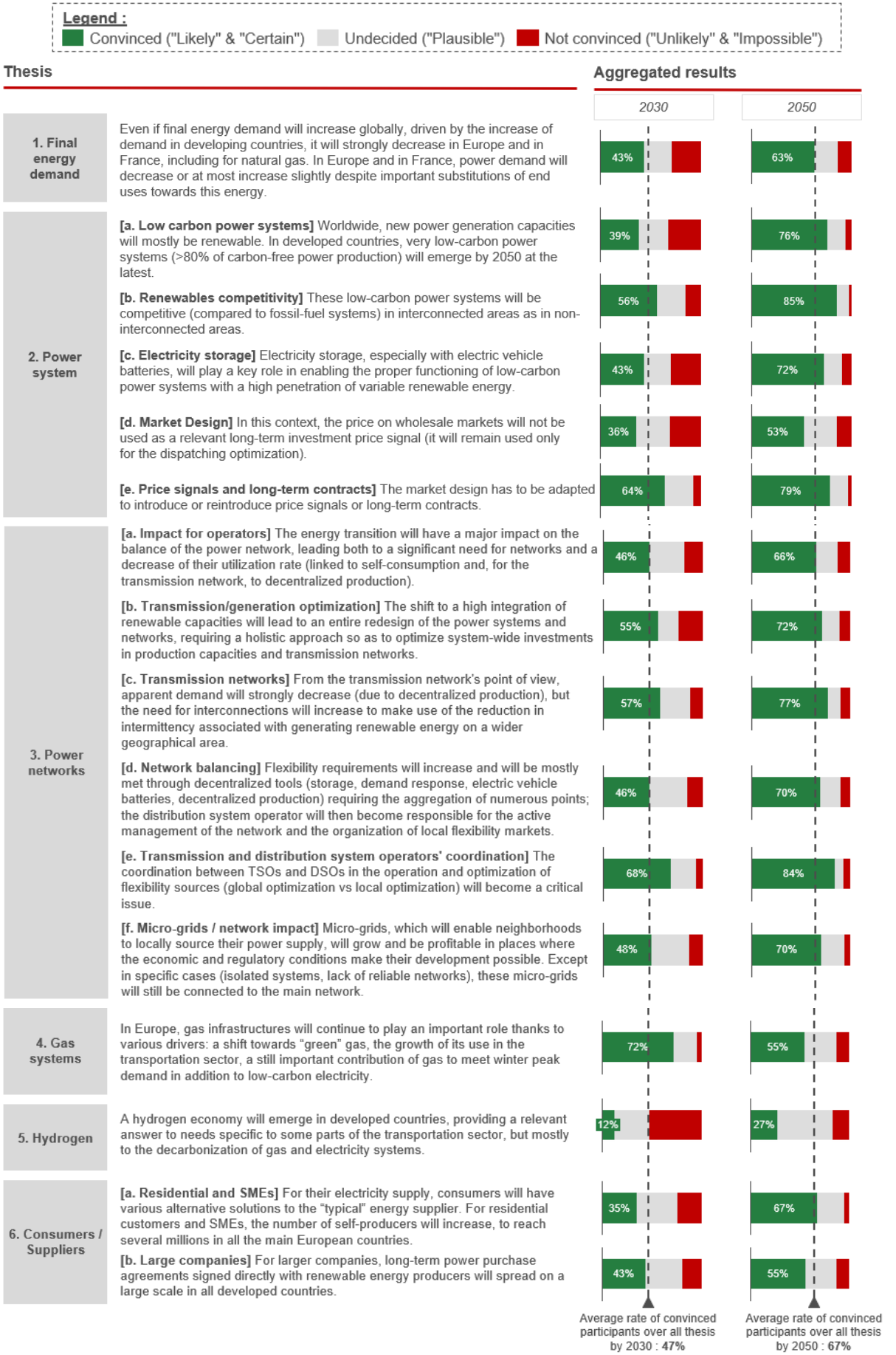
In order to characterize the level of uncertainty surrounding these "theses", they were submitted to a sounding board of over 80 international experts. The result from their evaluation points out topics on which opinions converge towards a consensus, and those on which uncertainties are more tangible. This evaluation also sheds light on divergences of opinions between respondents according to their geographical origins or professional interests.

Finally, each of these theses is the object of a thorough argumentation in a dedicated document, allowing the reader to appreciate the conditions that would lead to its realization and to forge its own informed opinion.

C. Results from the international experts sounding board

These theses were submitted to the evaluation of a sounding board of over 80 experts from the energy sector, French, European and from around the world. These experts have answered in their own name (and not that of the entity they represent or work for), by assessing the credibility of the formulated theses, first in the medium-term (2030), and then in the long-term (2050). The complete evaluation by this sounding board is detailed and analyzed in a dedicated document. Key results and messages from this opinion survey are presented below:

Summary of statistical results



Key messages from the Sounding Board

Several consensus areas emerge for the experts' answers. A large majority of the panel is convinced:

- of the major role of transport and heat electrification in the evolution of final energy demand, both for all energy products (due to lower demand for petroleum products) and for electricity (due to the offsetting of energy efficiency efforts),
- of the appearance, in the long term (2050), of decarbonated electrical systems with more than 80% or renewable generation, and the competitiveness of these systems compared to fossil fuels (including in interconnected areas),
- of the need in this context of a market design overhaul to introduce long-term signals,
- of the need in the medium and long term for better coordination between TSOs and DSOs on the one hand, and between the development of generation facilities and networks on the other, in order to optimize the development of future electrical systems and to develop new sources of flexibility,
- of the need to develop interconnections for the integration of renewable generation.

On the other hand, the majority of the panel interviewed seems unconvinced, even in the long term, of the development of an economy in which hydrogen plays a significant role in the future energy mix: this thesis is the only one to gather a majority of negative opinions by 2030, and a majority of respondents are undecided (which translates into a majority of "Plausible" opinions) by 2050.

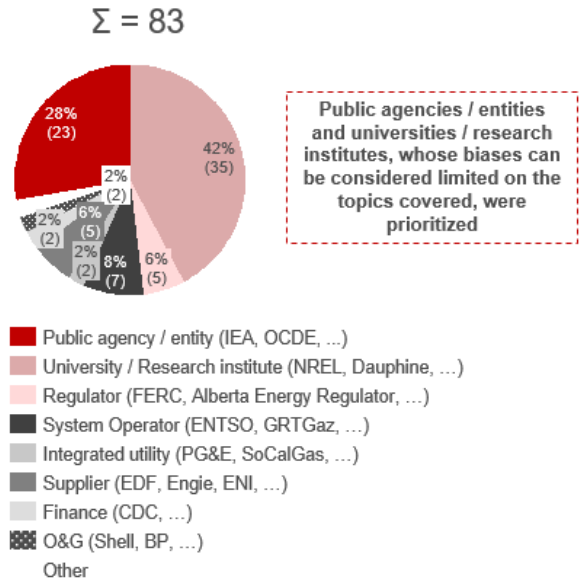
Finally, some other issues raise a debate. The opinions expressed are particularly divided on two important points:

- The decline in network energy consumption (gas and especially electricity) in Europe: opinions differ, in particular for electricity, on the compensation effects between energy efficiency efforts and the electrification of final energy uses.
- The long-term role of the gas system and its infrastructure in the energy mix: while the fact that the gas infrastructure will continue to play an important role by 2050 gathers a majority of positive opinions, uncertainties emerge, with a percentage of unconvinced or undecided respondents totaling 45%, compared to only 28% by 2030.

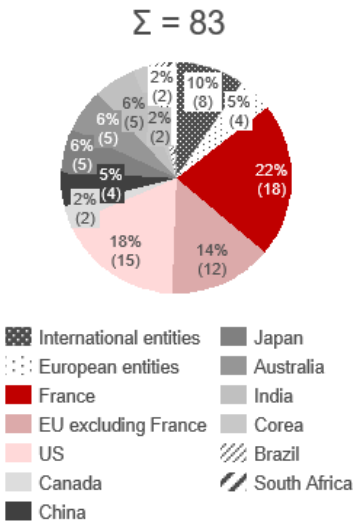
D. Description of expert panel

The surveyed experts were selected to represent all geographical areas. French respondents represent about 20% of the panel surveyed, as do American respondents. The rest of the panel is divided between: 25% respondents in the Asia-Pacific zone, 15% from Europeans outside France, 15% from international or European entities, and 5% from other countries.
A significant diversity of players in the sector is represented, but the academic or institutional profiles, which in principle have a more limited bias with regards to the issues addressed, have been deliberately targeted as a priority. They represent about 70% of respondents.

Breakdown of participants by category



Geographical breakdown of participants



E. List of study deliverables

The full study consists of the following deliverables:

- **Monographs (<u>9 documents</u>)**: these 9 documents, organized according to key topics, describe the changes taking place in the energy sector and observable trends concerning each analyzed topic. The analysis carried-out is based on benchmark elements and a review of recent literature.
    1. Compared competitiveness of power generation technologies
    2. Electricity storage
    3. Power networks
    4. Trends in energy supply and services
    5. Change in final energy demand *(including competition between natural gas, electricity and other energy sources, and trends in mobility-related energy demand)*
    6. Gas infrastructures
    7. Gas and power systems coupling
    8. The consumer in the energy transition *(in particular the participation of the consumer in energy production and grid balancing)*
    9. Greenhouse gas emissions and carbon pricing mechanisms

- **Developed « Theses » (10 documents)**: the analysis of changes currently taking place in the energy sector brought us to formulate “theses” describing the possible (and deemed most likely) medium and long-term development on each segment of the sector’s value chain. Each thesis is the object of a dedicated document presenting a detailed argument: reasons to believe in this vision for the future (arguments “in favor” of the thesis) as well as reasons to qualify, question or contradict this vision (arguments “against” the thesis).

- **Presentation of the Sounding Board results: (1 document)**: in addition to the argumentation developed for each thesis, we also requested the opinion of a sounding board, composed of over 80 French and international energy experts, on theses visions for a potential future. The experts have answered in their own name (and not that of the entity they represent or work for),

by assessing the credibility of the formulated theses. The complete evaluation by this sounding board is analyzed and synthesized in a dedicated document.

- **Study mission reports (2 documents):** these two documents synthesize the feedback and information collected from about 30 international private and public actors interviewed during two study missions carried out in California (USA) and China.