2. Overview French Electricity System

In order to be able to analyse the French capacity mechanism, a view on the context in which it was implemented is required. For this purpose, the electricity system of France is presented to point out essential characteristics, interactions and interdependencies. Firstly, the supply side is investigated, followed by the demand side. In a second step, possible future issues for the short-term security of supply and the long-term generation adequacy are identified, leading to the justification for the implementation of a capacity remuneration mechanism in France.

2.1. Supply Side

Like in many other European countries, the electricity supply in France was considered a natural monopoly for a long time. Thus, historically the electricity system was organized in a monopoly structure and regulated by the state. The monopolist EDF (Electricité de France) operated the generation and transmission system in France for several decades. In the course of the liberalisation of the energy markets, EDF was decoupled and vertically divested, to guarantee competitive markets and to avoid market distortions. In 2000, RTE (Réseau de transport d'électricité) was founded as the French transmission system operator (RTE 2017a). However, despite being organizationally decoupled and part of a liberalised energy market, the strong structural links between the French state, EDF and RTE remain until today. The French state holds 83.1 percent of the shares in EDF (EDF 2017), EDF holds 50.1 percent of the shares in RTE (CNP 2016). Thus, it can be concluded that the traces of the past remain until today.

The today installed production capacities in France too show a strong mark of the past market system. Considering nuclear energy as the mean to provide cheap and safe baseload electricity to the French population and economy, many nuclear power plants were commissioned by EDF in the 1970s and 1980s, to satisfy the growing electricity demand of France. Between 1976 and 1988, almost 50 GW of nuclear power plants were commissioned

E. Kraft, *Analysis and Modelling of the French Capacity Mechanism*,
BestMasters, https://doi.org/10.1007/978-3-658-20093-0_2

by EDF (Platts 2017), being the most important part of France's electricity supply until today. In total, there are 63.3 GW of nuclear power plants by today, operated by EDF (RTE 2017b). However, the rapid expansion of nuclear energy in the past leads to substantial challenges for the future energy system, since from 2026 on within fifteen years more than 50 GW of nuclear energy will become older than 50 years. Thus, major new investments or overhauls to extend the lifetime will be required in the future. Zimmermann et al. (2017) illustrate the imminent investment and overhaul requirements using an hypothetical lifetime of 50 years for nuclear power plants (see Figure 1).

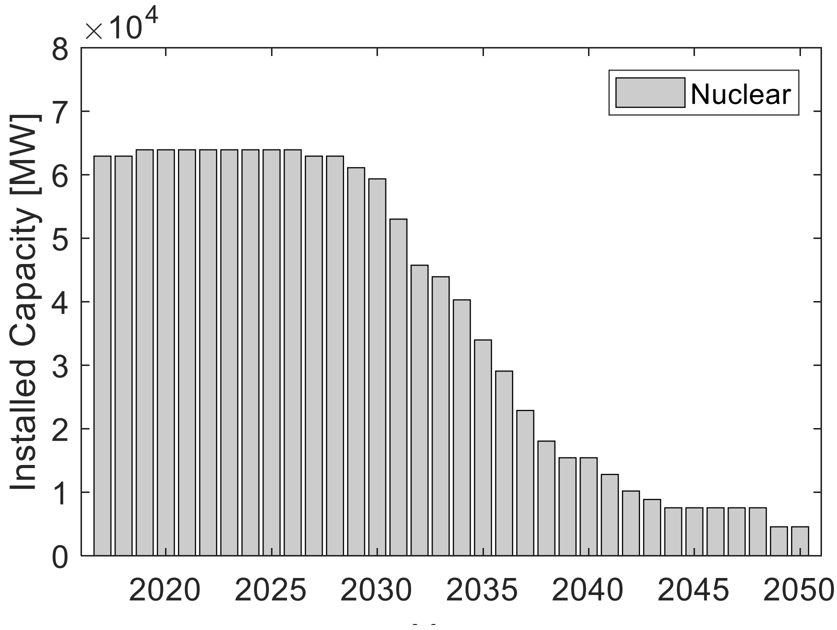

Figure 1: Installed nuclear capacity in France assuming a technical lifetime of 50 years (adapted from Zimmermann et al. 2017).

The installed generation capacity in France and the electricity mix are shown in Figure 2 below. In 2016, the nuclear generation capacity of more than 63 GW makes the major share of the installed capacity and contributes to the electricity mix to more than 75 percent. The second largest installed capacity comes from hydro power with 25 GW. Non-hydro renewable energies and fuel-fired thermal power plants have a minor share in the installed capacity. All fuel-fired thermal plants combined amount to roughly 20 GW, from which a large share are oil-fired or decentral generation units. The share of fuel-fired technologies in the electricity mix is very low compared to Germany, only amounting to less than seven percent.

Conclusively, the French electricity system shows clear traces of the past. The dominant market position of EDF as the former monopoly company is still outstanding, as well as the nuclear share in the electricity provision. Even if French energy markets are organised as a liberalised energy market today, the entire energy supply relies essentially on EDF and its nuclear power fleet.

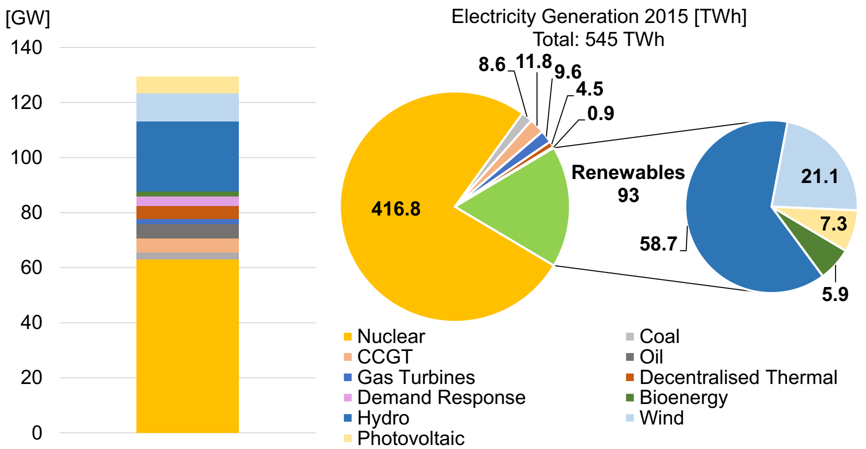

Figure 2: Installed Capacity in France 2016 and French Electricity Mix of 2015 (adapted from RTE 2017b).

To avoid an abuse of the market power and to generate a level playground for competition on the retail market, EDF is obliged to offer a share of its nuclear electricity to market competitors to same economic conditions. The ARENH (accès régulé à l'électricité nucleaire historique, French for: regulated access to historical nuclear energy) scheme, which was introduced by the NOME (nouvelle organisation du marché de l'électricité, French for: new organisation of the electricity market) law in 2010, states that retail companies can buy base-load bands from nuclear energy from EDF according to the load of their connected end consumers at a regulated price. The total volume of the ARENH electricity is capped at 100 TWh, thus roughly a quarter of the total nuclear electricity generation. The price is regulated by CRE (Commission de regulation de l'énergie) and published. Consequently, instead of buying on the spot market, retailers can buy nuclear energy directly from EDF. However, the price, which was determined to 42 € per MWh was more expensive than spot market prices for baseload recently. Thus, the regime was hardly used by any market player.

Nevertheless, for two reasons ARENH electricity is gaining importance again. Firstly, ARENH electricity is also accompanied with the respective capacity certificates, making it more attractive as additional revenues from the capacity market are generated. Secondly, expected future scarcity situations lead to increasing electricity prices on the wholesale markets. Especially in the past winter of 2016/2017, when several nuclear power plants had unplanned outages and prices were forecasted to be high the period of peak demand, many suppliers decided to buy ARENH electricity to decrease their risk, expecting high and volatile prices on the wholesale market.

The future development of the French electricity system's supply side is characterised by a strong expansion of renewable energies. According to SRCAE (schémas régionaux du climat, de l'air et de l'énergie), the government regional development plan for renewable energies until 2020, especially wind and photovoltaic capacities will increase substantially (Figure 3).

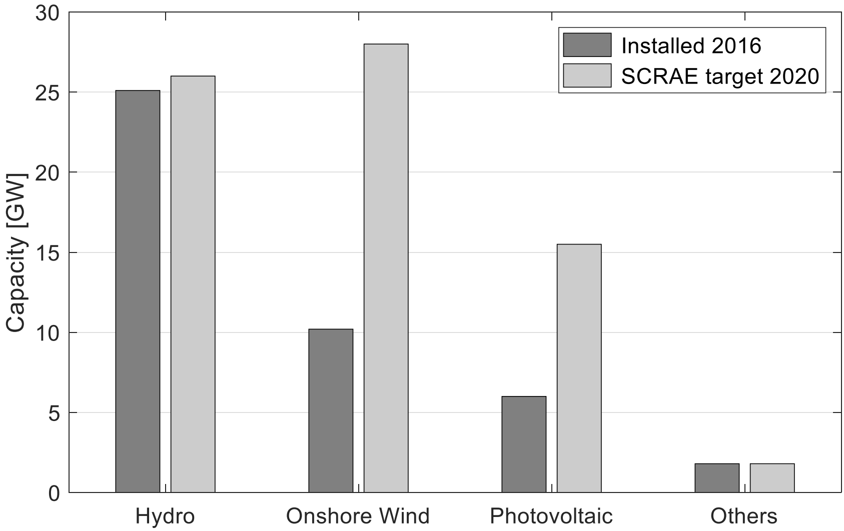

Figure 3: Targets for hydro, wind and photovoltaic power (left to right) of SRCAE until 2020 (own illustration based on RTE 2017b).

The renewable generation shall replace nuclear generation. As stated in the Green Growth Act of 2015, the share of renewable energies in the French electricity mix shall increase from currently 17 percent to 40 percent in 2030. Parallel, the installed nuclear capacity must not exceed the current 63.3 GW and the share of nuclear generation in the electricity mix shall decrease to 50 percent until 2025 (MEEM 2015). Whether and how these target will be met remains to be seen in the future.

2.2. Demand Side

The French electricity consumption in 2015 amounted to 479 TWh. With 34 percent, the residential sector has the largest share in the overall consumption, followed by the tertiary sector with 29 percent and the industrial sector with 24 percent. Agriculture, energy and transport contribute with the remaining 13 percent. (RTE 2017b)

The characteristics of the French demand, that are particularly important for the present work, are the strong seasonality and the temperature-sensitivity of the French load, which is mainly caused by heating use in the residential and the tertiary sector. As shown in Figure 4, the French load during summer is expected to be below 50 GW, whereas it increases strongly in the winter months. In winter, depending on the outside temperature the heating load can vary between 5 GW and 45 GW (RTE 2017b).

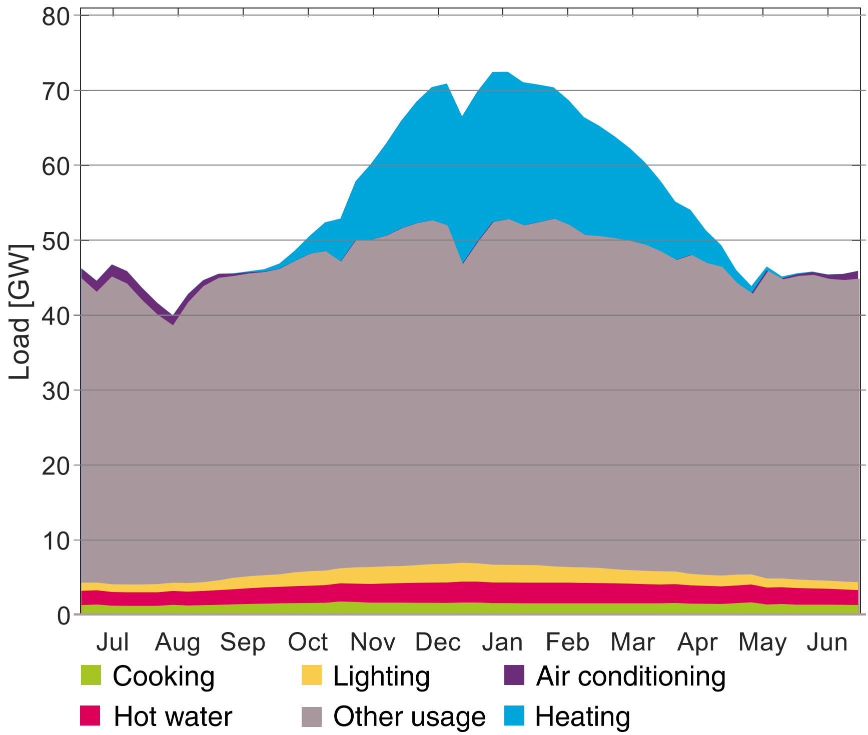

Figure 4: Seasonality of French electricity consumption in GW under smoothed temperatures by use (adapted from RTE 2017b).

The temperature sensitivity is illustrated in Figure 5. The figure shows the average load of each day of the considered year on the vertical axis and the average temperature on the horizontal axis. Applying linear regression on all observations with an average temperature below 15 degrees, the temperature gradient for the year is calculated. For 2012, the temperature gradient was determined to -2.4 GW per degree, in comparison to 1996 both the overall load level and the temperature sensitivity increased significantly. RTE identified an increased deployment of electrical heating throughout the last decades as the driver for the increased temperature sensitivity. Thus, especially during extreme cold waves, the French load is strongly increased for many consecutive days and causes scarcity situations in the French electricity system.

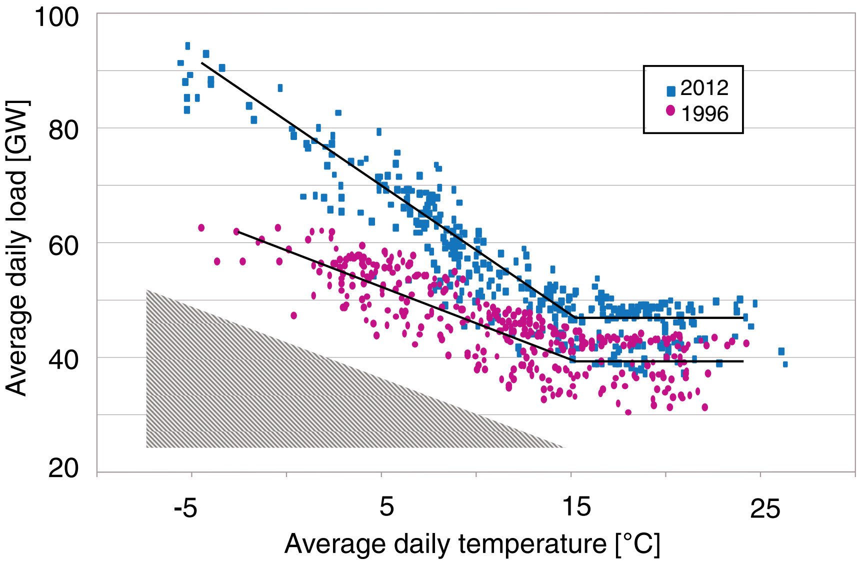

Figure 5: Determination and development of the heating gradient in 1996 and 2012 (adapted from RTE 2014).

Figure 6 shows the evolution of the French peak demand over the last decades. Especially in the time after 2000, the French peak load increased and became increasingly volatile, exceeding 100 GW in the winter 2011/12. This increase poses a serious threat to the French security of supply, and is mainly caused by the intransparency of electricity prices for end consumers. Through profiled consumers and unflexible tariffs, the scarcity in the system is disguised for the end consumers. RTE states, that an increase of price transparency, e.g. through flexible tariffs, may be able to significantly flexibilise the French electricity demand. This demand response potential in the residential sector shall be deployed in the next years, particularly fostered by the capacity mechanism. (RTE 2014)

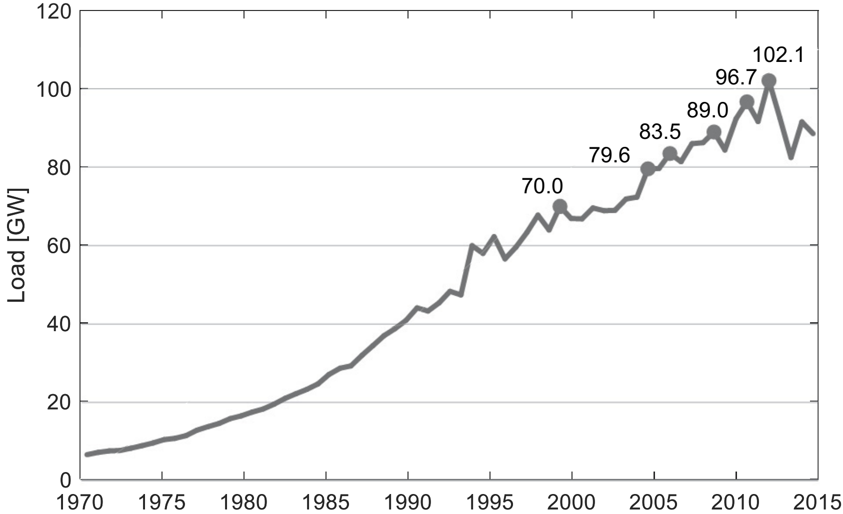

Figure 6: Evolution of the French peak load, effect of electrical heating (adapted from RTE 2014).

In terms of demand response measures, France used to have a total capacity of 6 GW in monopoly times, which were subsidised by EDF[1]. However, in the course of the market liberalisation, most of the interruptible load contracts expired and were not prolonged. As a result, in the current system

[1] Mainly decentralised emergency diesel generators in industrial sites were contracted to be activated in peak load periods to reduce the feed-out from the grid. Information obtained by RTE expert consultation.

there is around 3.5 GW of demand response capacity (RTE 2017b). A further deployment of demand response in future is likely, as the capacity mechanism seems to provide appropriate incentives to invest in peak load reduction measures.

2.3. France in the European Context

The French electricity system is part of the European Internal Market, thus in the majority of hours the French market is coupled with the neighbouring electricity markets. In scarcity hours in France, the neighbouring countries contribute with a significant share to the provision of security of supply and the reduction of the shortfall risk. However, this contribution is limited by the cross-border transfer capacities. See Table 1 for the net transfer capacities at the different borders that were available for import and export in the winter months of 2016.

Table 1: NTC values in winter months 2016 (RTE 2017c).

2016	January	February	March	November	December
[MW]	Import/ Export	Import/ Export	Import/ Export	Import/ Export	Import/ Export
Germany	2900/ 3500	3000/ 2300	1900/ 1700	1650/ 2500	4200/ 3250
England	2000/ 2000	2000/ 2000	2000/ 2000	2000/ 2000	1000/ 1000
Belgium	1150/ 3600	1200/ 3250	850/ 2850	700/ 1950	2000/ 2850
Spain	1750/ 2200	300/ 1400	300/ 1400	1300/ 2200	1300/ 2200
Italy	1160/ 2427	1160/ 2995	1160/ 373	1160/ 2427	1160/ 1494
Switzerland	2200/ 3200	1500/ 3200	1300/ 3200	1400/ 3200	1400/ 3200

It must be considered, that these transfer capacities are not necessarily available to the full extent and thus it is hazardous for the French electricity system to rely on the availability to be able to guarantee the security of supply. For example, in December 2016, January and February 2017 a transmission line connecting France and the UK was damaged and instead of 2000 MW only 1000 MW were available (Reuters 2016). Nevertheless, as load peaks in the European countries typically do not appear simultaneously, the abroad contribution is considered in the security of supply assessment. In the capacity mechanism, too, the foreign contribution is respected, as the capacity certificate obligation for the demand side does not match the peak demand, but is reduced by the security factor (see chapter 3.2).

2.4. Justification for a Capacity Remuneration Mechanism

As seen in the chapters above, the French electricity system is sensitive to extreme temperature events. The extreme situations in February 2012 and January 2017, where scarcity reached a critical level, showed the vulnerability of the French electricity system and prompted the French government to take action. As pointed out in 2.2, in the last years the French electricity system faces an increasing peak load as well as an increasing volatility of the peak load due to electrical heating. Thus it can be stated, that France has a peak load problem that endangers the security of supply and needs to be solved to prevent more critical scarcity situations in the future. However, the increasing share of renewables in the system exacerbates the uncertainty in the electricity system as the feed-in by renewables is fluctuating and hardly dispatchable. Defining the residual load as the load subtracted by the renewable feed-in, the residual load almost equals the total load in scarcity hours, meaning that renewable only slightly contribute to the security of supply.

The question that is addressed in this section is therefore, why the energy-only market is not able to guarantee the security of supply in the French market area and an additional remuneration scheme is necessary. Indeed, several analyses have attempted to answer this question in the past, identifying several issues leading to the lack of investments and to endangering the security of supply in energy-only markets. Among them risk aversion of investors, asymmetric investment incentives and flaws of the energy-only market are the most prominent (cf. e.g. Vázquez et al. 2002, Finon & Pignon 2008, Joskow 2008, Keppler 2017).

The issue of uncertainty of revenues and the resulting lack of investments due to risk aversion especially applies for peak generation plants. The profitability of investments in peak plants strongly depends on the occurrence and extent of price spikes. With the contribution margins in these few hours of spike prices, the plants need to cover their fix costs and investment payments in order to be profitable. However, especially if the spike prices depend on extreme weather events like in the French market area, they are associated with a high degree of uncertainty. As investors take decisions typically with uncertain information and in a risk averse manner, the energy-only market does not provide sufficient certain investment incentives (Finon & Pignon 2008). In the recent years, the expansion of renewable energies and the resulting merit order effect additionally lowers the profitability of power plants and makes their revenues more uncertain. The consequence is a lack of investments in peak power plants, leading to an insufficient security of supply level.

A second issue that is mentioned when analysing the reasons for a lack of peak capacity in systems with energy-only markets consists of the asymmetric investment incentives. De Vries and Heijnen (2008) mentioned the discrepancy between the social optimum and the theoretical outcome on the energy-only market (even under perfect knowledge) as a central conclusion of their investigation of investments under uncertainty and the effectiveness of capacity mechanisms. The theoretical reasoning for this asymmetry is thoroughly discussed by Keppler (2017). The inelastic demand curve in the electricity market leads to incentives for suppliers to underinvest. In this sense, the plant operators profit more from a slight scarcity than from an investment that leads to installed capacity exceeding the peak demand. Respecting that investment decisions are discrete, the argument for not investing in the marginal plant, but leaving a capacity gap is the following: The additional quantity sold by the additional unit does not lead to an overall profit increase for the supplier, because the overall revenue losses triggered by the price drop outweigh the revenue gains from the additional quantity sold. Thus, for each supply company it is better to not invest in the marginal generation unit, but to leave a capacity gap and profit from the higher prices caused by the scarcity.

In addition, market design flaws are adduced to explain the lack of investments in peak plants. Keppler (2017) points out why the benchmark model[2] cannot be assumed in the real-world market. In addition to the reasons mentioned above, the presence of an administrative price cap that is below the VoLL, leads to missing money for peak power plants and thus prevents sufficient investments to peak power plants. However, as Joskow (2008) observed, price caps are empirically rarely a binding constraint. This means that despite there are physical scarcity situations in the electricity system, the observed market prices do not reach the price cap, but remain on a lower level. In consequence, the theoretical missing money as the deviation between the VoLL and the price cap during scarcity hours is not the actual problem in reality, but the inability of the market to create sufficient price spikes. Reasons for the deviation between theoretical and empirical peak pricing are as well addressed in 4.2 of the present work.

The sections above summarised how the lack of sufficient investments in the energy-only market and the resulting threat to the security of supply is explained by economics theory. A solution in this context is the implementation of capacity remuneration mechanisms, which can be designed diversely. See e.g. RTE (2014, p. 44) for a classification of possible mechanism designs. With the capacity remuneration mechanism, the flaws of the energy-only market shall be counteracted and the provision of the public

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2 The benchmark model states, that in competitive energy-only markets adequate and welfare-maximising capacity levels are reached due to VoLL pricing.

good security of supply shall be guaranteed in an effective and cost-efficient way (Poignant & Sido 2010).

The justification for the capacity mechanism is based on its ability to provide sufficient investment incentives to risk-averse investors and to resolve the flaws of the energy only market. On the one hand, a capacity remuneration mechanism translates the complex value of the public good security of supply and uncertainties related to price spikes into a capacity price with a corresponding risk, that is better manageable by investors (Keppler 2017). On the other hand, it provides incentives to demand responses measures that exceed the current level. An expansion of demand response capacities leads to a more flexi of the demand curve, which can counteract the asymmetry of investment incentives. As a consequence of the capacity remuneration mechanism complementing the energy-only market, the welfare-optimal electricity system that guarantees the security of supply shall evolve, containing both sufficient peak generation capacities and a more elastic demand. Capacity remuneration is thus considered the mean to solve the problem of missing peak load generation respectively the inelastic demand and the resulting threat to security of supply in scarcity situations.

However, in addition to the peak load problem, that is the urgent concern of the French government and at which decentralised capacity remuneration mechanism is addressed at, a mid and long term generation adequacy issue arises in the French market area as well. As seen in section 2.1, the base load provision strongly depends on the nuclear plant fleet. As shown by Zimmermann et al. (2017), in the 15 years between 2026 and 2041 almost 50 GW of nuclear capacity will exceed a lifetime of 50 years. New investments or substantial retrofit measures associated with large investment activities are thus inevitable in the mid and long term to sustain a functioning electricity system. Having analysed the rationale and intention of the introduced capacity remuneration mechanism, it is obvious, that the mechanism does not address base load issues, but is designed to solve the problem of missing peak load generation respectively missing demand adaption in scarcity hours. When the nuclear investment phase comes closer, caution must be paid to avoid the mechanism causing unnecessary costs. To incentivise investments in base load capacity either the energy-only market must prove its feasibility or different measures have to be implemented.

http://www.springer.com/978-3-658-20092-3

Analysis and Modelling of the French Capacity Mechanism
Impact Assessment of Energy Policy Measures on the Security of Supply
Kraft, E.
2017, XVII, 128 p. 26 illus., 10 illus. in color., Softcover
ISBN: 978-3-658-20092-3