TWO ECONOMIC, ENERGETIC, AND ENVIRONMENTAL ASSESSMENTS OF THE FRENCH NUCLEAR PROGRAM

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The French nuclear program : an exceptional contribution to the supply of electricity

In France, nuclear power generation contributes decisively to energy supply. In 1994, nuclear power generation production was 341.6 TWh, i.e. more than 75% of the total electricity generation, with a total installed capacity of about 58.5 GW. In France nuclear power is far the most competitive source of base load electricity generation (see table I). In 1994, the nuclear sector (including research, plant construction, the nuclear fuel cycle and electricity generation) represented F. Fr 104 billion, i.e. 1.5% of the French gross domestic product (1). Moreover, the French nuclear industry exports electricity. In 1994, 66.9 TWh mainly from nuclear production were exported, which contributed F. Fr 15 billion to the credit side of the balance of payments. For 1994, the exports of Framatome are assessed at about F. Fr 8 billion, corresponding mainly to the manufacture of two power plant in China (Daya Bay 1 and 2). Cogéma, the French nuclear fuel operator, sold nuclear materials and services for F. Fr. 9.5 billion. So, nuclear activities contributed more than F. Fr. 32 billion to the balance of payments. It is also evident that nuclear power has contributed to reducing emissions of atmospheric pollutants in France.

Table I : Electricity generation cost in France

cF93/kWh	Investment	Operation	Fuel	R. and D.	**Total**
Nuclear	13.6	5.6	4.5 - 6.2	0.4	**24.1 - 25.8**
Coal[1]	11.3	5.8	11.7 - 17.7	--	**28.8 - 34.8**
Gas[2]	5.9	2.4	21.1 - 27.4	--	**29.4 - 35.7**

Source : DGEMP-DIGEC (1993)
Discount rate : 8% - Operating time : 6000 hours/year - Commercial commissioning on 2003
[1] Circulating Fluidised Bed Combustion [2] Combined Cycle Plant

This paper presents two studies (2), (3), which try to assess the economic, energy and environmental impact of the French nuclear program. First, the two models used are described briefly and then each study is discussed separately. The main results are summarized in the conclusion.

Micro-Melodie and Gemini-E3 : Two Macroeconomic Models

Micro-mélodie (4) and Gemini-E3 (3) are two macroeconomic models that were developed by the Commissariat à l'Energie Atomique. Each of the models incorporates a detailed representation of the energy sectors/products, with a classification adapted to the energy sectors and a specific representation of them. In the two models, electricity is described separately on the basis of a technological representation where the load curve is a major

component. The links between the energy sectors/products and the macroeconomic part have been established with great care. Concerning the macroeconomic framework, the two models are based on different specifications. Micro-Mélodie is mainly based on neokenesian specification, with simultaneous neoclassical demand and supply. Gemini-E3 is a general equilibrium model based on Walarasian theory and works mainly as a comprehensive tool devoted to performing cost-benefit analysis of various policy scenarios. Another major difference is the geographic area : Micro-Mélodie gives only a description of the French economy ; Gemini-E3 is a worldwide model in which three areas are taken into account : France, other members of the European Union and the rest of the world.

MICRO-MELODIE

Zone : France

Sectors/commodities : 3 Electricity, Fossil Fuel, Others

Running period : 1970-2015

Economic Background : Neokeynesian theory and neo-classical theory

Production function : Translog

Technological for electricity

Households' Demand : Translog

Atmospheric Pollutant emission : CO_2, SO_2 and No_x

GEMINI-E3

Zones : France, Other European Countries, Rest of the World

Sectors/commodities : 11 of which 4 for energy (Coal, Gas, Electricity, Oil and refined Products)

Running period : 1985-2010

Economic Background : Walrasian Theory

Production function : Nested CES

Technological for electricity

Households' Demand : Linear Expenditure System

Atmospheric Pollutant emission : CO_2

Two different assessments of the French nuclear program

France without nuclear power

In this scenario we assumed that France did not invest in a massive PWR program. If a program for replacement of nuclear power plants by fossil fuel fired power stations had been initiated in 1970, the first unit would have been brought into service in 1977. The date of commissioning would have been in the period immediately after the increase in crude oil prices and thus the fuel used would have been coal.

Brief description of the coal scenario

In order to secure a relatively high level of independence in energy supply, the French authorities would have had to develop coal mining. Taking into account the technical characteristic of coal deposits in France, an increase in output of coal of 5 Mt per annum in the Lorraine region for electricity generation was envisaged, while the remaining coal needed would have been imported from those countries which generally supply coal to France. Initially, all of the coal fired units would have been constructed with grate furnaces. We assumed that all coal fired units, with the exception of the four units constructed in the Lorraine region, would have been fitted with effective desulphurization equipment , in the form of flue-gas scrubbers, operating at 90% efficiency. Fluidized bed technology would have been introduced progressively between the year 2000 and 2005. The cost of investment for a coal fired power was adjusted in order to take into account the various impact arising from the development of a major program for the production of electricity from coal (see table II). Large scale plant construction would have reduced the cost by 7% before 1975 and by 9% after 1975. The consequence of an increased number of units per site was assessed at 3% cost reduction. A higher capacity per unit would have entailed a cost reduction of 4% after 1975. By contrast, difficulties in connection with siting would have increased the cost by 3% before 1975 and by 5% after 1975, and installation of desulphurization equipment would have led to a 20% higher cost after 1975.

Table II : Impact of a massive program for the production of electricity from coal upon the cost of investment in installed capacity

	Before 1975	1975 onwards
Impact of large scale production	-7 %	-9%
Number of units per site	-3%	-3%
Technical series	0%	-4%
Difficulties of siting	3%	+5%
Desulphurisation (90%)	0%	+20%
Total	-7%	+9%

On the other hand, the nuclear option is characterized by high levels of industrial investment in the nuclear fuel cycle. A proportion of these investments (approximately F. Fr 33 billion at 1994 values, mainly for the construction of UP2 and for prospecting) had already been committed prior to 1970 and may be classified as investments in the operation of graphite gas units. However, the major part of the investment in the nuclear fuel cycle took place after 1970. In our coal scenario, this expenditure (calculated at F. Fr 110 billion) would not have

been required. For nuclear power plants, the total cost of investment from 1970 to the present time was estimated at F. Fr 420 billion on a plant-by-plant basis. For the period from 1970 to 1994, the total cost of the nuclear program was estimated at F. Fr. 530 billion. The coal option, like the nuclear option, must be considered initially in terms of investment in the fuel cycle, i.e. including the cost of increased coal production in the Lorraine region and the extension of harbor capacity. The new harbor infrastructure and the new coal mines require an investment of F. Fr. 50 billion. To provide the same net capacity, 62 GW of coal fired capacity would have been required for replacing 64 GW of nuclear capacity (since approximately 2 GW are required to supply the Eurodif plant). This investment would have totaled F. Fr. 335 billion. For the same net capacity, the total cost of the program for the production of electricity form coal would have been F. Fr 385 billion.

Table III : Investment in the coal and the nuclear option (FF billion at 1994 values)

	Coal option	Nuclear Option
Mines	8	3
Harbor	42	
Processing		2
Enrichment		34
Manufacture		2
Reprocessing		69
Power Plant	335	420
Total	385	530

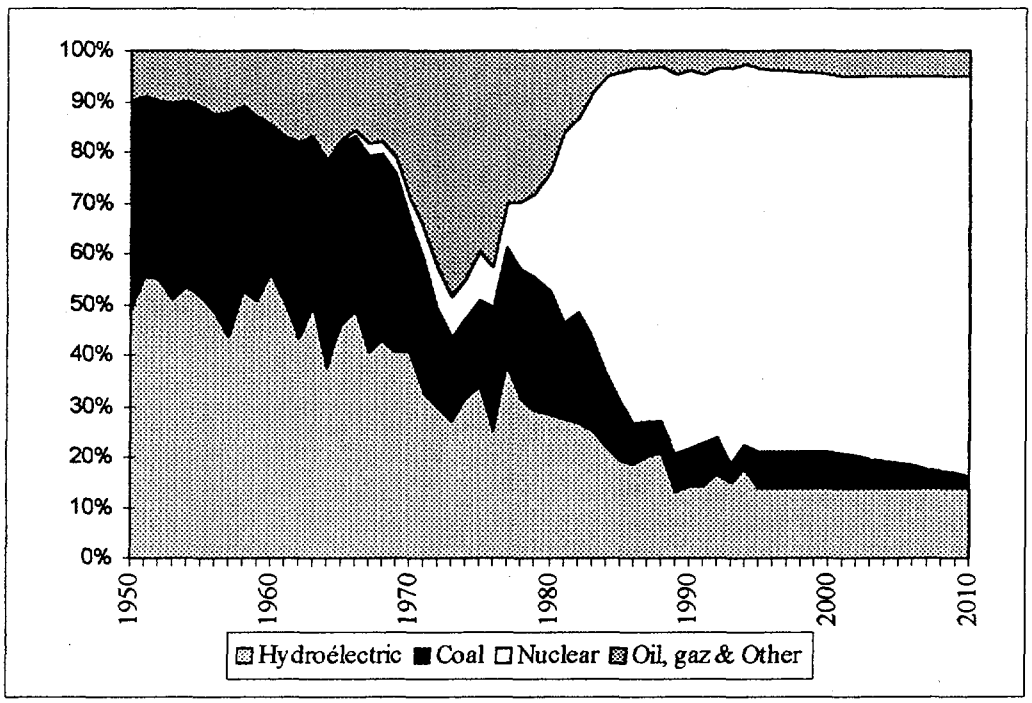
We assumed a 10% increase in the international coal price for the period from 1980 to 1986. Increased demand of coal in France at a time when the international market was restricted would undoubtedly have led to an increase in energy prices. In response to the increased coal demand in France, the worldwide demand on the international steam coal market have increased by 20%. For the period after 1995, our assumptions of coal prices are based upon US $ 44 per tonne of coal by the year 2010.

Energetic impact

Figure 1 shows the actual past development development of the structure of electricity production in France. Figure 2 shows how this structure would have developed in France without nuclear power. In terms of electricity supply, the situation in a nuclear free France would have been comparable with the situation in the United Kingdom, with 70% electricity produced from fossil fuel plants and approximately 30% produced from nuclear and hydroelectric plants. At present, the price per kilowatt-hour of electricity under the coal scenario would be some 15% higher. The increase in electricity prices would have reached 20% in 1986 (before the decrease in the international price of coal). By now, the price of electricity would be highly sensitive to fluctuations in the price of coal. Consequently, by year 2000, the price of electricity would increase by 16%. In a nuclear free France, the increase in electricity price would lead to a decline in electricity consumption and to the replacement of electricity by other forms of energy. In the energy sector, this decline in consumption would be due mainly to the absence of the Eurodif plant, which accounts for an annual electricity consumption of 20 TWh. In the industry, the impact of higher electricity prices would vary according to the industrial sector concerned. The impact on other sectors would be extremely limited. In the residential sector, heating would also be most affected by the electricity prices.

In particular, high electricity prices would lead to much less growth in central electric heating, with an estimated decline in electricity consumption of 10 TWh. The net exports of electricity would be close to the level of supplies delivered under contracts based upon long term cost differentials. In a nuclear free France, the comparative advantage of the French electricity cost would be considerably reduced, which would lead to total discontinuation of net electricity exports (63.4 TWh in 1994). In 1994, the total drop in national electricity production would have been close to 115 TWh, while the final energy consumption would have decreased by 28 TWh.

Figure 1 : Structure of electricity production, France with nuclear power.



The overall structure of the final energy consumption in a nuclear free France would have been close to the present pattern. The same can certainly not be said of the primary energy balance. The fossil fuel consumption in France would have been almost 60 Mtoe higher than the current value, with coal for electricity production accounting for the major proportion of this figure. Independence in energy supplies, as shown in figure 3, would currently be approximately 20% (as against its actual level of nearly 50%), which is close to the figure for 1973.

Figure 2 : Structure of electricity production, France without nuclear power.

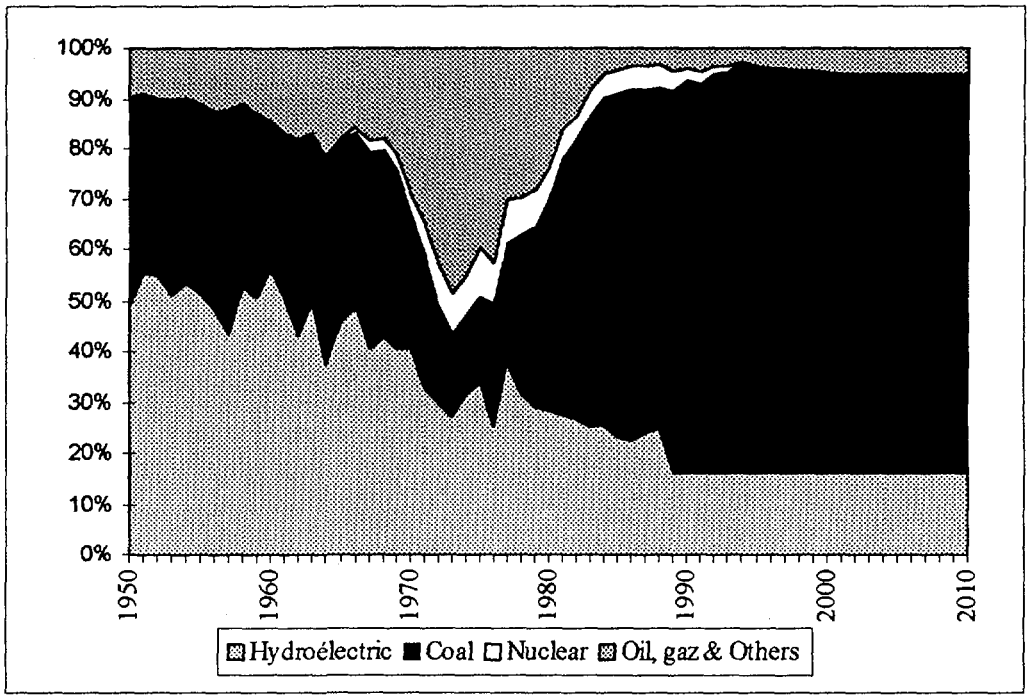
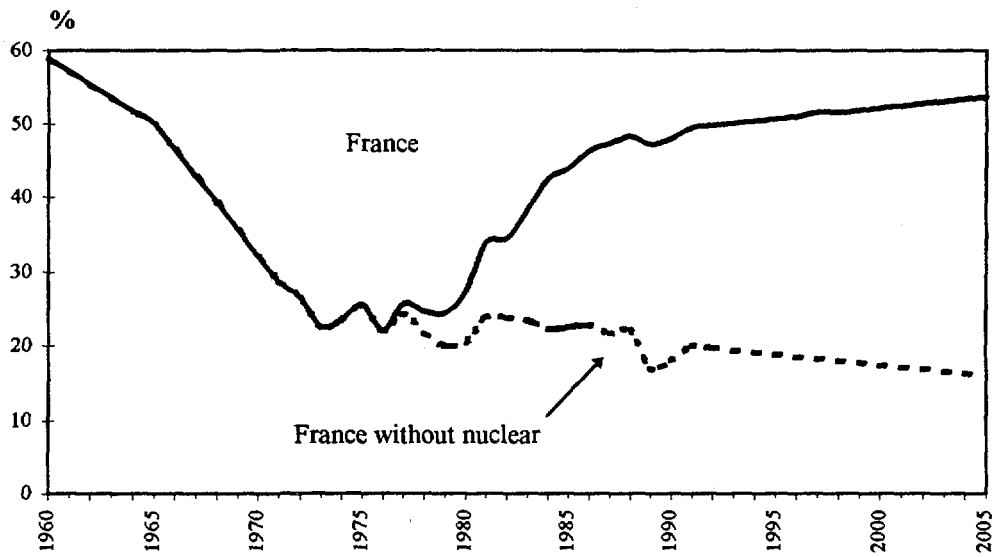


Figure 3 : Independence in energy supplies (%)



Macroeconomic effects

The structure of the economy (see table IV) would have been modified by the following three factors : decreasing investment in the electricity sector and the fuel cycle, rising electricity prices, and a substantial reduction of the independence in energy supplies.

Table IV : Nuclear Free France - Macroeconomic Impact.

	1975	1980	1985	1990	1995	2000	2005	2010
GDP	0.0	-0.4	-1.6	-1.3	-1.3	-1.3	-1.6	-1.6
Imports	-0.1	0.1	0.3	0.1	-0.1	-0.1	-0.3	-0.3
Exports	0.0	0.2	-0.2	-0.4	-0.4	-0.2	-0.2	-0.2
Consumption	0.1	0.1	-0.9	-0.9	-1.1	-1.2	-1.4	-1.6
Investment	-0.5	-1.9	-2.4	-1.3	-0.7	-0.5	-1.7	-1.3
Price of Consumption	-0.4	-0.4	0.9	0.4	0.7	0.7	0.8	1.0

Source : Micro-Melodie, Percentage deviation to reference scenario.

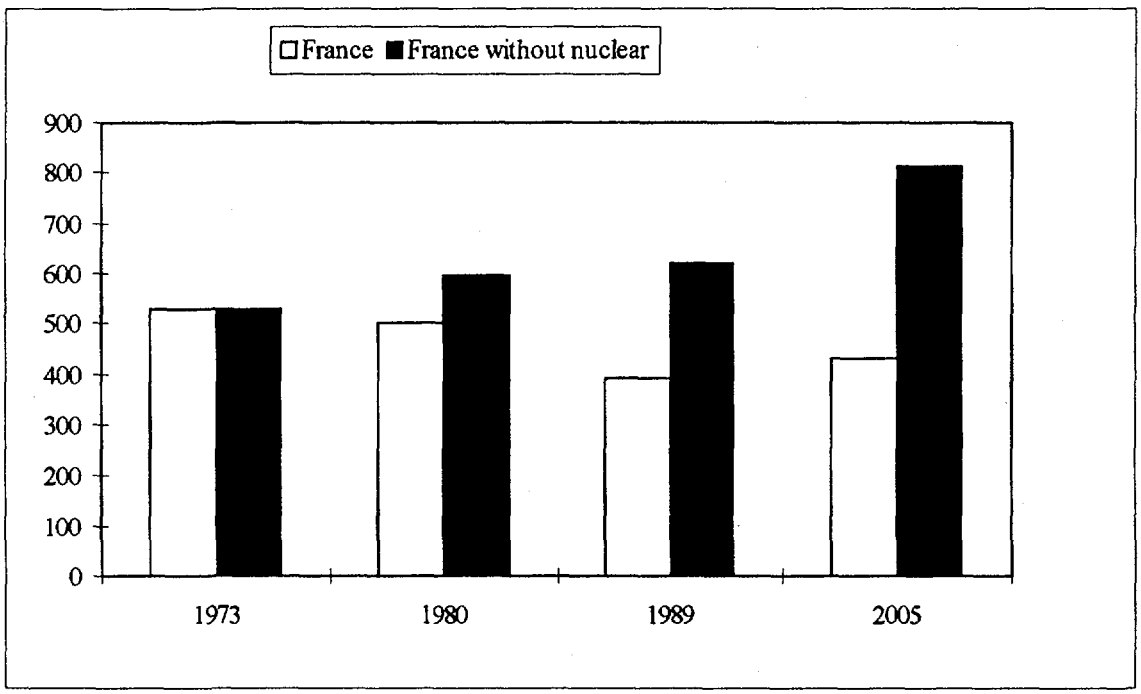
Chronologically, the first of these factors having any impact would be the decreasing investment in the electricity sector resulting from the discrepancy in the cost of investment per Kwe between installed nuclear capacity and coal fired capacity and resulting from the reduction of total net capacity required (which in itself, would result from the reduced demand for electricity). The macroeconomic impact of this factor would be equivalent to a keynesian multiplier. In general terms, there would have been two main consequences, namely a significant reduction of economic activities (see Table IV) and a reduction of the pressure on the trade balance towards the mids-1970s. The remaining two factors would have a significant effect from the early 1980s onwards, with their sudden impact exacerbated by the fact that this was a period of high prices on international coal markets. Higher electricity prices would have increased the production cost of firms, which would then have passed on these increased cost to the consumer in the form of higher prices. Households would have been affected by the increase in the cost of domectic electricity itself, and by the increased price of goods and services involving electricity. In wage negotiations, these increases would have been offset only to a limited extent by increased earnings, since index linking would have been limited by a significant rise in unemployment. By the present day, there would have been a 0.8% reduction in purchasing power. By the year 2000, this reduction would reach 1.2%. The main effect of this loss of purchasing power would have been a decline in household consumption (1.1% in 1995), which would have had a negative impact on economic activities (-1.3% in 1995). Nearly 100 000 jobs would have been lost. Reduced independence in energy supplies has a negative impact on the trade balance. This annual negative impact would have been almost half of the deficit actually recorded for the cif/fob trade balance. The decrease in final energy demand (investment and consumption) would have had a positive impact on the external trade balance (by reducing imports and releasing capacity for exports), but this would not, in itself, have been sufficient to offset the major increase in national energy cost. The cumulative deficit over the period from 1981 to 1990 would have exceeded F. Fr. 110 billion at 1994 values. Over the decade from 1991 to 2000, this cumulative deficit would reach F. Fr. 210 billion. At present, the impact of the French nuclear program (in terms of economic activities, employment and external trade) is generally positive. If this program had not been implemented, the impact might be compared with that of an oil crisis, with a long term increase in the price of oil by US $ 20 per barrel.

Environmental impacts

We consider now the consequences of the French nuclear program in terms of emissions of atmospheric pollutants. In the coal scenario considered, these gases are generally emitted by the generating plant. However, the significant economic changes by use of coal for electricity

production would certainly have had some impact on the emissions, particularly through the substitution of energy sources by other sources for the overall energy demand. All emissions of atmospheric pollutants (including indirect or induced emissions) have been recorded. However, we have taken no account of changes in the primary energy balance of foreign countries, such as Germany or Italy. The current amount of sulphur dioxide emissions would be higher by 230 kt per annum - an increase of 18%. This increase (which, after all, may be regarded as relatively modest) is closely linked to the assumption that effective desulphurization measures would have been applied to all coal fired power plant units constructed (otherwise, the sulphur dioxide emissions would have reached 11 400 kt per annum - an increase of 100%). At present, the amount of nitrogen oxide emissions would be higher by 510 kt per annum, an increase of 29%. In a nuclear free France, these extra nitrogen oxide emissions would reach 720 kt per annum by the year 2000. The amount of carbon dioxide emissions (390 Mt per annum in 1989) would be exceeded by 230 Mt per annum. By the year 2000, these extra emissions would recah 340 Mt per annum (see figure 4), which amounts to 6 Gt of carbon dioxide emission over the next twenty years, calculated on a cumulative basis.

Figure 4 : CO2 Emission in France million tonnes of carbon dioxide



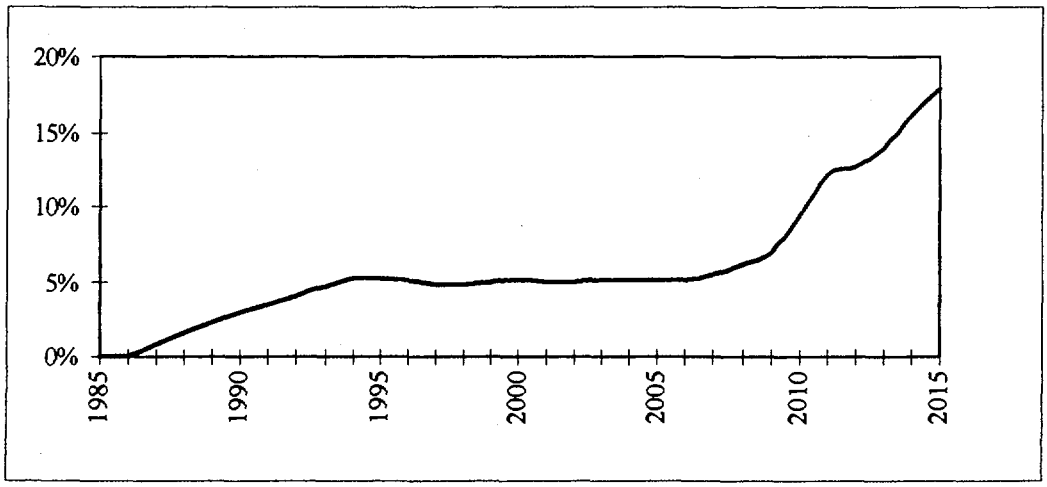
Nuclear Moratorium

In this study we assume France adopted a nuclear moratorium based on the scenario that France had decided to cancel all investments in nuclear plants starting from year 1985 and to progressively decommission existing facilities so as to obtain a complete denuclearization in 2015.

Effects on the energy sector

We assume that the net exchanges of electricity (70 TWh in 2015) are gradually reduced and that they will exactly balance by the year 2000. All remaining nuclear power plants (37.4 GW) will then be dedicated to French consumption. The use of the model Gemini-E3 yields the following results. The national demand of electricity is reduced by about 50 TWh (-8%) in 2015, with a price increase of about 17% (see figure 5).

Figure 5 : Percentage variation of electricity price



Concerning production, the canceled nuclear plants are substituted by coal and gas plants (see figures 6 and 7). By the year 2015, the installed capacities will be reduced by 13 Gwe. Coal would replace nuclear for base demand, coal capacities would increase by 50 GW, gas capacities would only increase by near 5 GW in 2015.

Figure 6 : Thermal capacities baseline scenario.

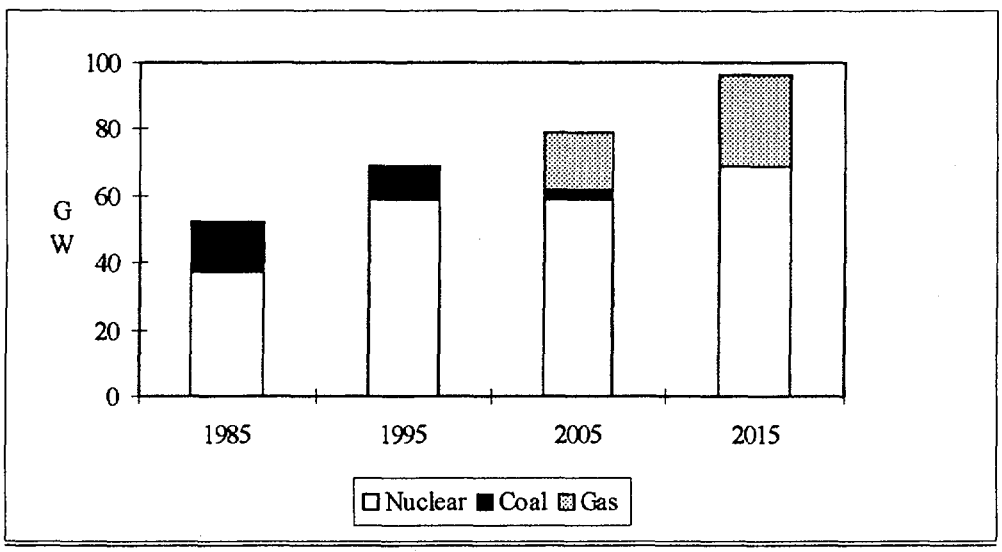
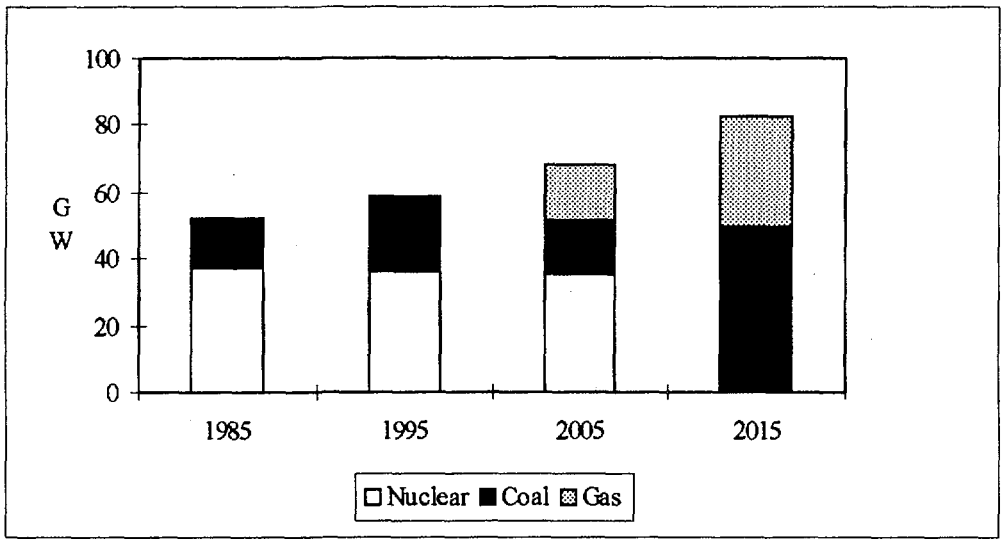


Figure 7 : Thermal capacities moratorium scenario.



By the year 2015, the structure of thermal electricity generation will be 75% for coal, 25% for gas, compared with the reference case (86% for nuclear and 14% for gas).

Macroeconomic effects

The results (see table V) are mainly explained by two factors : the increase in the electricity price and the devaluation of the French Franc. The increase in the electricity price will induce a substitution of electricity energy by others (coal, gas, oil and refined product) and a change in other factors of production (labor, capital and other non energy inputs). Furthermore, households will reduce their electricity consumption by 7%. The second factor is related to the increase in imported resources for electricity generation (gas and coal) which induces an ex-ante deficit of the trade balance. This deficit will be obliterated by a devaluation of the French franc (5.5% against the ECU and the US $ by the year 2015). The export of French products (except electricity) will be promoted by the devaluation and the total export will increase by 5% in 2015, while at the same time the imports will increase by 0.5% by the year 2015, mainly because the energy imports increase.
On the whole, the reduced efficiency of the economy will generate a loss in the welfare of people, whose consumption will be reduced by 2.6% in the year 2015. The GDP will be reduced by 2% in the year 2015.

Table V Nuclear moratorium - Macroeconomic Impact.

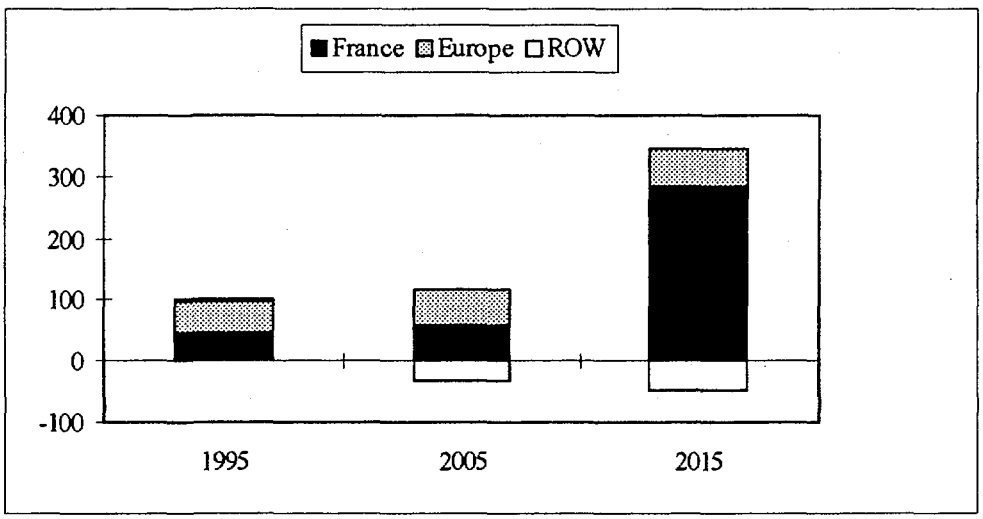
Variables	1985	1995	2005	2015
France				
GDP.	0.0	-0.3	-0.5	-2.0
Import	0.0	-0.2	-0.3	0.5
Export	0.0	1.3	1.4	5.0
Consumption	0.0	-0.6	-0.9	-2.6
Investment	0.0	-1.3	-1.5	-6.0

Source : Gemini-E3, Percentage deviation to reference scenario.

Environmental impacts

As for the coal scenario, the environmental effects of this scenario can be determined. This being done only concerning carbon dioxide emissions. Environmental effects are also very sensitive (see figure 8), with an increase of French CO2 emissions of 280 Mt of carbon dioxide in 2015. In Europe the increase would be equal to 62 Mt in 2015, in Rest of the world emission would decrease by 47 Mt due to the decrease of GDP (-0.1 % in 2015). The current worldwide carbon dioxide emissions would be exceeded by 100 Mt in 1995 and by 300 Mt in 2015.

Figure 8 : Variation of CO2 Emission million tonnes of carbon dioxide.



Conclusion

As environmental matters become the focus of increasing concern, the implementation of a major nuclear power program has allowed France to enjoy the benefits of a comfortable position. In France, the emissions of carbon dioxide per capita are among the lowest in the industrialized world.

In terms of economic impacts, the most obvious consequence of this program is the stability of the electricity prices resulting from the increasing self-sufficiency of France in energy supplies (from 22% in 1973 to 51% in the year 1994). Besides, the two studies, which use two different models, show that nuclear industry has a positive impacts in terms of the welfare of people, measured by the consumption of household goods. Thus we can say that the French nuclear

industry has improved the French economic efficiency, has increased the common welfare and has significantly contributed to the abatement of atmospheric pollution.

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