Nuclear: not up to energy and climate challenges

Nuclear power supporters see the emergence of an ambitious nuclear programme for the short and medium term as a cornerstone of the solution to the energy and climate crisis that humanity is facing. Fully endorsing this thesis, the President of the French Republic would try, during his Presidency of the European Union, to convince its European colleagues that a voluntarist nuclear revival plan is an inescapable rescue for Europe; thus he would propose this to be a major part of the 'energy and climate package'.

We question In this chapter the real capacity of such a plan to bring a decisive contribution, in the required timeline, to the goals of European energy security and short and medium-term mitigation of greenhouse gas emissions. In particular, we show what lessons could be drawn from the French experience, often displayed as an exemplary success on those two issues.

Global Chance

Energy & climate

Nuclear, short of power to solve energy and climate issues

1. The converging of risks in the short-term

In today's world facing a surge in prices of fossil energy products and fears of a climate upheaval in the short term, nuclear power seems to be moving up the political agenda once again. This comes after a 20-year period of global stagnation of which the French are generally unaware. Both in the EU institutions and at international level, the French Government is pressing for a strong revival of nuclear energy in countries which already implement the technology and for widespread access to nuclear energy for civil uses in countries which do not have it yet, particularly in the Mediterranean countries.

The main arguments put forward in support of this revival are climate change and energy security. **What are these two risks?**

The climate risk

The latest report by the Intergovernmental Panel on Climate Change (IPCC) shows the urgent need to take action to avoid the worst in terms of global warming. It first shows that if the global average temperatures in the atmosphere rise 2.5°C-3°C above pre-industrial levels, there is a strong risk that irreversible impacts, such as the melting of permafrost, a highly reduced role of forest cover and oceans as carbon sinks, will occur. These phenomena, in turn, can lead to unavoidable destabilisation of the climate. This is the reason why regions such as Europe have set a target which, if it became a multilateral commitment, would enable the global average temperature rise not to exceed 2°C.

Comparing the scenarios defined by climate experts shows that the only reasonable chance of statistically reaching the '2°C constraint' is if humanity manages to stabilise concentrations of all greenhouse gases (GHGs) between 400 and 450 parts per million by volume of CO_2 equivalent (ppmv CO_2eq) in the long term. However, the analysis also highlights that if GHG concentrations go significantly beyond this target threshold at any time in the intermediate period between 2020 and 2100 (above 475 to 500 ppmv), it is likely that it would become impossible to reach the target at all and that irreversible climate impacts would occur.

In 2005, atmospheric concentrations of CO_2 had already reached 379 ppmv and since the year 2000, global emissions of GHGs, as a whole, have been increasing at a rate of 3% per year and this upward trend shows no sign of reversing. Clearly, under these conditions, it is likely that the maximum acceptable concentration will be exceeded well before 2050.

Consequently, the climate question will arise in a far shorter term than policy-makers generally imagine. To avoid uncontrollable destabilisation of the earth's climate, a turning point needs to be reached in the extremely short term followed by a steep decline of around 40% of global emissions by 2030 (in t CO_2eq[1]) compared to 1990 levels.

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[1] One t CO_2eq: tonne of CO_2 equivalent, a conventional common unit to measure the emissions of all greenhouse gases.

This implies that policies must be adopted and implemented to reduce emissions of GHGs, each of which has a different impact on the climate over time. These emission reductions have to target very different sectors.

Energy security

National and regional energy security is generally – and wrongly – limited to **security of energy supply**. Obviously, it also depends on several other parameters. In addition to vulnerability in relation to raw material imports, depending on the nature of the energy products (and the associated geopolitical conditions), economic sectors and energy efficiency in the different sectors, there are a series of parameters concerning the vulnerability of economies on a domestic level: vulnerability to natural phenomena (rainfall, wind patterns, floods and droughts, hurricanes, earthquakes, etc.) or technological accidents, disturbances caused by man (malevolent action, strikes, peak consumption phenomena, etc.). Again, analysis of energy security infers not only analysis by technology, product, energy carrier, economic sector and region, but also an analysis of the wide range of alternative solutions in the event of a crisis.

Energy security problems in Europe are thus not limited to questions of dependence on oil or gas even if the recent and extremely sharp rise in the cost of these raw materials and the fear of resource shortages has rightly been the focus of attention of the Governments, citizens and consumers.

Rapid and vigorous action

These energy security and climate change concerns are not new.

However, what is new is that the associated risks are today no longer recognised as long term risks, likely to occur towards the end of the century, but as short term risks arising before or around 2030. The scale of values of the solutions put forward to deal with these two crises primarily depends on their potential dynamics to penetrate in the next 20 to 30 years.[2]

Not only do economic and financial considerations lie at the heart of these questions of dynamics but also a whole series of issues concerning technical training, social and industrial organisation, spatial planning, as well as regional and world trade.

Nuclear energy in the face of these issues

It is thus against the backdrop of these issues that the potential revival of nuclear energy must be assessed. If not, there is a high risk, as has happened several times in the past, that we will harbour illusions and let ourselves in for numerous difficulties.

2. In 2006 where are we at?

Figure 1 shows the breakdown of world primary energy consumption in 2006 by energy source. It can be seen that the source ‘primary electricity’[3] accounts for 9% of total world consumption. Taking into account the internationally recognised coefficients of equivalence between TWh (electricity production) and Mtoe,[4] the share of nuclear energy in the primary energy balance is 6%. World electricity production reached 2,800 TWh in 2006. Nuclear energy accounted for 15% of this total, renewable energy for 23%, and fossil fuels the remaining 62% (Figure 2).

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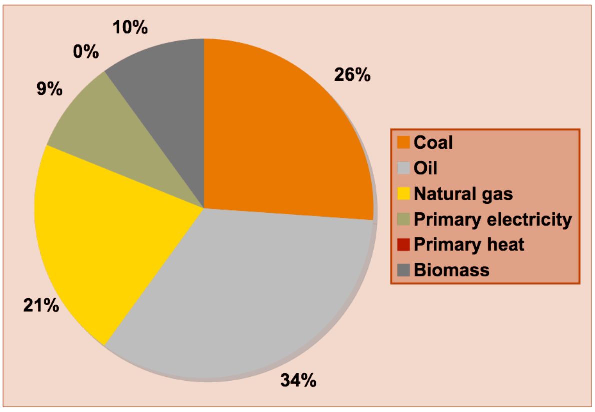
[2] That is the reason why a series of technological step changes, such as controlled thermonuclear fusion, and even 4th generation reactors (which will not be commercially available until at best 2080 and 2040 respectively, according to their promoters) do not appear to be plausible solutions to the problem.

[3] Mainly made up of nuclear- and hydro-generated electricity, but also wind and photovoltaics. World production of the latter two energy sources is still marginal.

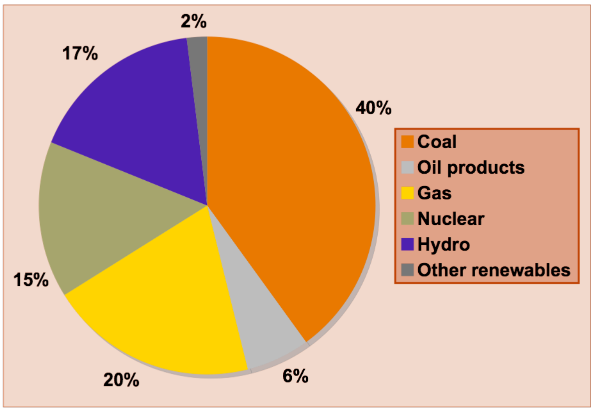
[4] 1 TWh of nuclear power = 0.21 Mtoe and 1 TWh of electricity produced from renewable sources = 0.086 Mtoe (TWh: TeraWatthour or billion kWh).

Figure 1 World primary energy consumption by source (2006)



Source: Enerdata

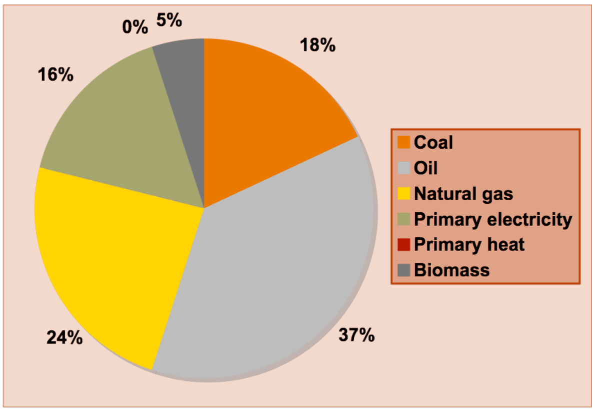
Figure 2 World electricity production by source (2006)



Source: Enerdata

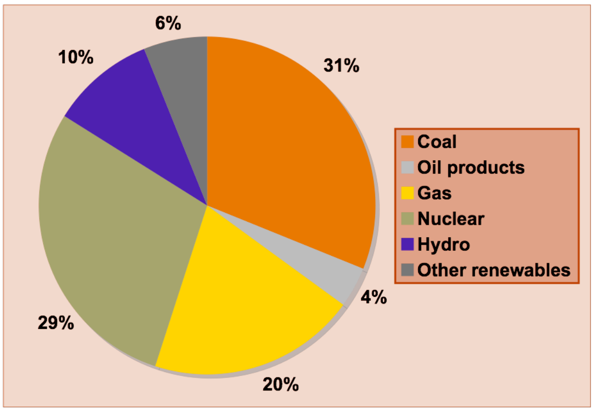
Primary electricity consumption in the 27 Member States of the European Union (EU-27) (Figure 3) accounted for 18% of its total primary energy consumption in 2006, ie double the share at global level. Nuclear power accounted for 13% of this primary balance. Nuclear generated electricity production in the EU-27 (Figure 4) accounted for 29% of total electricity production after coal (31%) and ahead of gas (20%) and renewable sources as a whole (16%).

Figure 3 EU-27 primary energy consumption by source (2006)



Source: Enerdata

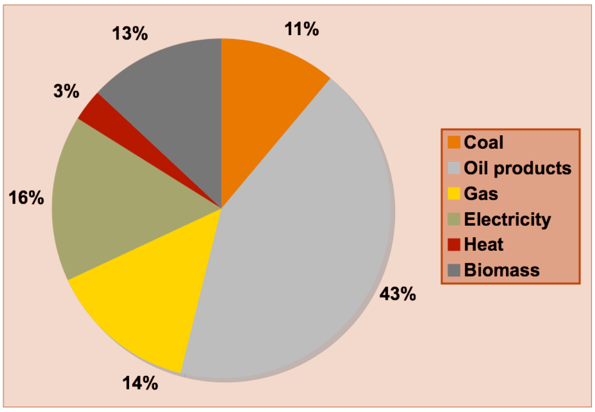
Figure 4 EU-27 electricity production by source (2006)



Source: Enerdata

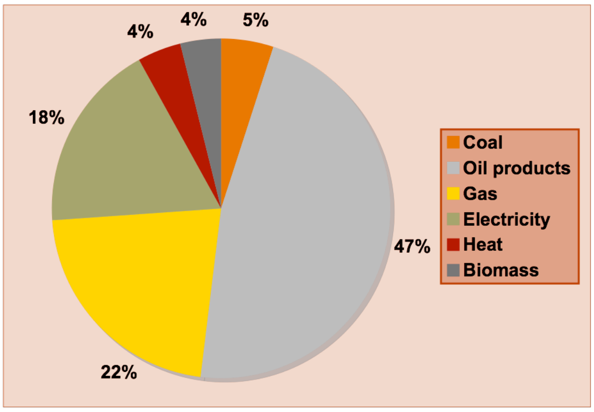
It is important to complete this general overview by an analysis of final energy consumption by energy source in the world and in the EU-27. This is the energy actually supplied to users after the conversion process: gas, electricity and heat to households, fuel for the tanks of heavy goods vehicles and cars, and for factories etc. (Figures 5 and 6).

Figure 5 World final energy consumption by product (2006)



Source: Enerdata

Figure 6 EU-27 final energy consumption by product (2006)



Source: Enerdata

Since electricity's share in the world final energy balance is 16% (Figure 5) and nuclear energy accounts for 15% of electricity production (Figure 2), it follows that the share of nuclear energy in world final energy consumption is 2.4%.

Similarly, as electricity's share in the EU-27's final energy balance is 18.3% (Figure 6) and nuclear energy accounts for 29.5% of electricity production (Figure 4), it follows that the share of nuclear energy in the EU-27's final energy consumption is 5%. Table 1 summarises these data:

Table 1 Share of nuclear energy in energy consumption (2006)

Share of nuclear energy in 2006 (in %)	In primary energy consumption	In electricity production	In final energy consumption
World	6%	15%	2.4%
EU-27	13%	29.5%	5%

Source: Enerdata

The share of nuclear energy in total electricity production varies enormously depending on the different countries. Three countries alone, the United States, France and Japan account for 56% of world nuclear-generated electricity production. France alone produces 45.5% of nuclear-generated electricity in the EU.

In France, and for year 2007, oil products represented 49% of total final energy consumption, far ahead of gas (21%), electricity (21%) and thermal renewable sources (6%). Final electricity consumption was 424 TWh, of which 24 TWh imported, 50 TWh from fossil fuelled power plants, 60 TWh from hydro power plants (and a small wind contribution) and 286 TWh from nuclear power plants. Which leads to a 67% contribution of nuclear in the final electricity consumption. Since the share of electricity in final energy consumption is 21%, the contribution of nuclear to the total final energy consumption of France is then 14%.

The claim that nuclear ensures the French energy independence is obviously farfetched. Table 2 shows the share of nuclear energy in national electricity production in the main countries which implement this energy technology. It highlights France's very specific situation in this field.

Table 2 Share of nuclear energy in national electricity production (2005)

Country	France	Ukraine	Sweden	South Korea	Japan	Germany	UK	USA	Russia	Canada	Rest of world
Share %	79	48	46	38	28	26	20	19	16	15	8

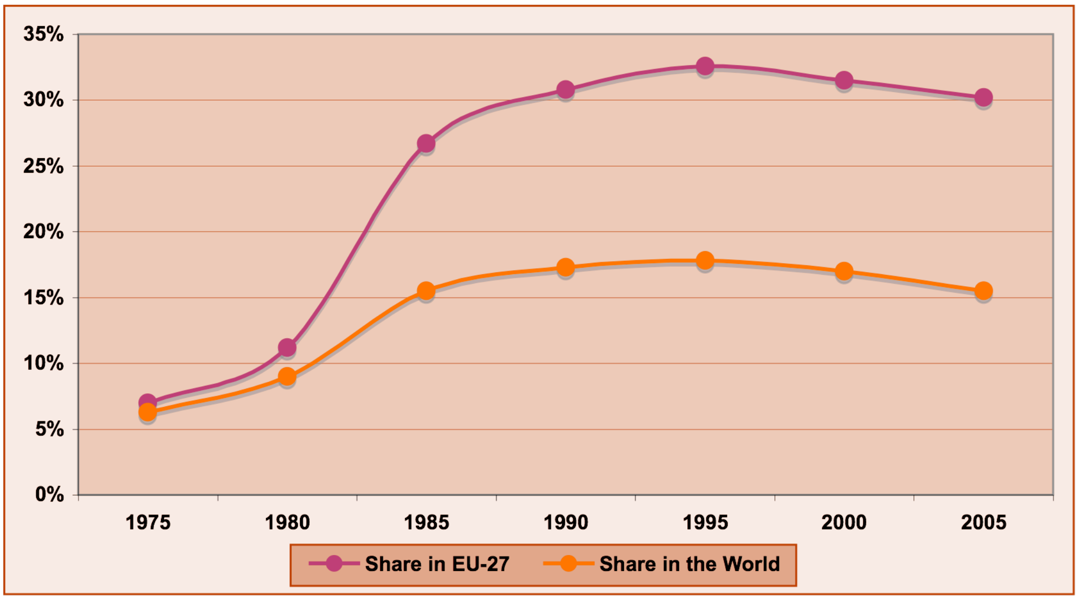
Source: IEA, *Key World Energy Statistics*, 2007

What has happened over the last two decades?

In the last 20 years, there has been a 40% increase in nuclear generated electricity production: 2,800 TWh in 2008 compared to 2,010 TWh in 1989. However, installed capacity, 371 GW in early 2008 (439 reactors) compared to 328 GW in 1989 (423 reactors), has only grown by 13%. This is a result both of orders for new build stagnating and an improvement in the use rate of existing plants.

During the same period (1989-early 2008), nuclear generated electricity production in the EU-27 rose from 775 to 999 TWh, ie +29%.This is less than the global increase (+40%). However, during the same period, world electricity production rose by 63% and that of the EU-27 by 33%. Changes over time in the share of nuclear generated electricity in world and EU electricity balances (Figure 7) logically show a peak around 1995 followed by a decline since then.

Figure 7 **Share of nuclear generated electricity in total electricity production in EU-27 and in the world (1975-2005)**



Source: Enerdata

Changes in capacity of the different sources of electricity production in recent years (Table 3) illustrate the reasons for this decline in the nuclear share which has been accentuated since the beginning of the 21st century. Worldwide, between 2000 and 2006, 18 times more gas generated electricity capacity was brought on stream than nuclear capacity, 13 times more coal generated electricity capacity, five times more hydro and even three times more wind.[5]

Table 3 **Increase in world installed capacity between 2000 and 2006, by source**

Source	Coal	Oil	Gas	Biomass	Nuclear	Hydro	Wind	Total
x1,000 MW	280	28	398	11	22	105	53	897
Share	31%	3%	44%	1.3%	2.4%	11.7%	6%	100%

Source: Enerdata

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[5] The table indicates installed capacity. In terms of electricity generated, a fossil fuel-fired power plant or a nuclear power plant, with the same capacity, and operating on base load, will supply between 2 and 3 times more electricity than a wind turbine subjected to the intermittent character of the wind.

CO_2 emissions avoided in 2006

In order to assess the CO_2 emissions avoided by the different nuclear energy programmes at world, European and national levels, it can be assumed that if there were no such nuclear programmes, the electricity substituted would be produced by a range of sources similar to that which we see today minus nuclear power.[6] On this basis, global CO_2 emissions avoided in 2006 as a result of world nuclear programmes would be 1.8 Gtonnes of CO_2. This figure would be 0.43 Gtonnes for the EU-27.

These emissions avoided in 2006 would account for 3.6% of global GHG emissions (50 Gt CO_2eq) and 10% of GHG emissions in the EU-27. If this analysis is confined to CO_2 emitted by energy systems, it is estimated that the nuclear programme would account for a 6% reduction in emissions worldwide and for a 15% reduction in the EU-27.

However, if, as part of the fight against climate change, all currently operating nuclear power plants were replaced by modern gas turbine power plants,[7] this would require an additional consumption of 420 Mtoe of natural gas (+17%), which would lead to 1 Gtonne of CO_2 emissions. Europe would use an additional 135 Mtoe of natural gas (+30%) which would cause an additional 320 Mtonnes of CO_2 emissions. Table 4 summarises the various aforementioned data for 2006.

Table 4 **Nuclear energy's contribution to avoid GHG emissions in 2006**

Nuclear energy's contributions to:	World	EU-27
Reduction of CO_2 emissions from the energy system	6%* to 4%**	15% to 11%
Reduction of emissions of all GHGs (in CO_2eq)	3.6% to 2%	10% to 7%

* current configuration of electricity production
** natural gas combined cycle gas turbine power plants

Source: Global Chance

In realistic terms, this is what nuclear power represented in 2006 in terms of the fight against climate change. It is obviously not insignificant. However, it is important to bear in mind that the impact of current nuclear programmes on GHG emissions, even in Europe, remains minimal and has been decreasing each year since the 1990s.

Nuclear and greenhouse emission reduction in France. In 2005, the total emission of GHG in France is 553 Mt CO_2eq, of which 378 tonnes of CO_2.

To evaluate the contribution of nuclear to the CO_2 emission reduction, we compare the level of emission of the nuclear system with the emission of the natural gas combined cycle power plants which would deliver the same quantity of electricity to the final consumer (see above). Depending on the level of emission attributed to the nuclear system , the difference in emission level is 60 to 100 Mteq CO_2eq, that is 15 to 20% of the total greenhouse gas emission of France: it is far from negligible but 80% or 85% are remaining.

If nuclear electricity is replaced by renewable electricity, the gain on emission reduction is the same, or even superior (for wind energy for instance).

Energy security

The global consequences of nuclear programmes on the world's and the EU-27's supply have been indicated in terms of primary energy (respectively 6% and 13% using the coefficients of equivalence for electricity production) and of final energy (respectively 2.4% and 5%). This global analysis must be completed by an analysis by sector and by energy source. Thus:

- **Electricity:** It is well-suited to certain uses in the residential, tertiary and industrial sectors but almost impossible to use in some sectors, such as road, air and maritime transport. In practice, the

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[6] The corresponding 'electric mix' is as follows: for the world, 21% renewable sources, 48% coal, 24% gas, 7% oil; and for Europe: 22.5% renewable sources, 44% coal, 28% gas, 5.5% oil.

[7] Combined cycle gas turbine power plants which reach a 58% energy efficiency.

specific features of nuclear generated electricity limit its uses to 'base load' operations (relatively stable use over a long period of the year).

- **Oil**: 68% of the consumption[8] of oil for energy purposes is due to transport at world and EU levels. The contribution of current nuclear programmes to the required substitution of oil is very small. Conversely, nuclear energy can be used as a substitute for oil in the industry sector, and more marginally, in the residential sector where electricity for heating may be supplied by oil-fired power stations (for back-up purposes) during peak consumption periods.
- **Coal:** This is where the contribution of world nuclear programmes is the greatest by replacing coal-fired electricity generation capacity which provides a similar service (base load or semi-base load power) and, via electric heating or specific electric processes, meeting industrial and residential sector needs. In the latter sector, electric heating is produced from coal during peak consumption periods.
- **Natural gas**: Current nuclear generated electricity in part replaces gas-fired electricity production capacity and, via electric heating, it replaces industrial and residential sector applications. In the latter sector, electric heating is produced from gas during peak consumption periods.

Table 5 illustrates these different points for selected European countries whose use of nuclear energy to produce electricity is highly heterogeneous.

Table 5 **Per capita consumption of fossil energy products and nuclear share in electricity production in selected European countries in 2007**

Consumption per capita (toe)	EU-27	Germany	France	Italy	UK
Oil	**1.32**	**1.36**	**1.46**	**1.31**	**1.33**
of which electricity production	*0.05*	*0.03*	*0.04*	*0.12*	*0.02*
Natural gas	0.88	0.95	0.62	1.17	1.35
of which electricity production	*0.28*	*0.22*	*0.09*	*0.47*	*0.45*
Coal	0.66	1.02	0.22	0.29	0.63
of which electricity production	*0.5*	*0.86*	*0.11*	*0.2*	*0.53*
Nuclear share	**28%**	**22%**	**77%**	**0%**	**16%**

Source: based on Enerdata

It can be seen from the table that a country like France which produces almost 80% of its electricity from nuclear energy consumes more oil per capita than the European average as well as Germany (22% share of nuclear generated electricity), the UK (20% share of nuclear generated electricity) and Italy (0% nuclear generated electricity).

It is thus obvious that nuclear power, contrary to widespread opinion, was not an effective answer to oil pressure in 2006. It is not the same for gas or coal, per capita consumption of which in France is lower than the European average (-25% for gas and -69% for coal). Finally, it should be noted that if all nuclear power plants were replaced in France by combined cycle gas turbine power plants in order to provide the same amount of electricity to the final consumer, this would require a consumption of 47 Mtoe of natural gas, or 34 Mtoe of natural gas plus 7.5 Mtoe of primary electricity produced from non thermal renewable sources (hydro, wind, solar PV). The per capita consumption of natural gas would increase by 0.6 to 0.8 toe,[9] but the primary energy consumption per capita would fall by 1.4 toe.[10] In these conditions, the quantity of natural gas 'replacing' nuclear would represent 16 to 20% of total primary energy consumption.

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[8] Excluding non-energy uses.

[9] Fact Sheet n° 4 in "Petit mémento énergétique – Eléments pour un débat sur l'énergie en France", *Les Cahiers de Global Chance*, special issue n° 1, January 2003.

[10] The reason for this difference is the poor thermodynamic efficiency of nuclear power plants (33% as opposed to 58% for combined cycle gas turbine power plants) and the energy consumption of the nuclear fuel cycle (in particular Eurodif, the uranium enrichment facility).

Other aspects of energy security

Centralising the means of production, exacerbated in the case of nuclear power,[11] makes a country highly vulnerable to the consequences of an electricity production or transport failure, particularly owing to the large size of the plants and sites. In the case of a high share of nuclear generated electricity in total electricity production (greater than 25 to 30%), and of course even higher in France (79%), possible generic breakdowns, which can affect a whole generation of power plants, are a further major source of vulnerability.

In addition to these different sources of domestic insecurity, there are intrinsic vulnerabilities associated with the nuclear industry: the supply of uranium, the risks of a major accident, environmental risks as a whole and risks of proliferation resulting from the nuclear fuel cycle. These problems will be dealt with specifically in the second part of the report.

In summary

The nuclear industry has been in relative decline over the last 10 years compared to other means of producing power and, more generally, energy. In 2006, its contribution to the world's final energy demand was less than 2.5%. Its contribution to the EU-27's final energy demand was 5%. This is obviously very low.

Nuclear energy enables between 2 to 3.6%[12] of GHG emissions to be avoided at global level, and between 7 to 11% at EU level. Worldwide, it prevents the use of an additional 420 Mtoe of natural gas and 550 Mtoe of coal (respectively 17% and 18% of current consumption).

Conversely, its effect on oil consumption remains altogether marginal.

Beside the specific risks that nuclear energy incurs (major accident, proliferation, waste), it creates particular vulnerabilities given its extremely centralised means of production.

3. The issues up to 2030

Is the currently planned, or rather proclaimed revival of nuclear power, both at global and EU levels, such that it will significantly change the order of things in the next 20 years with regard to energy security and climate change?

To assess the real issues, it is useful to take a closer look, in light of recent developments, at the SUNBURN world nuclear revival scenario[13] produced in 2005, the main assumptions of which are as follows:

- A universal solution, in the sense of refusing to exclude certain countries for ideological, political or economic reasons, etc.;
- Maintaining the national character of programmes that we know today until 2030;
- Base load operations (around 7,000 hours per year) to ensure sufficient profitability of the installations;
- A minimum threshold for annual electricity demand below which it cannot be envisaged, for supply security reasons, to bring new nuclear plant on stream. The minimum threshold proposed in the scenario is 4 GW. Combined with the assumption of base load production, this leads to an access threshold of around 60 TWh/year;[14]

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[11] Owing to the size of reactor units and the difficulties in finding sites (in France, 58 reactors located on some 20 sites which generated a net total of 419 TWh of electricity in 2007). The size of coal-fired power plant sites can however reach similar proportions to those of nuclear plants.

[12] Depending on the type of substitution envisaged.

[13] B. Dessus, Ph. Girard, "Le scénario SUNBURN de relance du nucléaire mondial", *Cahiers de Global Chance*, n° 21, March 2006.

[14] Basic needs account for about 50% of total annual needs.

- Contributions to base load production from other energy sources: hydro: 30%, wind: 20%, biomass: 60%, waste and geothermal: 100%;
- Lifetimes of the power production facilities ranging from 20 to 50 years depending on the technology used, construction times ranging from 1 year (wind) to 6 years (nuclear) and lead time to launch nuclear programmes ranging from 3 to 5 years for countries previously with no nuclear power.

Based on these assumptions and drawing on the 2004 'Business as usual' scenario published by the International Energy Agency (IEA),[15] the SUNBURN scenario estimates, by country or geographical region, year on year, basic power needs, existing capacity on stream and its contribution to base load power production, renewable energy capacity installed and its contribution to base load power production, and lastly, the remaining needs likely to be met by nuclear energy. A more or less large share of this remaining need is thus met by nuclear energy, given the initial lead times for starting nuclear programmes and industrial dynamics.

Based on these assumptions, there would of course be an extremely rapid development of world nuclear power from 2015 onwards. Under these conditions, new capacity coming on stream, around 3 GW per year on average between 2000 and 2005, would reach some 20 GW by 2015, 40 GW by 2020, 75 GW by 2025 and over 100 GW by 2030 (ie the equivalent of the current capacity of the US nuclear reactors on stream), this means a world market multiplied by 50 in 25 years. Nuclear capacity would amount to 1,200 GW in 2030, generating almost 9,000 TW of power per year. Some 30 new countries (8 in Europe,[16] 4 in South Amercia , 5 in Africa, 5 in the Middle East and 7 in Asia) would have nuclear power. The EU-27 would generate 1,400 TWh in 2030. Despite the abundance of cheap local coal resources, China, India and South Korea alone would generate almost 1,400 TWh in 2030.

However, even in circumstances so obviously propitious to nuclear energy, the consequences on CO_2 emissions and fossil fuel reserves would remain relatively insignificant. Comparing this with IEA's scenario, in which nuclear capacity is maintained at current levels, sheds an interesting light on the matter:

If it were fully implemented, the SUNBURN scenario would enable 9% of total CO_2 emissions from energy to be avoided in 2030 compared to IEA's forecast scenario (5 to 6% of GHGs as a whole in 2030), but only 2.9% of cumulative emissions from 2006 to 2030 in this same scenario, ie seven times fewer emissions in 2030. Furthermore, it would enable a 15% saving of fossil fuel-generated energy in 2030 but only a 5% saving of the cumulative fossil fuel-generated energy used between now and 2030, mainly coal and natural gas. It would prove to be widely ineffective for oil.

In Europe, this revival would enable a 200 Mtoe saving of natural gas (30%) in 2030 and 480 Mtonnes of avoided CO_2 emissions compared to a total phase-out of nuclear power in 2030.

When all is said and done, this situation is quite similar to the one we experienced in 2006.

The authors of the SUNBURN scenario strongly emphasised the many vital issues to be resolved:

- The financial question, with an annual investment of € 50 billion per year on average from 2015 to 2030, on the basis of an estimated cost, at the time, of € 1500/kW (with an exchange rate of €1 = $1.20);
- The question of a need for a skilled workforce requiring 500 000 technicians to be trained before 2030 for production facilities and control authorities yet to be created;
- The question of industrial capacity, both to build the power plants and to set up the fuel cycle, or to open new uranium mines;
- The question of governance, with the need for major investments in human resources and organisation on the part of countries wishing to adopt a nuclear energy programme in the next 10 to 15 years, but also the need to define and adopt international rules applicable to all

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[15] *World Energy Outlook 2004*.

[16] Including Portugal, Italy, Poland, Greece, Austria and Denmark.

countries concerned (transport of raw materials and waste, measures to protect against the risk of proliferation, safety and security of nuclear installations, etc.). In connection with this, a recent memorandum issued by the French Nuclear Safety Authority (ASN) insists on this issue in unequivocal terms, with a subheading as follows: “Let's be clear. Learning nuclear safety is a long process.”[17]

Not to mention of course the specific risks that this nuclear revival would incur (risks of major accidents, proliferation, waste) due to the increased number of installations, their rapid geographical spread and the irreversible nature of the technological solutions that such a scenario would entail by imposing the success of the challenge of widespread use of nuclear power in most countries of the world, relying on large-scale use of plutonium, which will have become essential for the sake of making the resource last.

Three years on, where are we at, beyond the declarations, in relation to this vision? First of all, it should be noted that in 2007 nuclear power production continued its decline (-2% compared to 2006) and that no large-scale programme has been launched since 2005. Construction of the only two planned reactors in Europe, the Finnish and the French EPRs (admittedly, with the exception of the two Bulgarian reactors Belene 1 and 2 officially under construction since 1987) has been beset with difficulties and significant delays (at least two years for the Finnish EPR).

It can also be seen that there has been a surge in nuclear power investment costs in dollars since 2000,[18] +170%, a far greater increase than for wind power investment costs (+110%) and particularly for coal-fired power plants (80%) and gas-fired power plants (90%). In these conditions, it is highly unlikely that the major Asian countries and the United States which have significant and cheap coal resources will give up using this energy source for base load power production and take up nuclear energy on a large scale.

Similarly, the lack of investment in research and production of uranium over the last 10 years has led to tension in uranium prices which have increased tenfold on the spot market since 2002. Although spot market prices went back down to half that peak by mid-2008, the odds are that some tension will continue and even increase since lead times for the opening of new mines keep getting longer. Lastly, since 2005, political tensions both in North Korea and Iran surrounding the nuclear issue have heightened the international community’s mistrust of a certain number of countries gaining access to nuclear energy, even if it is for non-military uses.

In light of these developments and despite the optimistic attitude of nuclear energy proponents, it appears clear that achieving such a scenario, which in 2005 was already considered particularly optimistic, is more and more unlikely (even with an additional 4 to 5 years’ lead time, which would have serious consequences in 2030).[19]

More recently, for no clear reason, the IEA cast aside its usually reserved stance on world nuclear growth capacities in 2030.[20] On behalf of the G8, it produced a much more pro-nuclear energy scenario.[21] It is based on the relatively simplistic assumption of a growth rate of nuclear energy in relation to world GDP similar to that which it showed during its most prosperous period. On this basis, the “bluemap” scenario, the most pro-nuclear one, drawing on plans for strong potential development as stated by China, Russia, South Africa, the United States, Ukraine and India, and estimating future nuclear energy investment costs at around $ 2,500/kW, projects that world nuclear power production will amount to about 6,000 TWh in 2030 and 9,000 TWh in 2050. But, unlike the SUNBURN scenario, this industrial-type analysis avoids any description of regional needs and constraints, does not address

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[17] The position of the French Nuclear Safety Authority (ASN): "Safety of the new plans to build nuclear reactors in the world must be ensured", 16 June 2008.

[18] Cambridge Energy Research Associates, *Construction Costs for New Power Plants Continue to Escalate*: IHS CERA Power Capital Costs Index.

[19] A five-year delay would cause a 30% fall in projected nuclear power production in 2030.

[20] In the Outlook 2004 and 2006 scenarios, nuclear energy growth stagnated or was slow (2 GW per year in *Outlook 2006*).

[21] *Energy Technology Perspectives 2008, Scenarios and Strategies to 2050*, AIE.

the issue of uranium resources and seems highly optimistic regarding investment costs in relation to the reality of today.[22]

Let us nevertheless imagine that it can be implemented in the timeframe envisaged. According to the IEA itself, it would enable 5% of CO_2 emissions from the energy system in 2050 to be avoided (around 3.5% of GHGs as a whole).[23] Not only is this a very small amount in absolute terms but also in comparison with other options put forward by the same study and in particular the saving of electricity generation, estimated alone to be more than double (10%) and incurring far lower costs.

Beyond the issues of political and economic credibility that they give rise to, all the studies focusing on a large-scale revival of nuclear power thus show the marginal nature of the results that can be expected in the medium term (2030) from the point of view both of energy security and climate change.

To say the least, it is far from having being proved that large-scale use of nuclear energy to address the main challenges facing humanity in 2030, climate change and energy security, is vital. In any event, nuclear power's contribution to solving these questions will be marginal.

On balance, on the basis of this marginality, deliberately omitted from the views aired by nuclear proponents, an analysis must be conducted of all the major political, economic, environmental and social problems that a large-scale revival of nuclear energy at EU and world level, as proposed today by the French Presidency of the EU, would give rise to.

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[22] These costs are under-estimated by 30 to 40% compared to the estimated costs of the Finnish EPR reactor.

[23] To the point where it is questionable whether the IEA did not deliberately produce this optimistic scenario to emphasise the ineffectiveness and lack of interest compared with other GHG emission reduction options.

Focus 01 Electricity savings versus nuclear revival?

In its report *Energy technology perspectives 2008: Scenarios and strategies to 2050*, the IEA proposes a scenario for a global relaunch of nuclear power which would allegedly enable an annual electricity output of 6,00 TWh to be achieved by 2030 compared with 2,800 TWh today, thanks to the installation of an extra 500 GW of capacity (as compared to its 'business-as-usual' scenario of nuclear stagnation), at an overall investment cost of at least €1 trillion. If extended until 2050, this programme, with an output of 9,000 TWh, would represent 6% of the minimum effort required to limit global CO_2 emissions to 14 gigatonnes per year at this point. In the same study, the IEA examines all the other possible means of reducing emissions by 2050, as shown in Table 6.

Table 6 **Contribution of the different options for reducing CO_2 emissions from the energy system by 2050**

CO_2 emission reduction activity areas	Gigatonnes of CO_2	Reduction (%)
Sequestration of CO_2 in industry	4.3	9%
Sequestration of CO_2 in electricity production	4.8	10%
Nuclear power	2.8	6%
Renewables	10.1	21%
Total for generating activities	***22.0***	***46%***
Efficiency and substitutions in electricity production	3.4	7%
Substitutions in final energy use	5.3	11%
Electricity savings	5.8	12%
Fuel savings	11.5	24%
Total for energy savings	***26.0***	***54%***
Total	**48.0**	**100%**

Source: IEA, 2008

Energy savings play the leading role with 54% of the total, followed by renewable energy at 21% and CO_2 sequestration at 19%. Nuclear power comes last of all with 6% of the total reductions, half the figure for electricity savings.

To illustrate this last point, it is worth recalling that in 2006 the IEA also published a report, *Light's labour's lost: Policies for energy-efficient lighting*, entirely devoted to a programme for electricity savings in the global lighting sector and the various consequences of this. This report states that total electricity consumption for lighting reached 2,650 TWh in 2005, or 19% of total global electricity consumption. The IEA then compares the projected consumption in a business-as-usual scenario and in a scenario in which low-energy bulbs are systematically installed wherever the annual level of use warrants it. Energy savings achieved by this means would reach 1,635 TWh a year by 2030, equivalent to half the additional nuclear electricity production proposed by the IEA.

But what would be the investment cost of this? The IEA gives cost estimates of $1 per 100W incandescent bulb with a lifespan of 1,500 hours, and $5 per low-energy bulb with a lifespan of 10,000 hours (around seven times as long). On this basis, since incandescent bulbs would have to be replaced 20 times between now and 2030, as against three times for low-energy bulbs, the cumulative investment required for this programme of supplying low-energy bulbs would reach $ 75 billion in 2030, compared with a cost of nearly $ 100 billion for the incandescent bulbs which would have had to be replaced seven times as often[24] – to say nothing of the electricity savings that would be achieved each year, of the order of $ 165 billion by 2030.[25]

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[24] A total purchase of 100 billion incandescent bulbs between 2010 and 2030 compared to 15 billion low-energy bulbs over the same period.

[25] Assuming a cost of 10 cents per kilowatt hour.

France, showcase for the limitations of nuclear power

> *"The production of energy with low CO_2 emissions requires to mobilize renewable energy sources (…) and nuclear generation. Any decrease of the share of nuclear energy in electricity production (75% today) would make it impossible to reach greenhouse gas emissions reduction targets."*
>
> **Report from the Energy Commission, chaired by J. Syrota, on 2020-2050 energy perspectives for France, Conseil d'Analyse Stratégique (CAS), February 2008**

> *"Nuclear energy accounts for 6% of final energy in Europe, 2% worldwide and 17% in France. Given these percentages, focusing the debate on nuclear energy in order to build up a climate strategy does not seem justified. In France, the areas that need urgent attention are existing buildings, transport and the development of combined heat and power technology (CHP) in industry."*
>
> **Report from the Working Group on "Achieving a fourfold reduction in greenhouse gas emissions in France by 2050", chaired by Ch. de Boissieu, August 2006**

While the contribution of nuclear power to the energy consumption is undoubtedly marginal at a worldwide scale – hence its potential role in solving energy and climate crisis at that level –, its distribution is also very uneven. Only 31 countries run nuclear power plants, and the 6 biggest producers (United States, France, Japan, Germany, Russia and South Korea) generate almost 75% of the world's nuclear electricity production.

Confronted to the issue of scale limitation for nuclear energy, the advocates of nuclear renaissance take argument of this situation and claim that at least, nuclear power has a major role to play in countries or regions where it is already developed and that are ready for more – altogether in the technical, economic and political sense. Although there is no evidence from the past of a clear advantage in terms of energy security and mitigation of greenhouse gas emissions for countries operating large nuclear fleet,[26] the idea is worth consideration for the future.

Then comes the case of France. With 78% of its electricity production provided by nuclear power plants, the country has pushed the use of nuclear energy as far as it could be using current technologies. Its "all electric, all nuclear" plan, which remained the pillar of its energy policy since the programme started in the mid 1970s, has no equivalent in the world. The analysis of the real contribution of this development to France's energy security, and now climate policy, therefore provides a unique benchmark for similar plans currently discussed in other countries.

The original myth of energy independence

The idea that developing a domestic fleet of nuclear power plants would provide "energy independence" to the country by cutting down its dependency on oil became a decisive argument to launch a large programme of PWR reactors just after the first oil shock in 1973. The argument is still, 35 years later, the cornerstone for most decisionmakers' support for nuclear energy in France.

Yet the reasoning was biased from the beginning. In 1973, electricity production was only the fourth sector for French oil consumption, with 11.7% of the total (including non energetic uses), well behind transports (24.4%), residential and tertiary use (25.7%), and industry and agriculture (21.3%). This was actually the reason for promoting, as a complement to the construction of reactors, the extension

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[26] The archetypal example being, of course, the United States that are the world leaders of both greenhouse gas emissions and nuclear electricity generation, with respectively more than 20% and around 30% of the world total in 2007.

of the use of electricity in sectors where this would be achievable, first the industry then the residential and tertiary sectors (through electric heating).

The substitution of nuclear power plants to fossil fuel-fired ones successfully brought down the share of electricity production in the French oil consumption down to 1.5% by 1985. By that time, about 30 reactors out of the 58 PWRs currently operating had been started-up. It is also the time when the counter oil shock, in 1986, put an end to ambitious energy efficiency policies that had been developed for the previous years following the oil shocks of 1973 and 1979. Altogether, the intensity of efforts on the demand side in the industry, residential and tertiary and transport sectors, related to the evolution of oil price, had much more influence on the level of French oil consumption than the nuclear programme alone.

This is true in both ways. Between 1973 and 1985, the reduction achieved in the power sector was only half of that obtained from the combined efforts on demand in the industry and residential and tertiary sectors. But the laxity of these policies from 1986, and the global lack of demand side policy in the transports sector reverted the decreasing trend to a growth of oil consumption up to now. According to the Ministry of Industry, the contribution of oil in terms of French final consumption reached a peak of 94 Mtoe in 1973 and went down to 74 Mtoe in 1985. The constant increase trend ever since has just brought the contribution of oil back to the record level of 1973, with 93 Mtoe in 2007 (see the part on evolution from the past years in Figure 9, below.) The actual dependency on imported fossil fuel is even higher if one considers that over the same period, the contribution of gas to French final consumption went up from 10 Mtoe in 1973 to more than 40 Mtoe in 2007.

Nuclear programme is nevertheless still considered a major contributor to French energy security in official reports. According to Government accountancy, it has brought French energy independence up from less than 25% to more than 50% – 50.4% exactly for the year 2007. This figure is based on a controversial choice to calculate the energy independence (the ratio between the energy domestically produced and consumed by the country) in primary rather than final energy: this allows for the two-thirds of primary energy used in nuclear power plants that are actually lost as heat in the atmosphere to be accounted for as produced… and consumed.

It is of course paradoxical that this large amount of wasted energy (roughly of the same order as the total oil use in the French transport sector) plays a positive role in the calculation. The absurdity shows when one considers that replacing French nuclear power plants, which reach a 33% efficiency, with less efficient plants would actually increase the official energy independence, while replacing them with hydropower and windmills, both assumed to have 100% efficiency, would bring it down to a mere 30%.[27]

Therefore it appears much more realistic to use a calculation based on final energy produced and consumed in the country. This implies, however, to make some choices in the calculation on how to account for energy losses, electricity exports, etc. Depending on those, published estimates range from less than 10% to 18% independence.[28] This is more consistant with the fact that nuclear power, after all, only accounts for 75% or more of the electricity produced in France, and electricity in turn only accounts for around 20% of French final energy consumption.

The difference between the two calculations is central to understand the huge gap that could develop between the importance given to nuclear power when discussing energy and climate options, and its real impact.

It should be noted that the authorities introduce other bias to enhance the role of nuclear power when they reduce energy security to the simple measurement of an ‘energy independence’ ratio. The first one is to discard any similarity when reasoning on security of supply of oil and uranium. On one hand, 99% of the oil used in France is imported and most of it (around 90%) is refined in France. On the

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[27] It is interesting to note that even the planned improvement of new reactors performances, should these reactors replace the current ones with all things even, would have a negative impact on the calculated energy independence: this would drop from 50% to 48% if using the European Pressurized water Reactor (EPR, aimed to reach 36% efficiency) for replacement, and 42% if using hight temperature reactors reaching 50% efficiency or so.

[28] See in the first part of this chapter Global Chance’s calculation of a 14% energy independence ratio for France in 2007.

other hand, 100% of the uranium used in France is imported since the last French mine closed in 2001, and most if not all of it is enriched and fabricated into nuclear fuel in France. Yet nuclear electricity is accounted for as domestic production, while oil use is accounted for as imported energy, one reason given being the difference in the number and nature of supplying countries.

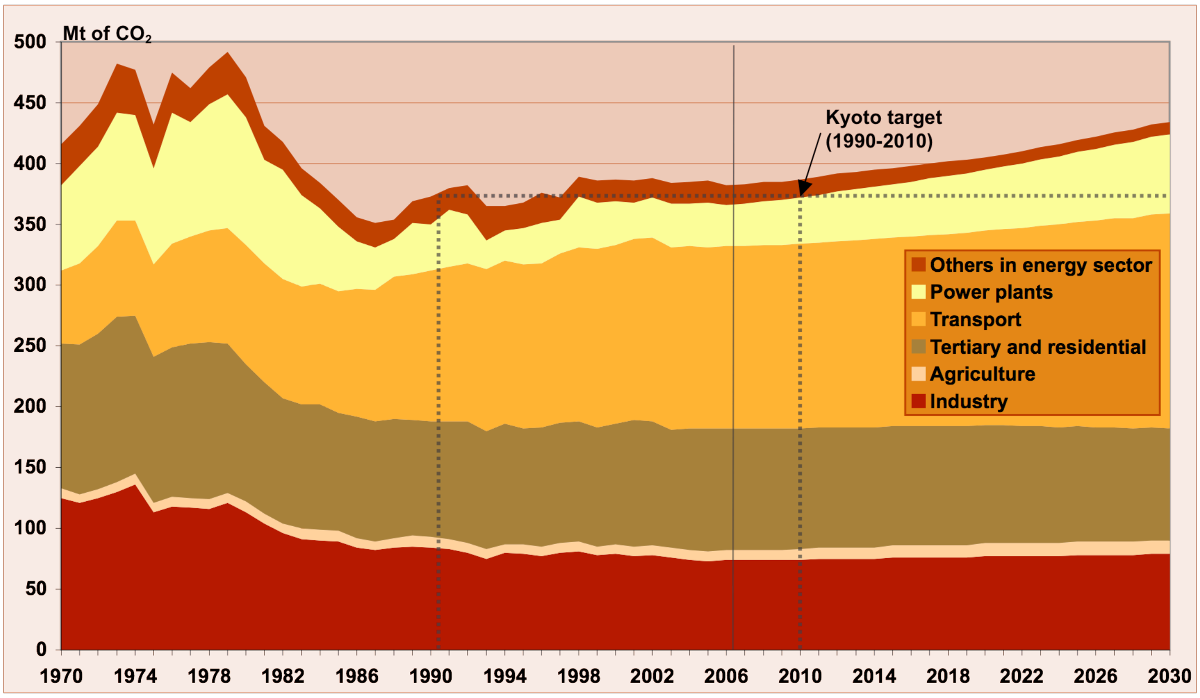
The second bias is to ignore any energy security issue besides the security of supply at the boarders, as if the domestic energy system were not impacting on the risk of energy shortage for end-users, which is what energy security is really about. The highly concentrated organisation of the electric grid that goes with nuclear power is not neutral regarding the potential for grid failures and their consequences. This systemic effect was involved in the very large extent, compared to the neighbouring countries, of the electric blackout following a record-breaking tempest in December 1999.[29] Moreover, the high dependency on nuclear power plants to 'fuel' the French economy and society with indispensable electricity creates, in addition to the remaining vulnerability to oil imports at least for transports, another serious vulnerability.

The inherent limits to the substitution logic

The failure of nuclear power to provide France with real energy security stresses the limits of an approach to energy policy that is based on technological substitution. Although this was obviously not intended at the time when the programme was decided, this rationale of substituting nuclear power to fossil fuels has been later extended to the growing issue of mitigating greenhouse gas emissions.

Figure 8 shows how the substitution mechanism applies to the evolution of greenhouse gas emissions – and more specifically to the CO_2 emissions from energy production and use, which are those concerned with nuclear development and account for roughly three quarters of France's total GHG emissions.[30]

Figure 8 **Past evolution of CO_2 emissions from energy production and use in France by sector and projection in a "business as usual" scenario (1970-2030)**



Source: Observatoire de l'énergie, DGEMP, 2008

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[29] More than 3.4 million households were left without electricity at the peak, of which more than 500,000 for at least 5 days. In 25 departments (or about one fourth of the total territory) it was more than 50% of the population that was affected.

[30] The CO_2 emissions shown in the figure are those calculated by the Energy Observatory, with a slightly different method than the official United Nations Framework Convention on Climate Change (UNFCCC) method.

The figure clearly shows the impact of the development of the nuclear programme from the start-up of the first French PWR in 1977. But the decrease is also due, for a great part, to the efforts during that period on the demand side. These efforts drop dramatically in 1986 and from then, the growth of energy demand as a whole results in more increase of new fossil fuel consumption than is substituted by new nuclear reactors. Once all nuclear power plants are in service and an upper limit of substitution is reached, there is no more counterbalance to the overall growing trend.

The relatively low level of French GHG emissions, compared to similar countries, was taken into account to attribute its share of burden to France as part of emissions reduction for the European Union in the framework of the Kyoto Protocol. As a result, the French objective under the Protocol is only to maintain its level of emissions in 2008-2012 compared to their 1990 level (one should note that the choice of this year of reference, when emissions were peaking after the steady decrease of the 1980s, was already quite favourable for France).

But the trend, according to the 'business as usual' scenario published in 2008 by the Directorate general for energy and primary materials (DGEMP), is a constant growth of emissions for the next years and up to 2030 (Figure 8.) Consequently, France with all its nuclear power plants is not on the right tracks to respect its Kyoto assignment regarding CO_2 emissions.

This situation has nothing to do with some kind of nuclear phase-out. On the contrary, the DGEMP scenario assumes that, beyond the start-up in 2012 of the EPR under construction in Flamanville, more EPRs will be constructed to compensate for the shutdown of ageing reactors, so as to maintain all the way until 2030 a total installed nuclear capacity of 65.4 GWe, compared to 63.3 GWe in 2008. This is hardly 'business as usual': it represents about 52 GWe of nuclear reactors to be replaced between 2015 and 2030, roughly an average of 2 EPR reactors per year. The problem is that maintaining the nuclear capacity brings no more substitution but drains resources away from other energy options, while the rest of the energy system just grows.

Nuclear in France and the 'Factor 4'

Obviously something different will be needed if France is to aim not only for maintaining, but furthermore reducing its GHG emissions. It has actually set for itself a very ambitious goal for the long term with the 'Factor 4' concept.[31] This objective is based on the assessment by IPCC on projected temperature rise depending on global GHG concentrations. As it was put by the French Prime minister Jean-Pierre Raffarin at the opening of the 20th plenary session of the IPCC in Paris in 2003, "global GHG emissions must be halved by the year 2050"; for France, "this is equivalent to a fourfold or fivefold cut in emissions."[32]

The objective has been incorporated in French law through the Energy Policy Act n° 2005-781 of 13 July 2005 and its Article 2, which states that "tackling climate change is a priority of the energy policy, which aims to reduce by 3% per year on average French GHG emissions." Moreover, "France supports the establishment of a twofold cut objective for world GHG emissions by the year 2050, which implies, given the different level of consumptions between the countries, a fourfold to fivefold division of emissions for the industrialised countries."

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[31] This application to greenhouse gas emissions is derived from the much broader 'Factor 4' concept introduced by E. U. von Weizsäcker and A. Lovins in a 1997 report to the Club of Rome, *Doubling wealth – halving resource use* (Earthscan Publications Ltd).

[32] The reasoning behind is as follows. The equilibrium of temperatures on the low side of projected warming by the year 2100 (i.e. a temperature rise of 2°C or less) implies, according to the models, that GHG concentrations are stabilised at 550 ppm by the year 2050, which roughly correspond to a stabilisation at 450 ppm of CO_2 alone.
This, in turn, implies that annual emissions in 2050 would have to amount to no more than 14.7 Gt of CO_2, roughly half of the current level of emissions. This corresponds to 2.3 t of CO_2 per person per year based on the current word population of 6.5 billion people. If this burden had to be shared on the basis of an equitability principle, France and its current 61 million inhibitants would be entitled to 138 Mt of CO_2 emissions, compared to French emissions of 382 Mt of CO_2 for the year 2006.
Finally, this target of 138 Mt of CO_2 emissions in 2050 is assumed to be about one quarter of a projected growth of French emissions up to 550 Mt of CO_2 in 2050 if prolonging the current trend up to then. The factor four has later been further interpreted as a need to reduce emissions in 2050 to a quarter of their reference level in 1990.

It should be underlined that this self-compulsory objective was set prior to any elaboration of a French official energy and climate scenario matching this factor 4 goal. In fact, the first prospective scenario demonstrating a path to reach a 4-fold reduction of French CO_2 emissions by 2050 was published by an independent group of energy experts, négaWatt, in 2003. This scenario, updated in 2006, is based on a comprehensive implementation of energy sufficiency and efficiency on the demand side and of renewable energies on the supply side.[33] It therefore considers no need to build new nuclear reactors, even for replacing the existing ones when they shut down: it stresses that achieving the potential efforts to curb down energy demand is necessary *and* sufficient for keeping it to an absolute level of primary energy which the potential of renewables can reach on the long term.

On the contrary, official scenarios that have been developed since are bound to some continuity with the nuclear power precept. In that sense, they fully illustrate the potential contribution of this energy to meet long term energy and climate objectives.

The first 'factor 4' study commissioned by the Ministry of economy in 2004 was published in 2005.[34] The authors are themselves very cautious with the results, as the long-term part of the scenario (up to 2050) is based on a model of equilibrium between energy supply and demand that is built on the rules of the past while the need for real rupture is recognised by all experts. The model favours the share of electricity in final energy and that of nuclear power in primary energy, but that is a "possible factor 4 scenario" which "might not be the most desirable, the most economic or the most likely".

This scenario, which actually achieves a 3-fold reduction of emissions between 2000 and 2050 – considered as a sufficient burden for France inside a 4-fold reduction of emissions of the developed countries – envisions an increase of French nuclear electricity, up to 420 TWh in 2050. Yet this compares to some 480 TWh of nuclear electricity by 2050 in the 'trend' scenario. Why it takes less nuclear power to reach important reduction goals? Because the main difference lies in the overall electricity production, respectively foreseen at 690 TWh in the 'factor 4' scenario against 890 TWh in the business as usual case.

The most important lesson is there: curbing energy demand is the main key to curbing CO_2 emissions. The scenario adapted from this first study and presented as 'factor 4' scenario by the Ministry of industry in 2005 therefore envisions an average decrease of 0.6% per year through 2050, bringing the final energy consumption down to 116 Mtoe from 159 Mtoe in 2000 (figure 9.) This decrease is remarkably comparable to that envisioned in the négaWatt scenario, demonstrating that the development of a low carbon energy supply based on renewables or nuclear energies is a secondary choice which is meaningless if not preceeded by a primary priority on reducing energy demand.

Unlike the négaWatt scenario which sees an immediate and progressive decrease of final energy consumption, the official scenario, however, concludes that curbing the demand is not realistic in the short term. It therefore postpones any inflexion to 2020 or even 2030. With less time remaining towards 2050 but the same level to reach, this obviously requires a much steady decrease, in the order of 1.7% per year between 2030 and 2050. The scenario has been deemed an unrealistic vision, for it fails to justify why it considers a slight inflexion impossible today but sees a steeper one possible 15 years later.[35]

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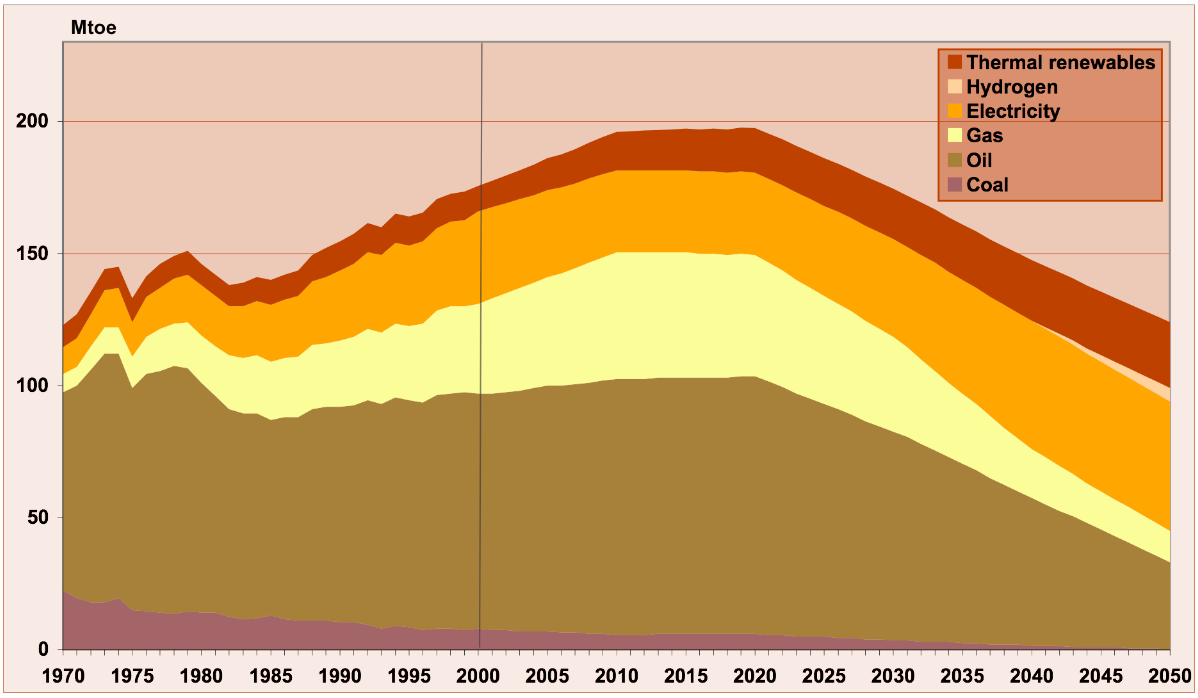
[33] négaWatt, *Scénario négaWatt 2006 - Pour un avenir énergétique sobre, efficace et renouvelable*, Document de synthèse, December 2005.

[34] Enerdata / LEPII, *Etude pour une prospective énergétique concernant la France*, commissioned by the Observatoire de l'énergie, Direction générale de l'énergie et des matières premières, Final report, February 2005.

[35] Commission Particulière du Débat Public on the project of a first EPR at Flamanville, *Rapport de restitution du groupe de travail dit "Bilan prévisionnel RTE"*, February 2006.

Figure 9 **Past evolution of final energy consumption in France by energy and projection in a "Factor 4" scenario (1970-2050)**



Source: Observatoire de l'énergie, DGEMP, 2006

Late developments of official consultancies to the Government on French energy and climate 'factor 4' strategy have notably insisted on the marginal role of nuclear power as compared to energy demand policies[36] and the need to curve the trends as soon as possible.[37] The most recent advice, provided by a commission chaired by a former director of the energy department in the Ministry of industry and former CEO of Cogema, Jean Syrota, states that "reaching a division by 2 or 4 of GHG emissions by 2050 would hardly be compatible with leaving them unchanges between now and 2020."

These findings are reflected in the basis of the 'energy/climate package' passed by the European Council in March 2007, which sets goals for 2020 as a key condition to reach long term objectives, and establishes a link between the reduction of emissions (20% cut by 2020 compared to 1990), the development of renewable energy (20% of energy supply by 2020) and the effort on the demand side (20% reduction of energy consumption by 2020 compared to the projected trend).

Nuclear power: an obstacle to change?

The first French official 'factor 4' scenario matches none of these objectives. The meaning of these intermediate targets, in the case of France, is that relying on nuclear power to maintain the relatively low level of French CO_2 emissions in the short term does not dispense with the rapid implementation of strong policies on the other parts of the energy system as key for reducing the emissions on the longer term. But the basic philosophy of the French 'factor 4' scenario is that such policies aiming at reducing energy consumption or developing decentralized renewable energies could not deliver in the short term. This actually suggests that the whole technical, economical and political organisation of the French energy system around the "nuclear pillar" is an obstacle to the deep changes needed to face energy security and climate change challenges.

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[36] Ch. de Boissieu (Dir.), *The Factor 4 Objective: addressing the Climate Challenge in France*, Report from the Working Group on "Achieving a fourfold reduction in greenhouse gas emissions in France by 2050", Ministère de l'économie et des finances and Ministère de l'écologie et du développement durable, August 2006 (free English translation of the authentic version of the report.)

[37] J. Syrota (Dir.), *Perspectives énergétiques de la France à l'horizon 2020-2050*, Rapport de la commission Énergie, Centre d'analyse stratégique, February 2008.

The Syrota commission of the Centre d'analyse stratégique (CAS), which pointed that need for rapid changes apart from pursuing the development of nuclear power, developed a series of energy scenarios combining these policies to reduce CO_2 emissions. The scenarios, which use two different sets of well established models (Markal and MedPro/Poles), compare reference or trend situations with voluntarist policies that are seen as the most efficient ones in realistic limits. The performances of these scenarios regarding the 2020 European targets and the national 2050 target are summarized in Table 7, which also includes the scenario developed by négaWatt.

Table 7 **Comparison of CO_2 emissions, energy efficiency, share of renewable energies and use of nuclear energy in 2020-2050 scenarios for France**

Scenarios[a]			CO_2 emissions (evolution /1990)	Energy efficiency (/2006[b])	Renewables (% of total primary energy)	Nuclear power (Twh and % of total electricity)
2006			+1%	0%	n.d.	428.7 (78.3%)
2020	CAS	Ref. Markal	-3%	+13%	n.d.	431.3 (70.6%)[d]
		Vol. Markal	-23%	+6.6%	10.4%	549 (82.1%)
		Ref. MedPro-Poles	+3.5%	+1%	8.1%	431.3 (70.6%)[d]
		Vol. MedPro-Poles	-21%	-16%	9.8%	439 (65.8%)
	négaWatt		-26%	-18%[e]	19%[e]	209 (53.7%)
2050	CAS	Ref. Markal	+2.5%	+35%	n.d.	n.d.
		Vol. Markal	-52%	0%	15.4%	731.6 (78.4%)
		Vol. MedPro-Poles	-58%[c]	-38%	16.2%	453 (59.8%)
	négaWatt		-75%	-41%	70%	0 (0%)

a. Scenarios include reference (or trend) versus voluntarist scenarios ('Ref.' and 'Vol.') based on two different sets of models: the Markal model used by a team of the Ecole nationale supérieure des mines de Paris (ENSMP) and the MedPro and Poles models used by Enerdata.

b. The European objective of 20% of reduction of final energy consumption by 2020 compared to a projected growth is assumed to be equivalent to 14% of reduction compared to the demand in 2006.

c. Excluding carbon capture and sequestration (CCS).

d. The reference for 2020 is the projection of electricity supply published in 2007 by RTE.

e. The authors of the négaWatt scenario rather refer to primary energy consumption and to the share of renewables in final energy. Regarding energy efficiency, the decrease from 2006 reaches 24.3% in primary energy; the difference in 2020 négaWatt's own reference (or trend) scenario is -31.9% in primary energy and -26.6% in final energy. Regarding renewable energies, they represent 22.4% of final energy consumption in 2020.

Source: CAS, 2008, based on ENSMP, Enerdata; négaWatt, 2007

The quantitative output of such prospective analysis should be cautiously considered due to the high level of uncertainty of the models and arbitrariness of some hypothesis. However, this summary of scenarios' results sheds an interesting light on the overall performance of energy and climate strategies embedding the nuclear option:

- the fact that CO_2 emissions rise in both models' reference scenarios, although they maintain a stable level of nuclear generation, recalls that a strong share of nuclear power is no guarantee against a negative trend;
- the comparison suggests an adverse effect of a high level of nuclear generation on the development of energy efficiency and renewables. In particular, the scenario with the highest development of nuclear power (Vol. Markal, +71% in 2050 compared to 2006) is also that with the least effort on final energy consumption (only coming back down in 2050 to its 2006 level)

and renewables (remaining with 15.6% far off the 2020 target even in 2050)[38]… and the least efficient of the voluntarist scenarios for cutting CO_2 emissions;

- conversely, it can also be noted that none of the scenarios published by the CAS reaches the same level of energy conservation and the same share of renewables than the négaWatt scenario, which excludes new nuclear reactors… and reaches more reduction of CO_2 emissions;
- finally, the performance of CAS scenarios, which all include an increase of nuclear power production, remains short of a 4-fold reduction of CO_2 emissions by 2050. The 2.1 to 2.4 reduction reached is deemed by the Syrota commission as a realistic maximum. The report therefore calls, instead of a further domestic effort, for diminishing France's commitment in the framework of a burden sharing within European Union of a European factor 4 objective (which is of course misleading, since France's factor 4 objective is already based on the application to the French population of a worldwide per capita target).

In addition, the CAS report acknowledges for significant biases in the models that clearly both increase the weight of nuclear energy in the calculated energy mix and its role in reducing emissions. Firstly, the models mostly calculate average energy supply and demand without including potentially significant variations through time. This is especially important for the macroeconomic modelling of the electric system in France, marked by a massive use of this form of energy – which can't be stocked on such a scale – for heating in buildings.[39] The huge variability of heating needs influences the needs for electricity generation through days and seasons.

The variation between the yearly peak and low of French electricity demand increased from 27 GWe in 1978 (between a minimum of 12 GWe and a maximum of 39 GWe) to 57 GWe in 2007 (between 32 GWe and 89 GWe), mostly as a result of the development of electric space heating that was decided together with the nuclear programme. By ignoring this structuring factor, the models used by the CAS do not account for its important economic and environmental impacts. Covering a large part of varying electric needs with nuclear power plants over the year actually combines periods when their capacity is higher than demand so they lose profitability, and periods when it is far from sufficient and a massive support of fossil fuel thermal plants is needed.

Also, the models do not provide an acurate representation of decentralized energy sources, especially those with the highest efficiency. The scenarios, according to the CAS report itself, give excessive importance to centralized sources like nuclear energy because they underestimate the potential for developing renewables and combined production of heat and power (CHP) – exactly those the most needed according to bottom-up scenarios like négaWatt.

The nuclear lock-in of the energy system

In summary, these models that have been developed in a context of supply oriented energy policies based on centralized technologies fail to give a fair representation of energy alternatives. The irony of the CAS report conclusion that without a high share of nuclear power France could not meet its long term energy and climate goals, while the scenarios actually show that this would not succeed, is typical of how the importance given to nuclear power locks in French long term energy policy.

The idea of a competition between the current energy system and a new policy based on energy efficiency and renewables is denied any relevance. Instead, the French authorities advocate the complementary nature of renewables and nuclear power to form a mix of carbon free energy supply. They claim that their support for nuclear electricity does not prevent other developments. Recent evolutions of the French energy debate on some key issues reveal on the contrary that clear choices against renewables or energy efficiency come with nuclear projects.

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[38] Although, due to the high level of energy demand compared to other voluntarist scenarios, this relatively low share of renewables in primary energy corresponds in absolute terms to a higher level of production than in the voluntarist scenario produced with the other model (Vol. MedPro-Poles).

[39] Electric heating represents around 10% of the total electricity consumption in France, and 30% of the consumption of households. About 7 million of flats and houses, or more than 29% of all lodgings, use electricity for heating. In 2007, 70% of new lodgings were equipped with electric heating.

This shows for instance in the very low development, if compared to the potential, of CHP or proven renewable energies like wind power.[40] The development of CHP practically came to an end in 2002 due to the end of public support, and there is no plan to back this technology. A report commissioned by the Ministry of industry in 2007 concluded that any development of CHP should be cautiously limited to the most efficient plants and underlined a potential waste of public money, judging that it would be more economic to invest in new nuclear reactors.[41] The decentralized development of windmills is limited by the instability that it can induce on the highly centralized French electric network. Also, any increase of wind power, which must be used when the wind blows, would reduce the share of baseload electric demand covered by nuclear power plants and therefore erode their economics. The government's clear intention is to constrain the development of wind power to a limited, controllable number of large plants instead of using the whole potential of the French territory (estimated to be the second highest in Europe).

There are even stronger hidden effects of competition between nuclear power and energy efficiency. This is particularly true with choices to be made regarding heating in the residential and tertiary sectors. Heating needs in buildings represent more than 20% of French CO_2 emissions and a clear consensus has emerged in recent years that the factor 4 objective implies strong changes in the consumption of this very slow evolving sector. This includes both a large programme of rehabilitation of the thermal performance of existing ones and the introduction of strong new constraints of thermal performance for new buildings. In October 2008, the introduction in a project of law of a plan to impose a level of 50 kWh/m^2/year of primary energy for space heating in new buildings forced political reactions in defense of the nuclear industry: this level could not be reached in new buildings using electric heating from thermal (nuclear and fossil) plants, which has the lowest overall efficiency of heating systems. The debate underlined the contradiction between the urgent need for a policy to reduce the huge wasting of energy in that sector and the will to maintain a supply-side policy favouring nuclear power.

Historical and prospective analyses of France's energy and climate policies clearly show that other priorities than the sempiternal stance on nuclear power must be developed in order to meet the country's medium and long term goals. However, the analysis also shows that the disproportional importance given to nuclear power makes it hard to grasp those real priorities. Moreover, it suggests that under the influence of nuclear power, the whole energy policy is trapped in some mechanisms and constraints that hinder appropriate shifts in the energy system, irremediably leading the country to failing to its own commitments. Although current level of CO_2 emissions create the illusion of a successful policy, the lack of further decrease comes as a warning. France appears well on track to show that long term negative impacts of this nuclear lock-in outweight positive impacts of nuclear substitution.

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[40] According to RTE, the French production of electricity from renewable energies other than hydroelectricity reached 7.8 TWh in 2007 (or 1.4% of a total of 544.8 TWh), of which 3.8 TWh from 960 MWe of thermal plants using renewable fuel and of photovoltaic, and 4.0 TWh from 2,250 MWe of wind power.
The capacity of electricity generation from CHP is around 4.7 GWe in the end of 2007, of which only 0.7 GWe have been installed between 2002 and 2007.

[41] Inspection générale des finances and Conseil général des mines, *Rapport sur les installations de cogénération sous obligation d'achat*, Report to the Ministry of economy, finance and industry, January 2007.

Focus 02

Electric heating: not so virtuous!

> *"We have a serious problem with electric heating in France. It was a mistake to develop it. One could think it was possible to do it because we have a very large nuclear fleet, but then it leads to peaks of electric consumption in winter time. […] It is French folly to aim for transforming electricity into heat, a nonsense from the point of view of thermodynamics."*
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> **Nathalie Kosciusko-Morizet, Secretary of State for ecology, interview in *Le Monde*, 1st October 2008**

The 'all electric, all nuclear' wave on which France had ridden since the 1970s in the name of its 'energy independence', and which had led to extensive use of electric heating based on joule effect, received a sizeable new justification from the mid-1990s in the shape of nuclear power's more or less complete lack of emissions of CO_2, the main greenhouse gas. It was an excellent sales pitch for the heating salesmen and EDF alike.

However, matters were not so simple. Even in France, where nearly 80% of electricity is nuclear-generated, electric heating requires the use of fossil-fuel-generated electricity with its attendant CO_2 emissions – in winter, the peak heating demand is very often met by fossil-fuel generation. As a result, the Environment and Energy Management Agency (Agence de l'environnement et de la maîtrise de l'énergie – ADEME) and EDF announced average emissions of 180g per kilowatt hour for domestic electric heating over the period 2000–04. This represents a modest saving by comparison with modern gas heating (<10%), although a more significant one as compared with oil heating (40%), as Table 8 shows.

Table 8 **Comparison of the CO_2 emissions of different methods of heating in France not involving electricity exchanges with European countries**

Method of heating	CO_2 emissions per kWh	Δ compared to electricity
Electric heating in France supplied by the *national* generating fleet*	180 g	—
Natural gas*	195 g	+8%
Domestic heating oil*	310 g	+72%

*Assumptions: electric heating efficiency = 1, gas boiler efficiency = 0.95, oil boiler efficiency = 0.85.

Source: ADEME / EDF, 2005

In short, a France self-sufficient in electricity shows a saving in CO_2 emissions, albeit a modest one. **But what about the present situation, now that Europe has pressed ahead with its internal electricity market?**

The electricity consumed by domestic heating in France is not only French: it is European. Moment by moment, the network manager finds the cheapest available electricity on the European market. ADEME and RTE, the Gestionnaire du Réseau de Transport d'Electricité (operator of the national electric grid), which manages France's electricity network, have calculated the effects of the opening of this market on CO_2 levels per kilowatt hour of electric heating, as shown in Table 9.

Table 9 **Comparison of the CO_2 emissions of different methods of heating in France in the context of the European electricity market**

Method of heating	CO_2 emissions per kWh	Δ compared to electricity
Electric heating in France supplied by the *European* generating fleet	500 to 600 g	—
Natural gas	195 g	-60% to -67%
Domestic heating oil	310 g	-38% to -48%

Source: ADEME / RTE, 2007

The table shows that, in the context of the European market, electric heating becomes a catastrophe in CO_2 emission terms – with emissions two-and-a-half to three times as bad as they would have been if gas boilers rather than convection heaters had been installed in our houses! Installing heat pumps does admittedly bring an improvement in CO_2 levels. But such pumps must achieve an average annual performance coefficient of a factor of three to achieve performance comparable to gas heating, which is not the case for the air/air pumps which are at present the most widely sold.