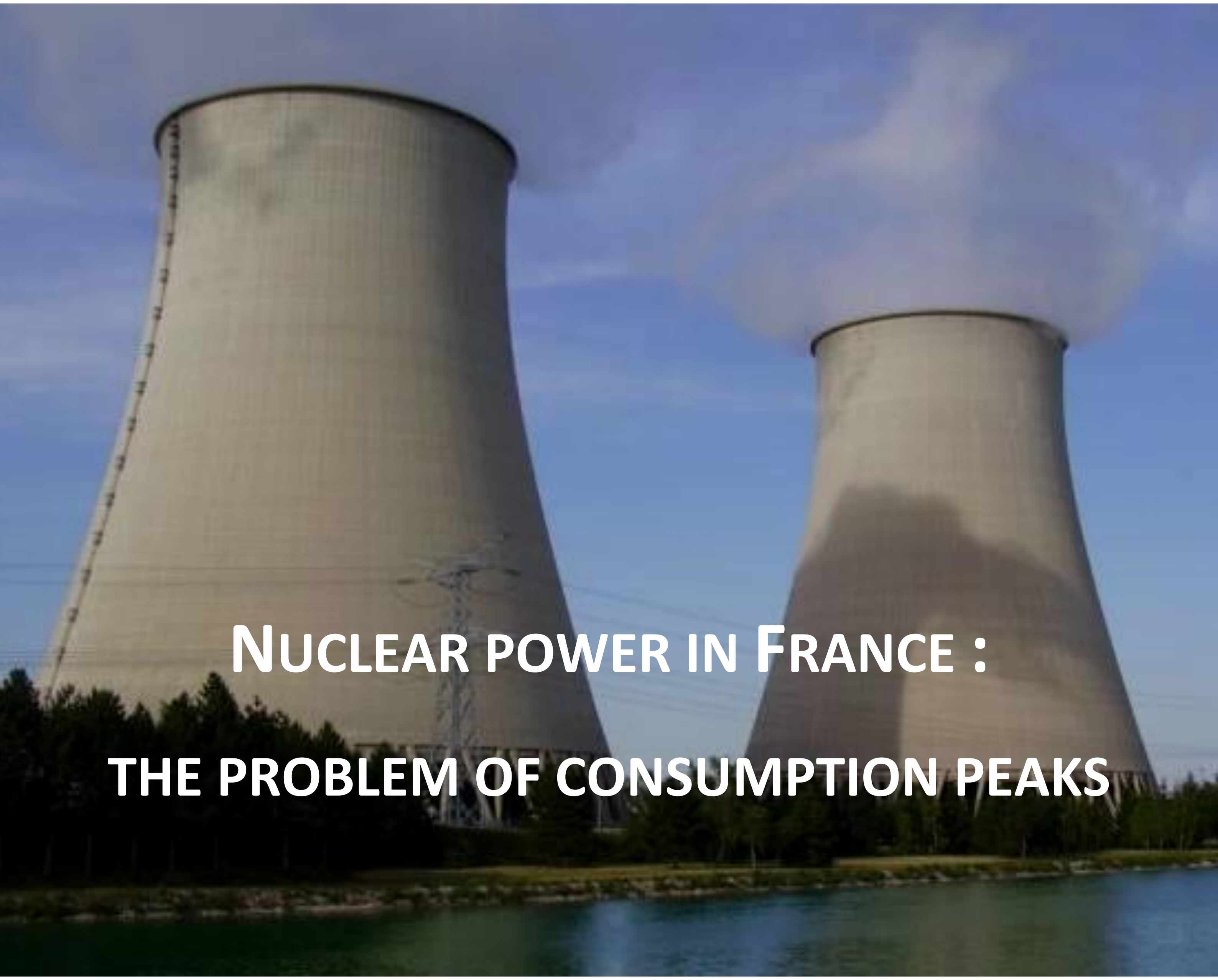

NUCLEAR POWER IN FRANCE :

THE PROBLEM OF CONSUMPTION PEAKS

Gabriel Saunier

Energy economics and policy
Prof. T. Rutherford ETH Zurich
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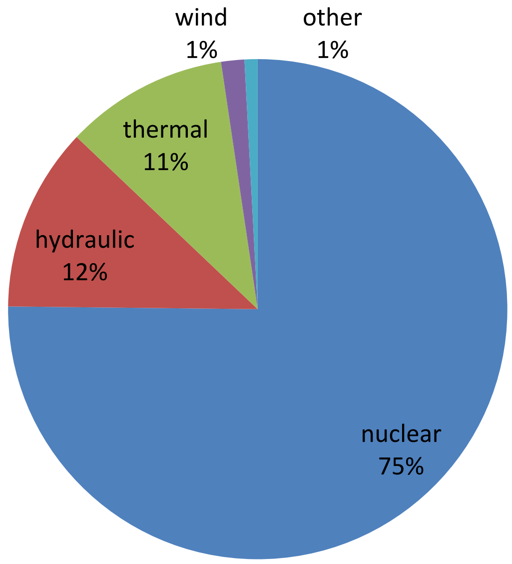
SUMMARY

INTRODUCTION

For its electricity production, France has bet everything on nuclear power. Indeed, according to the 2009 figures, 75.2% of its electricity is of nuclear origin. This makes it the second country in the world from that perspective, recently overtaken by Lithuania, with 76.2%, and far before Slovakia, with 53.5%.

This development of civil nuclear power in France is originally due to a desire of energy independence after the Second World War. Charles de Gaulle launched in 1945 the CEA (Commissariat à l'Energie Atomique), which started France's civil nuclear research program. It has led in 1962 to the construction of the first operational nuclear power station in Chinon. The amount of nuclear electricity produced in France then grew strongly until today, where it is the predominant form of electricity, as we can observe on the following pie chart:



Shares in French electricity production (RTE 2009)

This policy allows France to have one of the cheapest electricity prices in Europe and officially few carbon dioxide emissions. However, when we look at the utilization rate of French nuclear power stations, defined by the ratio of the effective production over the maximum potential production, it is only 75% in France, compared to more than 90% in the United States for instance. This is due to the fact that the basic electricity demand is too low, thus forcing France to export electricity at cheap price during low-consumption hours, whereas its production sometimes does not meet demand during peak consumption. Without this exporting activity, the utilization rate would be even lower – around 60%.

Therefore, we can ask ourselves if France's electricity production is really adapted to the demand, and what would be the effects on electricity price of a change in its nuclear policy.

We often hear that nuclear power in inappropriate for peak demand, but to what extent, and what are the other solutions?

In a first time we will examine the electricity demand in France to try to understand why it is difficult to fulfil with nuclear power, then we will study the existing solutions to that problem and their cost.

I – ELECTRICITY DEMAND IN FRANCE

1) VARIATIONS IN DEMAND

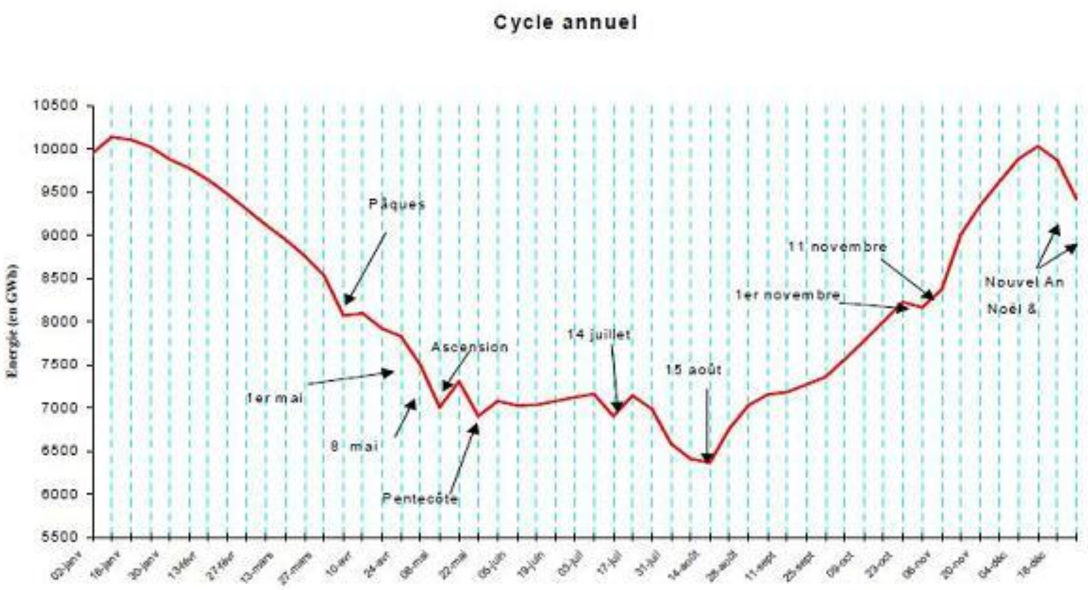
The data of French electricity consumption are made publicly available by RTE, the French electricity transport manager.

The average demand in 2009 was 53.5 GW, compared to the 63 GW of theoretical nuclear power capacity, so it would not be a problem if it was constant in time. But when observing these data, we can notice important variations on three different scales: over one year, over one day, and over a few minutes. These types of variations are different and cannot be dealt with in the same way.

- YEARLY VARIATIONS:

They consist in seasonal variations – the demand in winter is of course more important than in summer, due to heating – and exceptional under-consumption due to free days where most of the companies as closed.

This graph represents the 2007 demand profile:



Electricity demand in 2007[1]

[1] Source : http://www.journaliste-enqueteur.com/nucleaire/Acket-Nucleaire_et_suivi_reseau.pdf

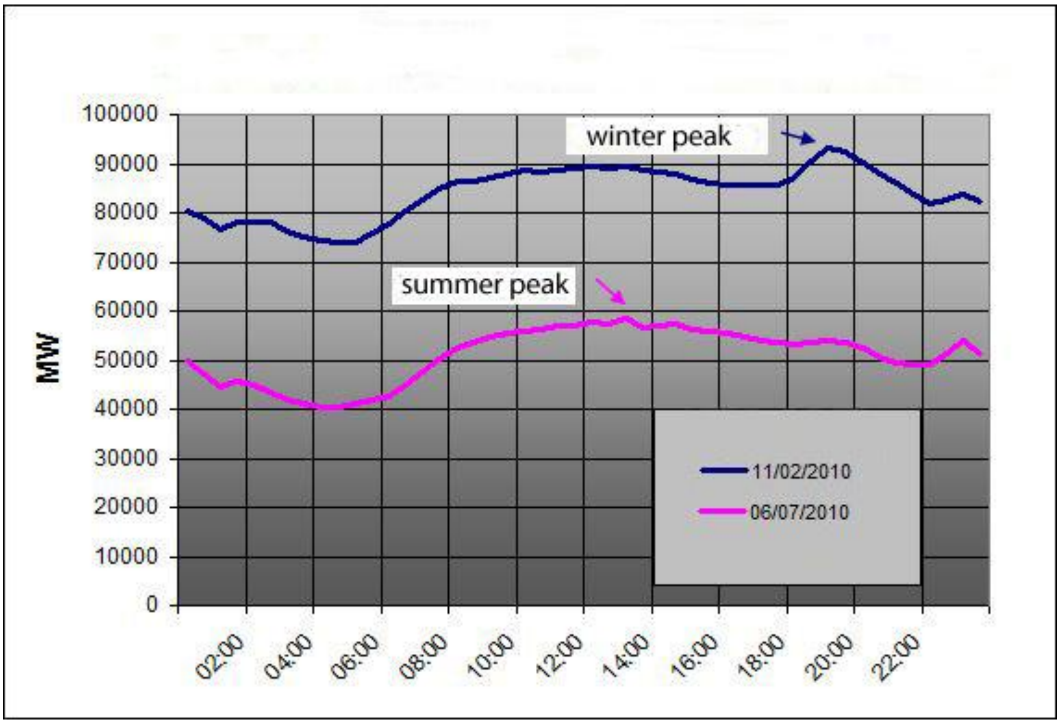
The minimum weekly average over that year is 38 700 MW and the maximum is 59 500 MW, which makes a 55% variation.

These yearly variations are the least problematic ones because they are slow, which gives enough time to nuclear power production to adapt, and they are quite predictable because similar from one year to another.

All these variations are taken into account in the basis electricity production of nuclear power plants, by modulating the quantity of nuclear fuel and concentrating inspection and maintenance operations in summer for instance.

- DAILY VARIATIONS:

As we could expect, there are differences between summer and winter intra-day variations. During winter, the maximum demand peak is at 7 PM whereas in summer it is around 1 PM, as shown on the following graph. Here we consider worked days; the profile would again be different on a Sunday for instance.



Comparison of demand in winter and summer[2]

[2] Source : http://www.agoravox.fr/actualites/citoyennete/article/pointes-electriques-en-ete-aussi-78198

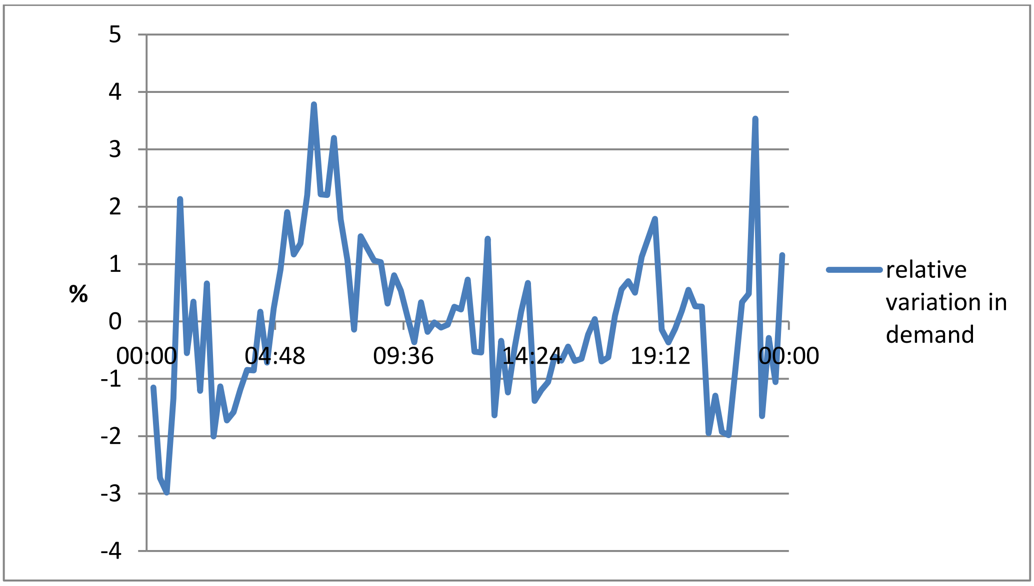
If the general form of these variations is well known, the peak intensity depends a lot on weather conditions. The 7 PM peak can be more intense during a very cold winter for example. In general, the difference between minimum and maximum demand in one day is between 20% and 30%.

These variations can partly be compensated with an increase of production by nuclear plants, and partly with hydroelectric power, as we will develop in the second part of this essay. If variations do not exceed expectations by too much, these means of productions are generally sufficient.

- HOURLY VARIATIONS:

Within the daily variations, there are even quicker changes that are observable by studying the figures from RTE.

On the following graph, we can observe for one day divided into 15 minutes time steps the relative variation in electricity demand from one time step to another:



Relative variations in demand on the 07/04/11 (RTE 2011)

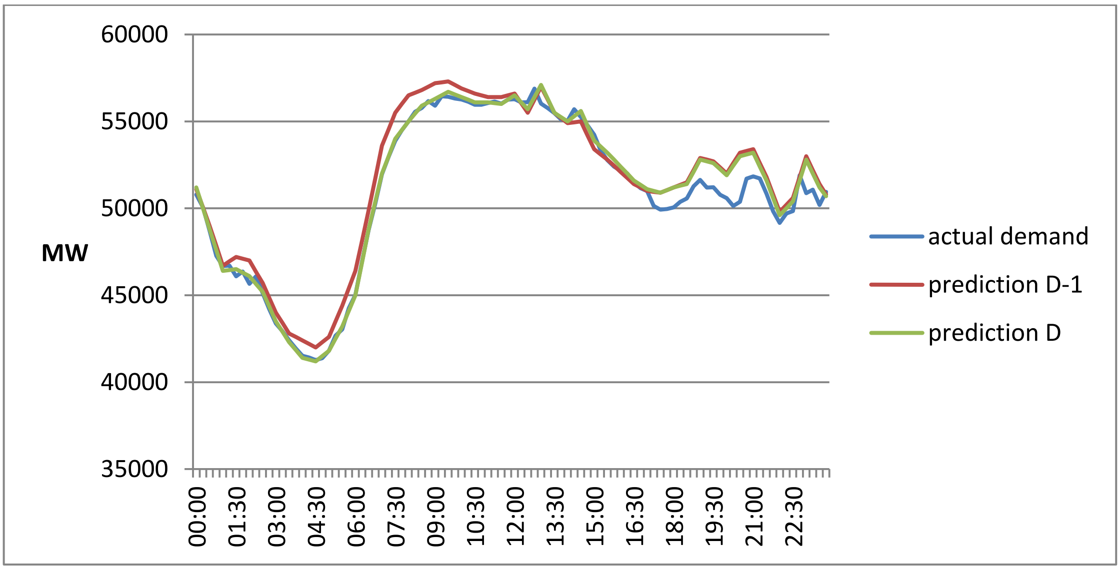
We can notice up to nearly 4% variation in only 15 minutes' time. A very important rise in demand in a short time period is called ultra-peak demand. These variations are the most problematic ones because they leave very few options for electricity production. They are partly due to the massive use of electric heating in France, which paradoxically comes from the preponderance of nuclear power that had made the electricity price very low.

The RTE company tries to estimate the « one-in-ten chance » peak demand, that is to say the maximum demand that has one-in-ten chance to occur during the year, or to put it another way, the demand corresponding to climatic conditions observed once in ten years.

By the year 2015, this peak is estimated to be 104 GW, and by the year 2020, it is estimated to be 108 GW. As a comparison, the maximum demand so far was 92.4 GW; it has been reached during winter 2009. Thus, these record peaks of demand are expected to get more and more important and difficult to follow.

2) DEMAND PREDICTION

The day-to-day electricity production is made according to statistical and meteorological predictions made the day before and updated during the current day. These predictions mostly concern weather conditions such as temperature and luminosity that influence significantly the electricity consumption. Indeed, it is estimated by RTE that in winter, a fall of 1°C in temperature leads to an augmentation of 2100 MW in consumption. However, there is sometimes an important bias between prediction and realisation.



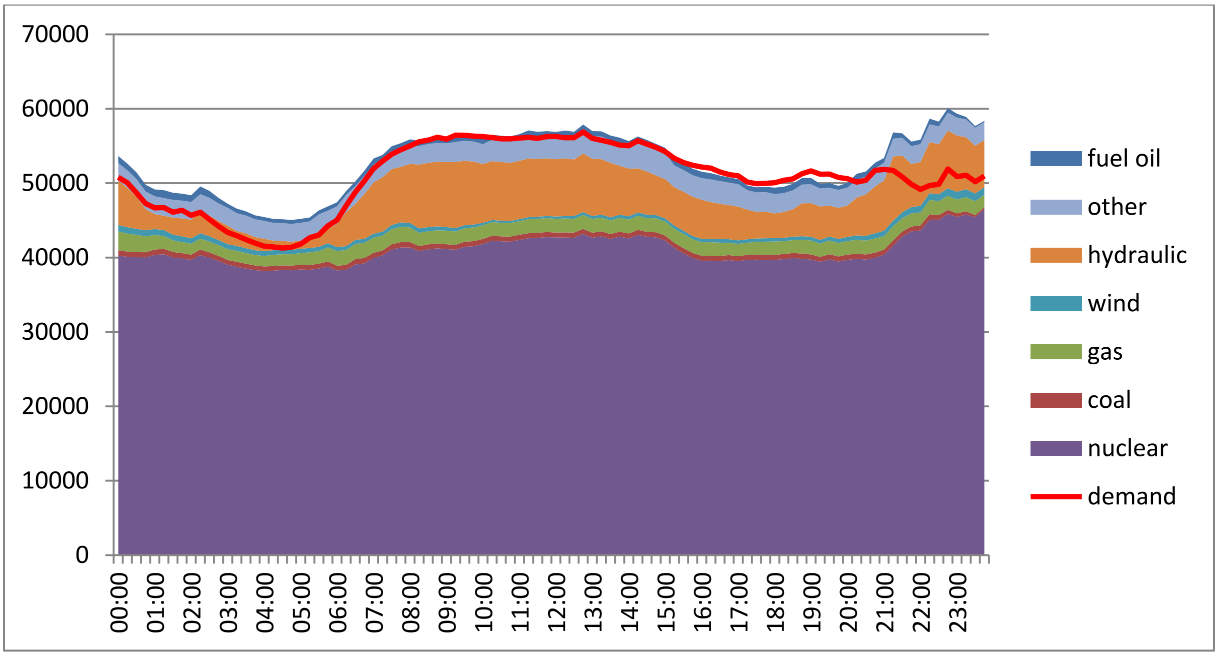
Demand compared to predictions on the 07/04/11 (RTE 2011)

Even predictions made a few hours in advance are not totally reliable, so nuclear power on its own could not answer to that demand, except by producing continuously at its maximum, which would be too expensive and a waste of energy. Thus, other sources of energy are used, which are more adapted to the profile of French electricity consumption.

II – CURRENT SOLUTIONS TO PEAK DEMAND AND THEIR COST

1) CURRENT SOLUTIONS

First of all, let's watch France's electricity demand and production by different sources over one day. All the electricity sources are represented here ("other" mainly corresponds to cogeneration and solar production), and the demand curve is the red line.



Production of different sources of electricity compared to demand on the 07/04/11 (RTE 2011)

Demand is generally met by French production, excepted during unpredicted peaks, as it happened during that day. These peaks do not happen every day and are mostly concentrated over winter. In these cases, France is forced to resort to importations to avoid power cuts.

There are four main ways to respond to the demand:

- ADAPTATION OF NUCLEAR PRODUCTION

Nuclear power adapts to follow the general tendency of the demand, which is enough 25% of the time. But it is limited by its variation speed (effectively under 5% per hour) on the one hand and its total power on the other hand. Indeed, we have seen that the maximum power given by nuclear stations is 63 GW and the record ultra-peak demand was 92 GW. Therefore, the use of other energies is sometimes unavoidable.

- HYDROELECTRIC POWER

Hydroelectric power is the second source of electricity in France. It is used as well for basic production than for peak and ultra-peak production. To that extend, water is pumped in tanks when the electricity demand is low, and released when the demand in high, thus nearly instantly producing electricity. To that day, it is the best way of storing a big amount of electricity with a minimum of losses.

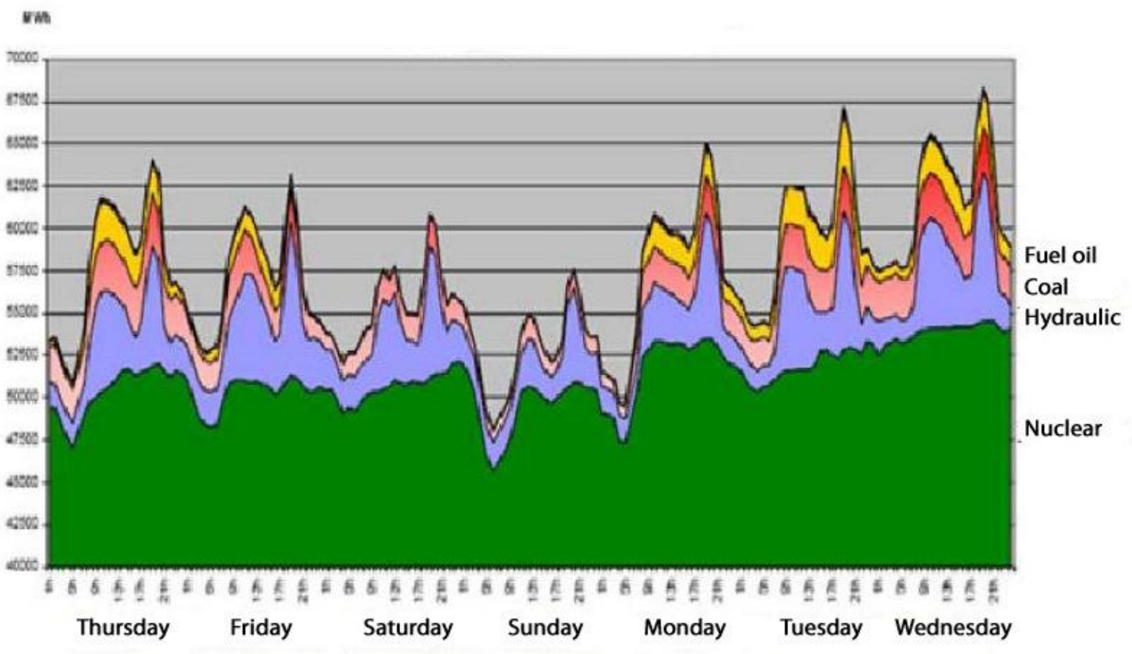
The French hydraulic system able to produce for peak and ultra-peak demand is around 13.5[3] GW. It is used to answer most of the demand that nuclear power cannot fulfil, but in some cases it is still not sufficient. Then, fuel oil power stations are started.

- FUEL OIL POWER

In France, fuel oil power stations are used only in case of ultra-peak demand because of their high cost and CO_2 emissions.

The total amount of electricity they can produce is equal to 7 GW[4]. When they are off, they can be started in only 20 minutes, to compare with two or three days for a nuclear power station, and once started, they can respond to demand variations almost instantly.

[3&4] Source : Poignant, Sido, Groupe de travail sur la maîtrise de la pointe électrique



Production of different sources over one week[5]

This weekly graph sums up what we saw. Most of the variations are absorbed by hydraulic production, and the residual ones are compensated by fuel oil production.

- IMPORTING

In last resort, when the total production is still under demand or has been wrongly planned, France needs to import electricity from its neighbours, mostly Germany. This constitutes the real problem, because this electricity is bought when the price is maximal, and it relies on other countries' ability to deliver that power. But if all Europe is in the same case, as it sometimes happens during a tough winter for example, it can lead to major power breakdowns.

On average, France exports electricity during most of the year, but it also imports it 60 hours per year[6], and this figure is rising.

2) MODEL FOR THE COST OF ELECTRICITY

[5] Source : http://www.journaliste-enqueteur.com/nucleaire/Acket-Nucleaire_et_suivi_reseau.pdf
[6] Source : Poignant, Sido, Groupe de travail sur la maîtrise de la pointe électrique

We can make a simplistic model for the total price of electricity according to its different components. Its goal is not to be realistic but to have an idea of how changing the part of nuclear power affects the electricity cost.

This table sums up the price of electricity for production with different sources, import or export, and the quantities involved:

Source of electricity	Average price in €/MWh	Quantity in TWh
Nuclear	$P_N = 28$	$Q_N = 390$
Hydraulic	$P_H = 50$	$Q_H = 62$
Coal+gas	$P_C = 34$	$Q_C = 51$
Wind	$P_W = 61$	$Q_W = 8$
Fuel oil	$P_F = 60$	$Q_F = 8$
Import	$P_I = 77$	$Q_I = 43$
Export	$P_E = 36$	$Q_E = 68$

Quantity and cost of different energy sources[7]

Note: These data are hard to get and a little imprecise because they try to take into account the investment cost with an actualization of the price. They differ according to the sources and some of the figures listed here are an average of different sources.

Considering this table, the formula for the price of electricity is then:

$$\frac{Q_N * P_N + Q_H * P_H + Q_C * P_C + Q_W * P_W + Q_F * P_F + Q_I * P_I - Q_E * P_E}{Q_N + Q_H + Q_W + Q_F + Q_I - Q_E}$$

We get a total price $Q_T = 35.6\ €/MWh$

We can use this formula to evaluate the price of electricity if all peak and ultra-peak demand was answered with hydraulic power. This corresponds to $Q_F = Q_I = 0$, $Q_H = 113\ TWh$

We would then get a price $Q_T = 33.1\ €/MWh$. This supposes that the price per MWh of hydraulic power would not change with the building of new installations, and that with that system France would never have to import any electricity. It is of course unrealistic but gives an idea of the variation of the price.

The new part of nuclear power in electricity production would be:

$$\frac{Q_N}{Q_N + Q_H + Q_C + Q_W} = 69.4\%$$

[7] Sources : RTE 2009, http://www.eolinfo.com/DOUANES.htm, https://www.cia.gov/library/publications/the-world-factbook/

On the opposite, we can determine what would be the price if France increased its part of nuclear electricity. Keeping all other parameters constant, the increase in nuclear production would have to be 22 GW (201 TWh/year) to meet the demand in any case without resorting to fuel oil or importing.

The unused basic power 201 – 43 – 8 = 150 TWh can be considered as lost because France cannot export more electricity at a profitable price. This electricity would not be produced but it does not affect the price a lot since nuclear fuel is only responsible for 5% of the price of nuclear electricity.

We then have $Q_F = Q_I = 0, Q_N = 591\ TWh$, and the new total price $Q_T = 39.3\ €/MWh$

This corresponds to a part of nuclear power equal to:

$$\frac{Q_N}{Q_N + Q_H + Q_C + Q_W} = 83.0\%$$

CONCLUSION

If nuclear power is the cheapest source of energy in France, it is often contested for its inability to meet the demand. As seen in this paper, this demand is very hard to predict and varies a lot over short periods of time, and this volatility is only increasing with years.

To help answering the demand, other sources of energy then appear unavoidable, although more costly. The most used sources today are hydroelectricity and fuel oil, but they sometimes fail to be enough and France has to resort to import, at a very disadvantageous price.

As we then figured out, a small reduction of nuclear production in favour of hydraulic power that is more flexible would have a positive impact on price, by limiting the necessity to import. It would also increase the part of renewable energy in the French electricity consumption. According to the Kyoto protocol, this part must be 20% by the year 2020, an objective that is still far from being reached.

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