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The French Disconnection:

Reducing the nuclear share in France's energy mix

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Introduction

France has entered into a national debate about its energy transition to meet its long range target to reduce CO_2 emissions by 75 per cent by 2050, while maintaining security of supply and the competitiveness of French industry. It is a muddled debate, because the trigger for it is an electoral commitment by President François Hollande to reduce the nuclear share in the country's electricity mix from over 70 per cent today to around 50 per cent by 2025, a commitment that few people in France – and maybe not even the president himself – regard as sensible or feasible to carry out to the letter. Indeed the origin of the commitment is almost an accident of electoral politics. And the national debate has done little to clarify the issue.

There is, however, a real nuclear issue to debate – how far is France content to rest on its past laurels of a nuclear industry that has produced some of the cheapest and certainly the most de-carbonised electricity in Europe, rather than to confront the long term cost challenge of replacing current reactors, the perennial systemic risk of operating a nuclear fleet of 58 reactors, and the prospect of one day re-carbonising its electricity system if it cannot replace today's generations of reactors with similar amounts of zero-carbon electricity?

This issue also raises the question of whether a reduction in the nuclear share of its electricity mix might improve France's relatively poor performance – relative to some of its EU partners – in renewable electricity generation and in energy saving. Able to offer some of the cheapest electricity in Europe, produced by largely amortised reactors, successive French governments have so far been reluctant to negate this cost advantage by loading on to consumers' bills the same level of renewable subsidies that many neighbouring countries have. Cheap electricity has also reduced incentives for energy saving. Yet, in order to meet its 75 per cent reduction in greenhouse gases (the so-called Facteur 4, that is, division of emissions by four), the government has the long term aim of reducing energy consumption by 50 per cent by 2050.

Political context of the 50 per cent commitment

The political impact of Japan's nuclear disaster at Fukushima in March 2011 was greater in some other parts of Europe than in France. Germany, which had long had a strong anti-nuclear movement, had already decided to abandon nuclear power; in the wake of Fukushima it decided to accelerate the timetable of this exit. Even though it was only an acceleration of an existing policy, the German decision shook the establishment in France which has in recent years become used to following, however reluctantly, the lead of Germany in many policy areas. Indeed this appeared to be happening in nuclear policy too. The arithmetic of Hollande's commitment to reduce the French nuclear share by around 20 percentage points matched Germany's decision to reduce its nuclear share from around 20 per cent to zero. After Fukushima, Switzerland also decided it would not replace its existing reactors when they came to the end of their natural life, while Belgium displays no desire to reverse its earlier decision to start phasing out its reactors by 2025.

But no country in Europe had more at stake than France, with its 58 reactors producing more than 70 per cent of its electricity. Occurring during the presidential primary contest for the Socialist nomination for France's 2012 presidential election, Fukushima had the effect of pushing Martine Aubry, first secretary of the Socialist party, into calling publicly for the phasing out of nuclear power altogether, albeit over a long period of 25–30 years. This was the first crack in the longstanding pro-nuclear position of all mainstream political parties in France.

As it happened, the socialists were negotiating an electoral alliance with the Green party in the belief that, otherwise, they might well not win outright against the incumbent president, Nicolas Sarkozy. In order to demarcate himself from his fellow socialist rival in the presidential primary contest, François Hollande proposed instead a reduction in the nuclear share to 50 per cent by 2025. This position had the advantage of being more moderate, and therefore more in tune with majority French opinion, but also of offering the Greens a more immediate and precise time scale for a reduction in nuclear power's dominance in the French energy mix. Hollande beat Aubry in the primary and Sarkozy in the 2012 general election, and, after a subsequent parliamentary election, he appointed a government of socialists in coalition with the Greens. His government then scheduled a national debate with all stakeholders, conducted through the first nine months of 2013; its declared aim was to prepare a new framework energy law. This debate, with sessions held in the provinces as well as in Paris, was a democratic departure from France's traditional top-down approach to energy policy.

It may also have been a delaying tactic. For the new energy law was originally to have been passed by the end of 2013, but is now scheduled to be presented to parliament in spring 2014 and passed by the end of 2014. In his speech concluding the national debate Hollande repeated his commitment to a one third reduction in the nuclear share of power, but with the less precise deadline of 'à l'horizon de 2025'. This lack of precision, in addition to the legislative delay, has given the impression that the president is backpedalling on his commitment under pressure from experts and parliamentarians.

A first report by the Parliamentary Office for the Evaluation of Scientific and Technological Choices (OPECST), published in December 2011, stated that Fukushima showed the wisdom of 'not putting all one's eggs in the same basket'. It warned that France would not have been able to weather the shutting down of its 58 reactors (producing more than two-thirds of its electricity) in the same way that Japan, thanks to imported hydrocarbons, survived the closure over several months of its 55 reactors, cutting the country's electricity generating capacity by no more than a third. A similar systemic risk, would arise from any generic fault found in the French nuclear fleet, because it includes 34 near-identical 900 Mw reactors, as the head of France's ASN nuclear safety authority has warned. In a 2013 report the OPECST came out against any idea of going to 50 per cent in the next dozen years, saying that this reduction of 20–25 Gw would, if not offset by other generating sources, be the equivalent of wiping out one day's consumption in every week. Instead, the report suggested a gradual reduction, on a '*trajectoire raisonnée*', of the nuclear power share down to 50 per cent by 2050 and eventually to 30–40 per cent by 2100. This could be done, it proposed by installing 2 Gw of new capacity for every 3 G withdrawn.[1] This prescription, however, for a gradual reduction of capacity coupled with progressive modernisation, assumes that new nuclear build is still an economic proposition although, as argued below, this is no longer clear.

The cost curse

This construction cost curse, as well as construction delay, has been dramatically underlined by Électricité de France (EdF)'s new European Pressurized Reactor (EPR) of 1,630 Mw at Flamanville in Normandy. This is now expected to cost more than €8bn, two and a half times the original estimate, and to be completed at the end of 2016, four years later than originally scheduled. Part of the reason for this is put down to the fact that this EPR is the first of its kind to be built in France, and that it is being designed from the outset for a life cycle of 60 years. Post-Fukushima safety improvements have also imposed extra time and money. But costs were already rising before the 2011 Japanese accident – the estimates for Flamanville were of €3.3bn in 2007, €4bn in 2008, and €5bn in 2010.

Flamanville looks like becoming the cost benchmark for EPRs, or at least for any early EPRs. This is confirmed by EdF's 2013 contract to build two 1,600 Mw EPR reactors at Hinkley Point in the UK, for £7bn each (at 2012 prices).[2] Again, these EPRs will be the first of their kind in the UK, indeed the first reactors of any kind to be built in the UK for a quarter of century. The cost is very high considering what the UK government has agreed to in order to give EdF financial certainty. While EdF and its partners will take the construction risk of sticking to budget and schedule, the UK Treasury is to underwrite the debt they incur for the project of up to 65 per cent of total costs prior to operation. Moreover, EdF will get a guaranteed price of £92.5 per Mwh, almost double the UK wholesale price,

1 La transition énergétique, Office Parlementaire d'évaluation des choix scientifiques et technologiques (OPECST), 2013.
2 An additional £2bn to be spent by the reactor builders on land purchase, construction of a fuel storage facility and some ancillary costs will bring the total cost of the two new Hinkley Point reactors to £16bn (at 2012 prices).

under a 35-year contract that will begin from the date of commissioning, expected to be 2023. An important caveat is that this UK state aid requires approval from the European Commission if the deal is to go ahead.

Such overt state aid is apparently what is needed for new nuclear build in a market such as the UK that is considerably more liberalised than the French market. As EdF becomes more exposed to competition, however, at least from foreign if not domestic competition, the UK contract may be an indication of the future extra state support that the French utility will need to build more reactors in France.

Cost inflation in new nuclear build is not confined to France or to French-built reactors, but has been evident for some decades in other industrialised countries such as the US and Germany. According to a UK study,[3] as early as the 1960s construction costs began to increase as regulators ordered design changes which added cost and prolonged construction times. These lengthened further as the result of new safety measures. On average, US nuclear plants took 5 years to build before the 1979 Three Mile Island accident, and 12 years after it. Sometimes the lengthening of construction times was deliberate. Lower trending electricity demand caused some utilities to stretch out reactor building, as was the case in France in the late 1980s as its crash programme of reactor building started to produce more electricity than its economy could absorb. For a period, from around 1990 to the mid-2000s, construction costs appeared to be stable or even to fall. But this reflected the fact that industrialised countries had generally stopped building by this period, and most of the new build cost data came from developing countries. By the mid-2000s the economics of new nuclear reactors appeared to look attractive again, with the prospect of carbon taxation penalising fuel sources which rivalled nuclear power. Carbon taxation, however, never fully materialised, and the commodity boom of the mid-2000s raised the cost of many of the materials going into reactor building.

The degree to which France was part of this cost inflation was surprising. Indeed as François Lévêque, an expert on nuclear economics at the École des Mines, has pointed out, there was every reason to expect French reactor construction costs to fall:

> ‘The French nuclear programme offered the best possible conditions for powerful learning effects. The power stations were built by a single operator, EdF, which was able to appropriate all the experience accumulated with each new project. The plants were built in a steady stream over a short period of time. In the space of just 13 years, from late 1971 to the end of 1984, work started on construction of the first 55 reactors. The programme as a whole only slowed down at the end, with work on the last three units starting between late 1985 and mid-1991. The average construction time was consistent, but increasing slightly over time. Unlike what happened in the US, the regulatory framework did not upset construction of nuclear plants. The fleet expanded gradually thanks to dialogue and cooperation between all the players (EdF, Atomic Energy Commission, Framatome, Ministry of Industry), well out of sight of non-specialist outsiders’.[4]

Yet, as Mr Lévêque points out, there were other factors. France made step changes in capacity – from 900 Mw to 1,300 Mw to 1,450 Mw – which did involve changes in technology. It went to some expense to ‘frenchify’ the basic American design of Westinghouse, and further expense to source components and machinery in France. The move to larger units means fewer units, and therefore shorter production runs in order to ‘learn by doing’. The first reactors of the third generation – the EPRs – were probably bound to have teething problems. But there appears to have been little cross-over learning from the first two EPRs, because EdF and Areva (the reactor building successor company to Framatome), are only working as a team on the second EPR at Flamanville, the first EPR

3 UKERC Technology and Policy Assessment, Cost Methodologies Project: Nuclear Case Study, Philip Greenacre, 2012.
4 Estimating the costs of nuclear power: benchmarks and uncertainties, page 26, François Lévêque, Working Paper, 13-ME-01 May 2013.

at Olkiluoto in Finland being entirely an Areva project. (Hopefully, the EdF–Areva team can apply some of the lessons from Flamanville to their next joint project at Hinkley Point).

France's nuclear bill has recently been calculated by the government auditor, the Cour des Comptes.[5] The construction cost of reactors between 1969 and 2004 was, at 2010 prices, €72.9bn or €83.2bn with engineering and labour costs added in. Costs have continued to rise, per unit of capacity. While the construction cost per Mw installed was €1.37m (including engineering costs) for Civaux commissioned as late as 2002, the comparable cost for Flamanville will be above €4m per Mw. Another historic cost has been the €55bn (at 2010 prices) spent on research between 1967 and 2010.

Table 1: Construction schedule and costs (in 2010 euros) of existing reactors

Pairs of units	Net continuous output	Mean date of commissioning	Construction cost in 2010 million euros	Cost per Mw in 2010 euros
900 Mw reactors				
Fessenheim 1.2	1,780 Mw	February 1978	1,488	835,955
Bugey 2.3	1,840 Mw	March 1979	1,630	885,869
Bugey 4.5	1,800 Mw	October 1979	1,619	899,444
Tricastin 1.2	1,840 Mw	Dec. 1980	2,191	1,190,760
Tricastin 3.4	1,840 Mw	August 1981	1,512	821,739
Blayais 1.2	1,830 Mw	July 1982	2,185	1,194,535
Blayais 3.4	1,820Mw	October 1983	2,032	1,116,483
Dampierre 1.2	1,800 Mw	Nov. 1980	2,109	1,171,667
Dampierre 3.4	1,800 Mw	August 1981	1,575	875,000
Gravelines 1.2	1,840 Mw	Dec. 1980	2,294	1,246,739
Gravelines 3.4	1,840 Mw	August 1981	1,620	880,435
Gravelines 5.6	1,820 Mw	June 1985	1,989	1,092,857
St Laurent 1.2	1,760 Mw	August 1983	1,972	1,120,455
Chinon 1.2	1,740 Mw	May 1984	1,997	1,147,701
Chinon 3.4	1,760 Mw	Sept. 1987	1,969	1,118,750
Cruas 1.2	1,760 Mw	October 1984	2,206	1,253,409
Cruas 3.4	1,760 Mw	Nov. 1984	1,722	978,409
1,300 Mw reactors				
Paluel 1.2	2,580 Mw	Dec. 1985	3,950	1,531,008
Paluel 3.4	2,580 Mw	April 1986	2,985	1,156,977
St. Alban 1.2	2,600 Mw	Sept. 1986	2,935	1,128,846
Flamanville 1.2	2,580 Mw	January 1987	3,320	1,286,822
Cattenom 1.2	2,565 Mw	Sept. 1987	3,484	1,358,285
Cattenom 3.4	2,600 Mw	July 1991	2,837	1,091,154
Belleville 1.2	2,620 Mw	Sept. 1988	2,987	1,140,076
Nogent 1.2	2,620 Mw	Sept. 1988	3,128	1,193,893
Penly 1.2	2,660 Mw	Nov. 1991	3,420	1,285,714
Golfech 1.2	2,620 Mw	August 1992	3,265	1,246,183
1,450 Mw reactors				
Chooz 1.2	2,910 Mw	July 2000	4,758	1,635, 052
Civaux 1.2	2,945 Mw	May 2002	3,683	1,250,594
Total	62,510 Mw		72,862	

Source: EdF data, cited in the Cour des Comptes report on the cost of nuclear power, 2012.

[5] The cost of the nuclear power sector, Cour des Comptes, January 2012.

As to the future, EdF has estimated the cost of keeping the existing fleet going for the period of 2011 to 2025 at €55bn. This includes the cost of upgrading safety after Fukushima, as well as that of replacing large components such as steam generators, upgrading fire safety equipment, enlarging fuel storage pools and measures to deal with any recurrence of the extreme heat conditions experienced in the 2003 heatwave, such as the replacement of chiller units. This adds up to €3.6bn in annual maintenance costs, more than double the average annual cost of €1.5bn in the 2008–2010 period which was itself considerably higher than in the early 2000s.

End-of-life cost estimates have also risen. By the end of 2012 EdF had set aside €20.9bn for decommissioning in a fund that is paid for out of current electricity sales. Mr Leveque contends that this works out at a relatively low rate of decommission funding per Kw compared to similar per KW decommissioning estimates in the USA and Germany. In common with virtually every country except Finland, France has not yet embarked on burying its residual nuclear waste. But the cost of deep geological storage in France was estimated by ANDRA, the agency responsible for dealing with such waste, at €20bn in 2005, and at €35bn in 2010. It has also has to be said, however, that these back-end costs of the nuclear cycle would be paid over a very long period. The actual dismantling of the 58 reactors is currently foreseen as taking place between 2035 and 2057, and some of the cost of deep burial for the waste would occur even later.

France's options

Useful though it may have been as a democratic exercise, the 2013 national debate managed to come to absolutely no conclusion about the eventual future of the French nuclear fleet. The final official document summing up the debate had only this to say on the crucial nuclear question: 'all participants agree on the need – in order to prepare for future decisions – to define a strategy for the evolution of the nuclear fleet [*parc nucléaire*], whatever the choice of evolution beyond 2025 (renewal, continuation, reduction or phase-out)'.[6] So what guidance can this paper offer about these options?

Renewal or replacement?

This is not a question that France needs, or is inclined, to answer soon. The oldest reactors in the current fleet, at Fessenheim, are not yet 40 years old, and there is every prospect (explained below) of prolonging their life to 50 or maybe 60 years, as in the USA. But replacement, if and when it comes, will be difficult. Because so many reactors were built in one decade (1978–88), their replacement would need to be almost as rapid. The EPRs may be bigger, but they also take longer to build. EdF has had a plan to build a second EPR at Penly, but this appears to be suspended until Flamanville is completed. The cost of EPRs is, as we have seen, beginning to appear prohibitive.

Nor does EdF appear to be putting anything like enough money aside to provide for one-for-one replacement of today's reactors. The amount that the company is putting aside for depreciation runs at over €1bn a year (€1.35bn in 2010, according to the Cour des Comptes). But at this rate it would take EdF eight years to pay for another Flamanville out of its own retained earnings. Moreover, EdF would like to lengthen its depreciation schedule so that it can reduce the amount it has to set aside each year. It has already done this once. In 2003 it changed its accounting schedule for depreciation from 30 to 40 years, in anticipation of the decision which the ASN made in 2005 to extend, in principle, the life of reactors from 30 to 40 years. In 2015, the ASN is due to make its next 10-yearly review of nuclear safety and possible extension of reactor life-cycles. In anticipation of a further extension, in principle, to 50 or even 60 years, EdF is pressing also to be able to spread depreciation over 50 or even 60 years, so that it has more money available to spend on immediate repairs, maintenance and replacement of components.

6 http://www.transition-energetique.gouv.fr/la-transition-energetique/synthese-des-travaux-du-debat-national-sur-la-transition-energetique. July 2013.

EdF is a company that carries a heavy debt. It also has a majority owner, the French state, which last gave the company a capital injection in 1982 and which has been slow to reimburse EdF for subsidy payments it must make to renewable electricity producers and for discounts to alleviate energy poverty. The company is supposed to recover these subsidy payments through a charge on its customers' bills, known as the Contribution to Electricity Public Services (CSPE in its French acronym). But for some years, this tax, whose level is decided by the government, has been insufficient to cover EdF's costs. The resulting deficit sits on EdF's books. It stood at €4.3bn at end-2012. The government has agreed to pay off the deficit with interest, but will only fully do so by 2018. Nor is France as open to outside investment as, for instance, the UK. It is hard to imagine the French state allowing EdF to call on Chinese help to invest in the French nuclear sector as the UK government is permitting EdF to do at the Hinkley Point project.

So one-for-one replacement of today's reactors looks most unlikely, at least from today's perspective. The picture could change if, at the time when a replacement decision would have to be made, energy prices in general, and electricity prices in particular, were much higher than today's levels. At present, EdF has to sell most of its electricity at regulated prices. Moreover, at the insistence of the European Commission which wanted to prevent EdF using its cheap electricity to totally dominate the market, EdF is obliged under a system known as Regulated Access to Historic Nuclear Electricity (ARENH by its French acronym) to sell about a quarter of its nuclear power to its competitors at a low fixed price (currently €42 per Mwh). The ARENH price is set at a level that covers EdF's current reactor operating costs, but because it is aimed at giving buyers the benefit of France's past investment in nuclear power, it explicitly excludes coverage of the future costs of replacing the 58 reactors. This is yet another indication of the lack of any serious provision for reactor replacement.

Continuation/prolongation of existing reactors?

This is by far the most likely option – for the simple reason that it maintains the status quo which is relatively satisfactory to all concerned, except to France's Greens and perhaps also President Hollande and a few of his fellow Socialists. French consumers can continue to get relatively cheap electricity either directly from EdF or, through the ARENH mechanism, from EdF's few rival suppliers in the French market. It also satisfies EdF, because it postpones the headache of planning any replacements for today's reactors. But it depends crucially on prolonging the life of existing reactors.

This is not a foregone conclusion. In contrast to the USA and Germany, no limit is fixed in advance on the life of nuclear power plants. Instead, France has a process in which every 10 years the ASN reviews the safety of an entire capacity level or *palier* within its nuclear fleet (for instance, all the 900 Mw reactors). It then makes a decision in principle on whether to prolong the life cycle of this tranche, with actual approval of life extension for individual reactors being decided one by one. The process involves examining the safety record of the type of reactor in question, both in France and abroad, over the previous decade, and reviewing modifications and improvements proposed by the operator (EdF). The declared aim is, at each 10-year milestone, to raise the level of safety above its previous level.

The last decennial review was in 2005, in plenty of time to negotiate modifications and award any necessary upgrading contracts before the oldest of the Mw 900 reactors – Fessenheim passed its 30th anniversary in 2009. The result of the review was to let the Mw 900 reactors go to 40 years. In exactly the same way, the next review will be in 2015, four years in advance of Fessenheim reaching its 40th birthday in 2019. As it happens, the one firm commitment that President Hollande has made is that Fessenheim should close by end-2016, in other words during his current term and before the next presidential election in 2017. In the absence of any generic fault being discovered between now and 2015, there is every expectation that the ASN will take the decision in principle to prolong the life of the Mw 900 tranche of reactors to 50 years. This would include Fessenheim, leaving President Hollande free to take his political decision about its closure.

Reduction of the nuclear share to 50 per cent of France's electricity mix?

Common sense would indicate that such a reduction would leave France less of a hostage to any future problems in the nuclear sector, and might actually enhance energy security. But closing Fessenheim will certainly not, by itself, reduce the nuclear share to 50 per cent by 2025. Fessenheim is an obvious target for a gesture by President Hollande, both to his Green allies and to Germany where its promised closure has been welcomed; the reactors are located on a canal linked to the Rhine in an area of some mild seismic activity that has always caused some local concern. But some in France have questioned whether President Hollande has the right to close the plant on grounds of policy or politics, and have suggested that any closure decision should be made either by the ASN on safety grounds or by EdF on operational or economic grounds. These complaints would grow if the president were to order other premature reactor closures.

'Very probably in the long term, nuclear will diminish, given new build costs, popular opposition and systemic risk – all these point to the probability that by, say, 2040 France will not have a 70 per cent nuclear in its mix', Mr François Lévêque has argued. But, he insists that,'as an economist, I would say it is completely stupid to close reactors early, it is throwing money out of the window. From an economic point of view there is no debate – it would be destruction of value'.

In theory, the proportion of nuclear generation should automatically decline as the share of renewables grows. France has an EU-agreed target to raise the renewable share of its total energy consumption to 23 per cent by 2020, which would reduce the nuclear share to around 27 per cent of its electricity mix. But the renewable share of electricity, produced and consumed, is still very small. Of electricity production in 2012, hydroelectricity accounted for 11 per cent, but this share has only grown very slowly. All other renewables amounted to another 5 per cent. As one international expert disparagingly puts it, 'at their present rate of growth, it would take renewables 178 years to replace French nuclear power'. The nuclear share might also automatically shrink if nuclear power output remained constant, while total electricity consumption expanded. But most forecasts predict flat electricity demand or at best a 1 per cent annual increase. If, contrary to these forecasts, electricity demand were to fall, then the nuclear share could actually increase.

Marriage of nuclear and renewables

If, in designing a country's ideal electricity mix, one had to choose an ideal source of back-up electricity for intermittent renewables, you would not choose nuclear power. The simplest and most economical way to run nuclear reactors is at stable levels close to full capacity to provide baseload electricity. But France is where it is as a result of a big nuclear programme, conceived long before climate change was deemed a problem or renewables a solution. The country is therefore fated to try to integrate nuclear and renewable power. So far their compatibility has not been put to the test, because, while France may have the highest combined share of nuclear and renewables in its mix of any country, the proportion of volatile renewable electricity is low. Later, as this renewable share steadily expands, other places will closely observe the results of this marriage.

The influx of must-run or first-run renewables onto the grid creates problems for nuclear, as for gas and coal, because renewables lower average wholesale electricity prices and reduce the call on all other forms of generation. But as an extensive study by the Nuclear Energy Agency of the Organisation for Economic Cooperation and Development shows, today's nuclear power plants will suffer less than gas or coal plants.[7] This is because existing nuclear plants, especially those which have fully amortised their capital costs, will find it easier to cover their relatively low variable costs (chiefly fuel) despite lower revenue from electricity sales. Justifying the huge initial outlay of capital involved in building of new reactors is another matter. As the study points out, 'in the long run, high-fixed cost technologies will be affected disproportionately by the increased difficulties in financing

[7] Nuclear Energy and Renewables: System Effects in Low-carbon Electricity Systems, OECD/Nuclear Energy Agency 2012.

further investments in volatile low-price environments'. This conclusion underscores the likelihood, already explored in this paper, that France will neither replace its current reactors nor terminate them prematurely, but run them for as long as possible, up to 60 years for some reactors.

Nuclear power is commonly supposed to be inflexible or, in the jargon, to be bad at 'load following'. This used to mean following the relatively minor gyrations of electricity demand or load. These days it means ramping nuclear output up or down to offset the far sharper fluctuations now occurring on the supply side, of weather-dependent wind and solar power. In fact, French reactors have considerable experience in load following, because their capacity has exceeded baseload needs at certain points in history (when in the late 1980s reactors were coming on stream faster than electricity demand was increasing) or at certain times of the year (low demand in summer). In Germany, nuclear operators have learned to load follow when surges of renewables have driven electricity prices below the marginal operating costs of their reactors, and therefore reducing power output makes sense.

Regulators in both France and Germany allow reactor operators to load follow within certain pre-set maximum limits on the rate and frequency of power variation. In the USA, load following is not automatically allowed, but even there nuclear power plants are required to engage in frequency control. In France, reactors have to be ready to reduce operating power by 2 per cent for primary frequency control, and by 5 per cent for secondary frequency control. Most older reactors cannot be operated for a prolonged period below 50 per cent of their rated capacity. France's EPR reactor, by contrast, has been designed to provide daily load following capability in a power range between 25 per cent and 100 per cent for 80 per cent of its fuel cycle. (For safety reasons, French reactors do not operate in load following mode for the first two weeks after a start-up and for the last 15 per cent of a fuel cycle).

Table 2: The Storm on St Jude's Day (28 October 2013) – nuclear shows flexibility

Time (28.10.2013)	00h00	04h00	12h00
Domestic demand	46,000 Mw	36,600 Mw	56,100 Mw
Onshore wind	5,913 Mw	5,868 Mw	5,767 Mw
Hydro-electricity	5,334 Mw	4,389 Mw	8, 076 Mw
Nuclear	40,607 Mw	34,081 Mw	45,420 Mw

Source: RTE

Generally speaking, France uses its nuclear power flexibly to cope with seasonal rather than daily variations in power demand. On occasion, however, French reactors can adjust quite dramatically in a short period of time. One such occasion occurred during the recent storm, on St Jude's Day (October 28) 2013, which hit northern France as well as southern England. As the table above shows, during the first part of that day the wind continued to produce nearly 6 Gw of onshore wind power (around 80 per cent of installed onshore wind capacity of 7.5 Gw), even when domestic demand dropped sharply in the small hours of the morning, as it usually does, from, in this case, 46 Gw at midnight to 36 Gw by 4am. This forced a 6 Gw reduction in nuclear output which, however, then was able to ramp up again by some 11 Gw in order to meet normal midday electricity demand (helped also by a doubling of hydro-electricity, a largely controllable source of generation).

This incident 'shows the de-stabilising impact of volatile wind power coming massively on to the grid during night-time hours of low demand', according to Jean-Jacques Nieuviaert, chief economist for the Union Française de l'Électricité.[8] 'It also shows', he concludes,' that nuclear is flexible enough, and much more so than coal or lignite, but this has a cost both in terms of lowering the utilisation co-efficient of reactors (increasing their marginal cost of production) and of de-optimising use of the fuel'.

[8] Author interview, November 2013.

Load following or load cycling also carries technical costs, as the NEA study points out. The extra wear and tear on some components leads to the need for extra inspections, repairs and replacements. The main consequence of this is slightly longer outages for reactors involved in load cycling. But an EdF study of 10 of their reactors practising load following compared with 10 reactors involved in nothing more than standard frequency control showed that load following only reduced reactor availability by 1.8 per cent.

The NEA study rates nuclear reactors, in the table below, as comparing relatively well with other forms of firm, dispatchable back-up power. In this role, they perform much worse than quick-reacting but relatively inefficient open cycle gas turbines and somewhat worse than combined cycle gas turbines, but are comparable to coal plants.

Table 3: Load following ability of various types of dispatchable power plants

	Start-up time	Maximal change in 30 sec	Maximum ramp rate (%/min)
Open cycle gas turbine (OCGT)	10-20 min	20-30%	20%/min
Combined cycle gas turbine (CCGT)	30-60 min	10-20%	5-10%/min
Coal plant	1-10 hours	5-10%	1-5%/min
Nuclear power plant	2 hours - 2 days	up to 5%	1-5%/min

Source: OECD/NEA, 2012

Capacity mechanisms

In the view of Professor Jan-Horst Keppler of Paris-Dauphine University, one of the authors of the NEA study, nuclear will, like gas and coal, need support from a capacity mechanism if it is to stay in a market experiencing a growing influx of subsidised renewables. Indeed he regards some of the European Commission's complaints about national capacity mechanisms fragmenting the European electricity market as 'bordering on the irresponsible',[9] because governments need to take action to prevent the impending shortage of back-up capacity from endangering continuity of electricity supply.

France is Europe's top electricity exporter, with net exports of 44 Twh of power in 2012 or 15 per cent of its national consumption. It runs a steady electricity trade surplus with all its neighbours, except for Germany which in 2012 was the source of half of France's total imports of electricity. But France has a problem, born out of its success in electrifying its heating system more than any other country in Europe except for Norway. The result is that one degree drop in temperature creates an extra 2.3 Gw load on the French system. This sensitivity to temperature change is such that France accounts for nearly half of the entire temperature sensitivity of power demand in the whole of the EU, amounting to 5 Gw extra load across the EU for every one degree drop in temperature. The normal load in France is around 80 Gw, but the record was 102 Gw in the very cold spell of February 2012. For about 10 days in that month, France had to draw on imports from virtually all its neighbours – the UK, Belgium and Spain, as well as Germany. 'These peaks seem to keep increasing', according to Yannick Jacquemart of the Réseau de Transport Electrique (RTE), the French grid operator.[10] As the chart below shows, annual peaks in load have increased by 33 per cent over the decade up to 2012, while total consumption has only risen by 15 per cent. After 2015, EU legislation will force the closure of heavy fuel and coal plants, and as a result, in 2016–17, the reserve margins of supply over demand will be very low. Furthermore, any further electrification of the economy, in heating or transport, will tend to augment peak demand.

9 Author interview, October 2013.
10 Author interview, November 2013.

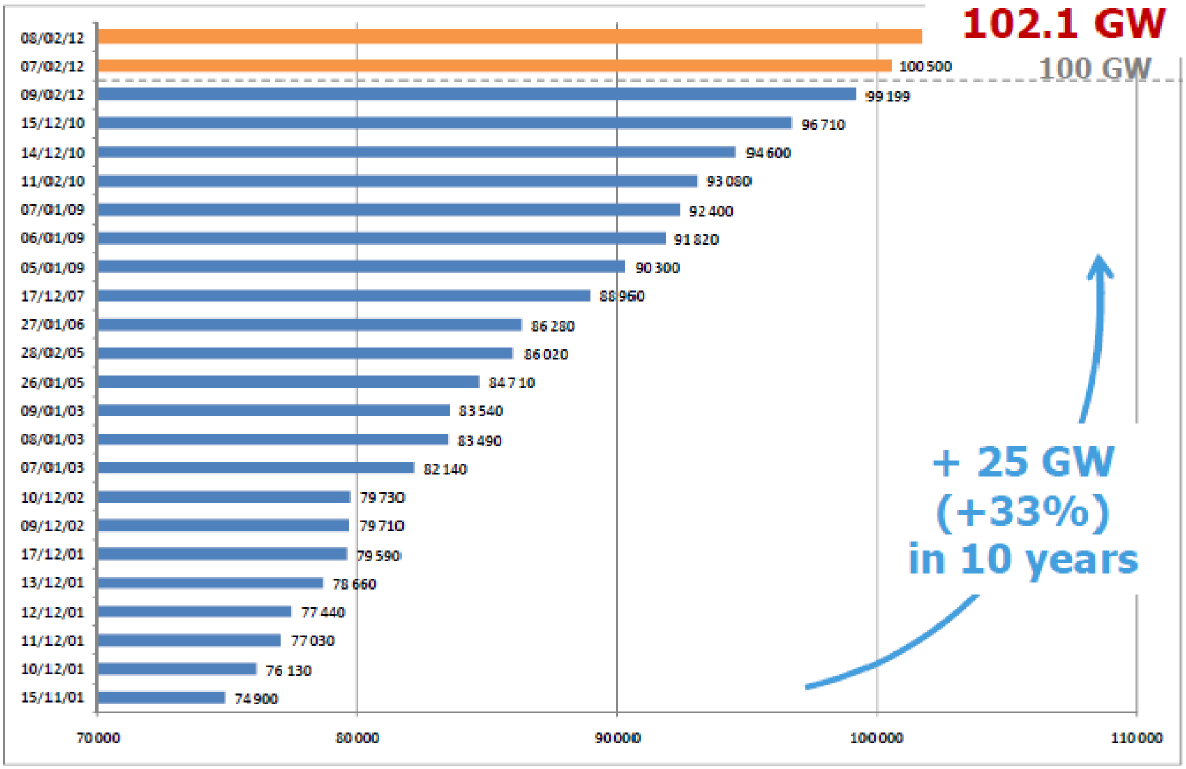
For the moment, France is relying on a combination of imports, expensive combustion turbines and demand-side measures to cover the peaks during cold winter evenings for an average of about 200 hours a year. In 2014, however, it plans to set up a capacity market, operating on both the supply and demand side, which would take effect in 2016. The basis of this is the imposition of reliability obligations on providers of final supply to electricity users. These suppliers will need to make advance forecasts of their customers' peak demand, and then to obtain sufficient reliability certificates to meet this peak demand. They will be able to do this either by paying their customers to agree to reduce demand by a certain amount in case of supply shortage, or by buying certificates directly from generators (or any generation which the supplying company may own) or by buying certificates traded on the capacity market. RTE will control the system – certifying guarantees of demand reduction and of supply provision, the latter on the basis of installed capacity and of the nature of the technology concerned. There will be penalties to ensure suppliers deliver enough power to their customers and to ensure generators or demand-reducers live up to their commitments.

The essence of the system is to place the responsibility on each and every supplier to balance supply and demand. It is, therefore, according to Fabien Roques of Compass Lexecon, a specialist on capacity markets,[11] 'a decentralised approach which puts the cost of balancing precisely on those causing imbalances'. He contrasts this with the UK plan for a more centralised capacity market which 'will tend to socialise the cost of security across all market participants'. He concedes that 'the decentralised approach may provide the authorities with less overall visibility of the capacity market, but making each supplier responsible for balancing is more compatible with current trading arrangements'. This French capacity plan has been welcomed by the country's trading partners, Germany in particular, and by the European Commission.

To placate the European Commission's concern about national capacity schemes becoming a restraint on cross-border trade, there will no curb on exports; suppliers will be left free to juggle any exports with their commitment, under threat of financial penalty, to supply the home market at peak times. No individual generator based outside France will be able to sell certified capacity into the French capacity market. But RTE plans to take account of the contribution of imports to security of supply. It will do this by calculating the average contribution of imports to meeting French peak demand, and by making allowance for this when setting the total level of capacity certificates circulating in France.

[11] Author interview, November 2013.

Figure: 1 Peak load hit 100GW for the first time in 2012



Source: RTE

Renewable energy

France has considerable natural potential for the development of renewable energy. In terms of dispatchable renewables, it has dams in the Alps to produce and stock hydroelectricity, and a large agricultural and forest sector to produce biomass. In terms of intermittent renewables, it can use its unique location as the only country to bridge the north and south of Europe to produce solar power in the south and wind power in the north and along its many coasts. Yet, efforts to increase renewables appear to struggle against a parallel awareness that renewables, at least in the short and medium term, will bring little environmental, security or industrial benefit. Nuclear energy has already largely decarbonized the country's power supply, and therefore replacing nuclear with renewables brings no benefit with respect to CO_2 emission reduction. France already has a well-diversified supply of gas from many sources via pipelines and LNG tankers. Using renewables to reduce the relatively modest amount of gas that France uses would therefore confer no advantage in terms of external energy security – and could be a positive disadvantage in reducing a good source of flexible back-up for renewables. Nor is France's renewable industry yet big enough to create much of an industrial policy logic for supporting the sector. According to ADEME, the government agency responsible for renewables as well as energy efficiency, the number of French citizens directly employed in the renewable sector has grown only modestly from 58,460 in 2006 to 83,260 in 2012, which is around a quarter of the level in Germany.

Nonetheless, France committed itself in 2009 to increasing the renewable share in its total energy consumption from 10.3 per cent in 2005 to 23 per cent by 2020. In terms of percentage points, this was the fourth most stretching target among the EU-28, only slightly exceeded, measured in percentage points, by the national targets which the UK, Ireland and Denmark accepted. (One reason may have been that this commitment came as part of the overall EU energy and climate package stitched together by President Nicolas Sarkozy, who chaired the EU Council of Ministers at the time).

We may struggle to reach the 23 per cent', says Francois Moisan, director of ADEME.[12] The reason for his caution is that while renewables now count for around 16 per cent of total electricity production, this share will have to rise to roughly 27 per cent of electricity output by 2020 if the overall 23 per cent target is to be met. French renewables are competing against some of the cheapest, and the most carbon-free, electricity in Europe. Almost all (87 per cent) renewable heat in France is produced with biomass, which is only increasing slowly and with little contribution from solar or geothermal power or heat pumps. 75 per cent of renewable electricity is still hydroelectric, which has hardly progressed for the past quarter century because of the absence of new dam sites that would not pose environmental problems. Onshore wind capacity is progressing, with 7.7 Gw capacity installed by end-2012, but solar PV lags behind with less than 5 Gw capacity installed.

A cause for concern is that the rate of new wind and solar deployment has slowed in the past year. The problems are several. The French wind energy association complains that the period between filing a project proposal and a wind farm's entry into service is 6–8 years in France, while in Germany the average is 2.5 years. Wind farm opponents (in particular, the organisation called *Vent de Colère*, literally Wind of Anger) have also challenged the legality of French wind subsidies in terms of EU state aid rules, and this legal uncertainty is hanging over the sector. The government is belatedly trying to boost offshore wind. It held a tender last year for 2 Gw of offshore wind, and is now holding a second one for 1 Gw, with the aim of reaching 6 Gw of offshore wind by 2020. While France does not have as much shallow continental shelf for placing offshore wind turbines as the UK, it has almost as much tidal power potential as the UK, and contains one of the world's oldest tidal power generators on the Rance estuary in Brittany. Visiting Cherbourg in autumn 2013 to launch a tender for four pilot projects off the Normandy and Brittany coasts, President Hollande said 'if our projections are correct there could be in the next decade three gigawatt installed off our coasts – it represents [the equivalent of] three reactors'.

The solar PV sector, on the other hand, in a mess. France, like many or most EU states, had 'a solar bubble' a few years ago, as developers rushed to reap windfall benefits created by a fall in the cost of Chinese-made solar panels to well below the generous solar subsidies still on offer. At the peak of the solar bubble in 2011, the subsidy for solar PV was €500 per Mwh, amounting to 62 per cent of all support for renewables in 2011, while production was only 2.7 per cent of renewable electricity in that year. Since then the government has cut tariffs for new solar subsidies by 20–70 per cent. As a result, 'solar in France is doing terribly', according to Thierry Lepercq, chief executive of Solairedirect.[13] Having installed 200 Mw in France, his company is the market leader with 6 per cent of a market that is so fragmented that 86 per cent of the installations contain 16 per cent of total PV capacity. In the last 12 months 400 Mw of PV capacity was installed, a quarter of the peak in 2011 when 1,760 Mw was installed. The head of Solairedirect, which operates in India and other countries outside Europe, says that while permitting takes an average of one month in India and six months in Germany, it can take as long as 36 months in France. But Mr Lepercq also complains that France is foregoing the chance to give itself an international edge in solar power by focussing its tenders in France too much on concentrated photo voltaics (which require expensive optics to focus sunlight on more compact arrays of cells), and too little on the more competitive technology of silicon crystalline photovoltaics with wider commercial potential.

The French market rates fifth in the world, behind Germany but ahead of the UK, for attractiveness for renewable investment, according to Ernst & Young's 2013 ranking of renewable markets. But this may be partly because their All Renewables Index gives a heavy 55 per cent weighting to wind, with 32 per cent for solar and 13 per cent for biomass.

[12] Author interview, November 2013.
[13] Author interview, November 2013.

The future increase in subsidies (see below), as estimated by the Commission de Régulation de l'Énergie (CRE), France's energy regulator, is not particularly steep, compared to those forecast in some other EU countries, although in addition to these operating subsidies, renewable energy projects benefit from various tax advantages.

Table 4: Forecast evolution of renewable electricity subsidies (million Euro)

	2013	2014	2015	2016	2017
Wind	561	531	581	641	697
Solar PV	1,899	1,990	2,101	2,182	2,257
Other renewables	330	654	868	1,029	1,176
Total	2,790	3,175	3,550	3,852	4,130

Source: Commission de Régulation de l'Énergie, 2013.

These estimates reflect the government's desire to pursue a gradual approach that avoids over-paying for de-stabilising quantities of renewables. The official government auditor, the Cour des Comptes, praised this prudence. Its 2013 audit of renewable energy and its costs, argued: 'the French strategy, which was sometimes described as too cautious, especially compared with German and Spanish enthusiasm, so far spares it [France] the difficulties these countries are facing'. Yet in the same report, the Cour des Comptes, warns that if France is to meet its EU commitments for 2020 'the extra renewable electricity and renewable heat to be achieved between 2011 and 2020 represents six and seven times, respectively, what was achieved in between 2005 and 2011'.[14] This would seem to indicate that France needs to accelerate its relatively slow start in renewables.

One advantage of the gradual approach, however, is that renewable generation has not run ahead of the grid's capacity, as it has in Germany. The hexagonal shape of the country means that its grid is better meshed than the strung-out British grid. France's production zones for wind along its several coasts, and in the south for solar power, are not as separated from consumption centres as Germany's stark split between wind in northern Germany and industry in southern Germany. Much of the modern high voltage grid has been created for nuclear power plants, which need to be located near water. The nuclear plants are therefore sited along the coasts or along the Loire and Rhone rivers, locations that coincide quite well with areas of renewable potential. While there are good connections to the traditional hydroelectricity sources in the Alps to the east, RTE says that France needs more north–south links to exploit wind power in the north and solar power in the south, as well as improved interconnections with neighbouring contries. Even so, just as much as its neighbours, France needs to extend and improve its low-voltage grid to which most renewables are linked.

Prices, competitiveness and efficiency

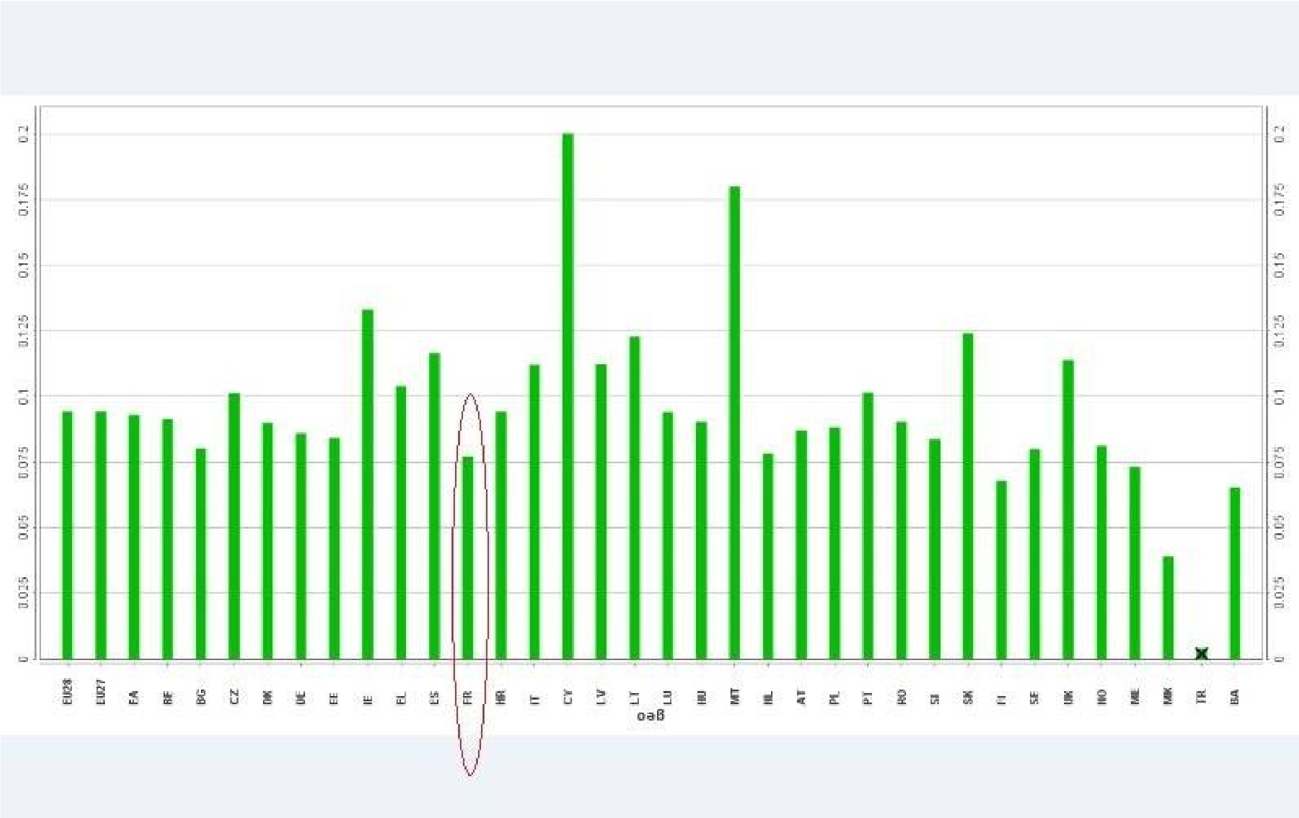
Thanks to nuclear power, France has relatively low electricity prices. These have made it hard for competitors to enter the French market, and they have also acted as a brake on further improvements to energy efficiency. By virtue of owning all nuclear reactors in France, EdF has been able to dominate the French electricity market long after EU liberalisation policies swept aside its legal monopoly. The true cost of French nuclear power is not easy to calculate, because it depends on assumptions about discount rates and about the amortisation schedule of the capital costs of the country's 58 reactors. But EU action has shed some light on nuclear power costs.

As a result of pressure from the European Commission to enable some competition in the French market, France passed a law in 2010 establishing the ARENH system. This requires EdF to sell 100 Twh of electricity, or around a quarter of its nuclear output, each year to rival suppliers at a price

[14] Author interview, November 2013.

reflecting the historic investment and current operating cost of its 58 reactors, plus a 'normal margin'. The price of this ARENH power is currently Euros 42 per Mwh, which for example is below the average spot price in France of Euros 47 per Mwh in 2012. (If the ARENH price were to also reflect the costs of a future generation of reactors, which it is not allowed to do, it would be considerably higher).

Figure 2: Electricity prices (excluding tax) for industrial consumers (euros per Kwh) Jan–June 2013



Source: Eurostat

This table charts the average national prices, excluding taxes, charged to final consumers during the first half of 2013 for medium size industrial companies with an annual consumption of between 500 and 2,000 Mwh. It shows that the average price in France (circled in red), at €0.0771 per Kwh as being nearly the lowest in the EU, thanks largely to France's past investment in nuclear power. This French price is only slightly lower than the German price, but the competitive concern of French industry is that, while French and German medium size companies pay more or less the same price, electricity-intensive companies in Germany pay a very small proportion of the German renewable energy levy and are exempt from grid access charges. So they end up paying less for their power than their French counterparts.

Any premature closure of reactors or refusal to prolong their life cycle to 50–60 years would lead to an increase in electricity prices. This is the, almost certainly correct, assumption of the Union Française de l'Électricite (UFE), which has illustrated its point with three scenarios for 2030. The first one is a 70 per cent nuclear scenario, which assumes that the lifetime of existing reactors is extended and that two EPR reactors are built (the first under construction at Flamanville and the second one that is pencilled in at Penly). Renewables would increase to meet France's targets for 2020, but remain virtually stable thereafter until 2030. The second scenario is more or less President Hollande's commitment to reduce nuclear power to a 50 per cent share of generation, with a compensating increase in renewables and an accompanying increase in conventional generation as back-up. The third scenario would reduce the nuclear share in generation to 20 per cent by shutting every reactor on its 40th birthday, and require a huge increase in renewables and the installation of further fossil fuel back-up capacity. The UFE estimates that, compared to the 70 per cent nuclear business-as-usual scenario, the 20 per cent nuclear option would lead to a wholesale price *increase* of €38 per Mwh, or almost the absolute level of today's regulated ARENH price. Pursuing a radical reduction in nuclear generation would mean, according to the UFE, saying goodbye to 'the relative competitive advantage enjoyed by France as a result of the investments made in nuclear power in the 1970s and 1980s'.

To French industry's concern that a change in the country's electricity mix will erode competitiveness is now added its fear that US manufacturing will draw a new cost advantage from cheaper shale gas. This fear is compounded by the fact that France has now passed a law forbidding the extraction of shale gas by hydraulic fracturing, which is so far the only known means to extract it.[15] In its 2013 World Energy Outlook, the International Energy Agency forecasts that the gap between lower electricity and gas prices in the US and higher ones in Europe and Japan will persist for many years, with the result that Europe and Japan will lose market share to the US in global exports of energy-intensive goods.

Even before the shale gas phenomenon burst upon an unsuspecting world, the electricity-intensive sector in France was concerned about securing the supply of electricity. Since 2008 a group of 26 companies, including Air Liquide (industrial gases), ArcelorMittal (steel), Rio Tinto (metal products), Rhodia (chemicals) and Total (refining), have been in a consortium, known as Exeltium, formed to make long term purchases of electricity from EdF over a 24-year period; the consortium had to make adjustments to reassure the European Commission that this collective purchasing was not effectively foreclosing the French power market to other electricity suppliers. The companies concerned, however, now complain that their Exeltium arrangement has been undercut by cheaper power available under the ARENH system, and that they are obliged to deduct their Exeltium-contracted amounts of electricity from the power they are allowed to buy at ARENH prices.

Yet, overall, the electricity-intensive sector is not a very big part of French industry. The industry ministry's division responsible for competitiveness of industry and services defines an electro-intensive company as one which uses more than 2.5 Kwh for every euro's worth of value added, and rather precisely puts their number at 523 companies or 3 per cent of French industrial companies. These electro-intensive companies, which employ some 97,000 people, account for about half the electricity consumption of manufacturing industry. They are also are more geared to exports than the mass of French industry. These companies do not have an enormous world market share to lose. Among steel exporters, France ranks 12th in the world, and 6th in paper and cardboard, another electro-intensive sector. One of the reports compiled for President Hollande's national debate was the work of a committee, intriguingly chaired by a Green member of the National Assembly but with a

15 Faced with the ban on hydraulic fracturing, some French scientists have suggested two alternatives of a) using liquid CO_2 as a fracking fluid, and b) using explosives or electric pulse fracturing. However, they caution that to prove their safety and effectiveness, both techniques would need underground testing, which might mean they run up against the same objections as fracking.

rapporteur from the Medef employers' federation.[16] This report on the planned energy transition's impact on competitiveness concluded that 'the sectors likely to be most exposed to competitive impacts from high energy prices represent a relatively small part of the French economy. It is therefore difficult to affirm – even if this point remains to be quantified more precisely – that the French economy depends to any large extent on low energy prices, since 95.2 per cent of economic activity are not exposed to international competition or to severe energy intensity'.

This report noted that a rise in French electricity prices would have the disadvantage of hitting French companies in particular, in contrast to increases in the global price of oil that affects all oil users around the world. But it suggested that increased electricity prices would encourage energy efficiency, leading to economy-wide productivity gains that could outweigh any damage to electricity-dependent companies, which could be helped with special sectorial measures. France has seen a reduction of around 30 per cent over the past 30 years in the amount of energy needed to produce one unit of output. But this is in line with declining energy intensity in all mature industrialised economies over this period. An abundant supply of cheap electricity has obviously not incentivised energy saving in France. Indeed a long-serving official responsible for energy efficiency remembers that, in the 1980s when new nuclear reactors were regularly coming on line, electricity saving was discreetly *discouraged* – 'it was not said like this, but the attitude was we have the electricity, we must use it'.

A modern version of this attitude is provided by the UFE. The electricity industry association argues that the first priority of French energy policy should be to reduce carbon emissions, which are now primarily produced in the heating and transport sectors. So it calls for a policy of 'transferts d'usages', using more carbon-free electricity (from nuclear and renewables) to replace heavy fuel oil in heating and using carbon-free electricity, as well as gas and biofuels, to replace petrol and diesel in transport. In a small way this is happening already. In the hope that electric cars will catch on, the Bolloré group has created an electric car sharing scheme called Autolib in Paris, Lyons and Bordeaux. This energy-use switching allows the UFE to reject the idea that France has to cut its energy consumption in half (Facteur 2) in order to reach its goal of cutting its emissions by three-quarters (Facteur 4). Germany may have to slash its more carbon-intensive energy consumption to reach future emission reduction targets, says the UFE, but France has no need to. Along the same lines is the view of Pierre Audigier of the *Sauvons Le Climat* network. 'It is a false idea that energy saving is always the best option – not if it is cheaper to provide decarbonised electricity than to save energy'.[17]

Conclusion

An accidental combination of the Fukushima catastrophe, of Germany's decision to accelerate its exit from nuclear power, and of the twists of French electoral politics, has led France to start debating its 'energy transition'. But the debate has been useful. It has begun the questioning of how long France's nuclear sector will last, and of the systemic risks while it does last. It has shaken the widespread complacency that France accomplished the necessary transition to carbon-free electricity long ago, and that any further transition should just be more of the same – extending electricity further into the transport and heat sectors.

France faces no urgent decision about the fate of its relatively young reactors. Prolonging the lives of most of these reactors to 50 years or some even to 60 years is the most sensible course of action. Replacement of these reactors is still a distant issue. But the huge cost that is now apparent for the new EPR reactors makes it a big issue, and a bigger one for France than for its customers in Finland and the UK. For these countries are only contemplating buying a few EPRs, France would need several dozen to replace its current generation of reactors one-for-one.

16 http://www.transition-energetique.gouv.fr/la-transition-energetique/rapports-au-conseil-national-du-debat
17 Author interview, November 2013.

So what needs to be done to reduce the scale of this future transition? First, the government should do what it can to prevent the nuclear share of generation rising further and thus magnifying the challenge of diversifying away from nuclear. Obviously it can do little or nothing if the cause of an increase in the nuclear share were to be a collapse of electricity demand. However, the government has said the EPR at Flamanville will not be allowed to come on stream before Fessenheim closes. Second, prolongation of the lifetime of current reactors will have some accounting consequences for EdF that will free up extra money that EdF could return to its majority owner, the French state. The government could in turn use this extra money to give French renewables a needed boost. As we have seen, the marriage of nuclear and renewable power is not impossible. France has little to fear from a more ambitious approach to renewables. Third, French electricity prices need to rise, in order to reflect the future cost of replacing at least some of today's reactors, to give renewables more of an economic chance in the French market, and to encourage energy efficiency.

Finally, it will be important to spread out over time the future replacement of reactors. It might appear economically rational to try to extend the life of all current reactors to 60 years. This is what EdF is pushing for, in principle. In practice, however, it would make no sense. Having the majority of its reactors that were built over a concentrated 15-year period in the past all come to the end of their life in a 15-year period in the 2030s and the 2040s would present France with an impossible reconstruction challenge. France will not, in the future, be able to rebuild all that it built in 15 years in the past. Better to retire some of today's reactors at 50 years or less, and so stretch out the task of replacement.