National Academy of Technologies of France (NATF)

First contribution to the Energy Transition National Debate

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des technologies au débat national sur l'énergie »
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FOREWORD

SUMMARY

Production and utilisation of energy round the world are changing, due to a combination of forces. Some of these changes are imposed (redistribution of energy needs and the Earth's resources, measures that anticipate the depletion of fossil fuel sources); others are voluntarily implemented (the search for energy autonomy, the fight against global warming and climate change, industrial competition).

France has launched a nation-wide debate on possible future policies in these areas. The National Academy of Technologies of France (NATF) — in its endeavours to gain the widest consensus possible on these thematics — sets out the technical data that will hopefully modulate the Government's strategies up to a horizon 15 to 20 years ahead. This document is not as such a formal academic Advice Note and does not propose to make particular choices among the scenarios studied. It is a first contribution of NATF to the ongoing debate, prior to defining strategic decisions and making comparative economic assessments.

NATF investigated two evolutionary, almost contradictory, trends with close attention: the policy paths chosen respectively by the USA and Germany. This comparison provides some very useful information and food for thought.

The first certitude, in the case of France, is that demand must be controlled, energy saved and its utilisation improved. We can hope to decrease needs by taking measures such as installing more/better building insulation, including older buildings, encouraging the purchase of more efficient household appliances, meeting heating needs by direct heating, geothermy, recovered heat redistributed *via* urban

networks, thermal solar panels, heat pumps, etc. New urban areas and cities must be (re)designed to be energy lean and require less commuting. We must not underestimate the difficulties in addressing these questions; none of them are new and the solutions will call for a high level of financial outlay and societal commitment.

If we consider the future of fossil fuels, it is the liquid phase fuels where competition will be strongest and will occur earliest. Use of fossil fuels must be 'reserved' for transport uses and for the chemical industry sectors. Cars and vehicles will evolve towards models that will increasingly use electricity, at least in the case of hybrid vehicles and perhaps gas-driven models, but this *per se* will not represent an important energy source transfer by 2025. Industrialists will be led to stabilizing their energy requirements, by continuous product improvement.

Where production of electricity is concerned, the nuclear power capacity in service today in France will continue to be available, but might move to a lower power output. Improvements should be sought in terms of nuclear power flexibility, if only to avoid seeing the development of intermittent renewable energy sources (wind, sun) leading to an increase in use of fossil fuels. Problems associated with the intermittency factor for wind power and solar power are studied in detail below; solutions do exist but they carry a higher price-tag. Current construction programmes in renewables energies (RENs) are sufficient if pursued at a steady pace. There is no need to go beyond summer-time peak demand since the excess energy produced would not easily find a buyer in summer-time. Nuclear power can prove useful to offset long intermittencies (outages due to low winds or overcast skies), hydro-electric generation (notably the 'Step' hydro pump storage installations) the combined cycle gas turbine stations or the thermal (coal, oil or diesel fuel burning) power stations that are already commissioned can be used for short intermittencies. To ensure overall power supply/demand balance, there is a clear need for increasingly "smart" grids.

No-break renewable energy sources (hydro-electric turbines, geothermy, biofuels, and biogas) must be developed. It will also prove vital to assure our energy procurement in the future, to assess the possible shale gas reserves accessible within French frontiers.

Total decrease of energy consumption in France could attain –15% by 2025 and –30% by 2050.

INTRODUCTION

The Fellows of the National Academy of Technologies of France (NATF) embody and combine a wide range of skills, such as in: technologies, economics, societal issues, the environment and ethics. This scope allows them to apply their 'collective intelligence' to carrying out complex systemic analyses. Energy issues are conducive to this approach.

Energy procurement/utilisation is an area for fierce debate throughout the world and has again been brought to the forefront in France by the Government's decision, taken end 2012, to launch a national debate on France's energy transition (acronym DNTE[1]). NATF logically is desirous to contribute on these themes, which have been studied by the Academy and its Standing Committees ever since it was created in 2000.

Over recent years, the 'world of energy questions' has been upset by large-scale phenomena that have deeply changed the guide-line principles even though the latter have not been clearly perceived or their consequences fully analysed: the discovery of shale gas/oils, technological progress with renewable energy sources and equipment whether they are intermittent or not, the major accident at Fukushima and the oil spill in the Gulf of Mexico, development of deep offshore drilling for oil/gas and on top of all this, the context of economic recession that reigns in the industrialised countries, etc.

1 *Cf.* in French only – http://www.transition-energetique.gouv.fr/

The world of energy is characterised above all by today's installations and infrastructures. Renewal/rehabilitation here represents a huge commitment and the time scale to undertake this is very long. Today's consumption/production figures relate to sites that were built in the past (housing, cars, urban infrastructures, transport systems and equipment; the power production sites or means needed to import energy) where the price tag for rehabilitation can be measured in thousands of billions of euros! Evolution can therefore only take place slowly and will have to be planned and implemented over several decades.

Consequently:

a. the evolution adopted must target stable long-term objectives;
b. a long-term energy procurement policy cannot rely on binary type options; it must take into account the unforeseen changes, necessarily part of the future; it must therefore favour energy sources in a mix[2] that does not lead to brutal breaks in supply/demand.

The situation prevailing in France can be summarised under three headings: the status of the energy mix today, European stance and commitments, orientations[3] towards a future mix that the Government has named as the "energy transition" and that lies at the heart of the national debate now under way in France.

The political commitments at European level are included in the provisions of the Treaty of Lisbon (2007) http://europa.eu/lisbon_treaty/full_text/, in which the question of energy is shared by all Member States left free to choose their energy mix while the Union drafts the overriding policies and controls their enforcement. In December 2008, the EU adopted the Energy and Climate Package

[2] Acronyms used in the document are explained *in fine*.

[3] France's energy transition is drafted by the Government using the political orientation electoral platform given by the President of the French Republic for his 5 year term of office, *viz.*, two points:
- *to preserve France's energy independence while continuing to diversity sources*: reduction, from 75% to 50%, of the nuclear electric power contribution in the future energy mix, installation of more REN facilities and infrastructures, compliance with international commitments to reduce emissions of GHGs;
- to set in motion a wide-spread national plan to ensure that "1 million home/yr benefit from possibilities to install high-quality thermal insulation".

http://ec.europa.eu/clima/policies/package/index_en.htm, also known as "20–20–20", because of the three key objectives set as targets for 2020:

- a 20% improvement in the EU's energy efficiency;
- raising the share of EU energy consumption produced from renewable resources to a targeted 20%;
- a 20% reduction in EU greenhouse gas emissions from 1990 levels [and a subsequent target of an 80–95% reduction for 2050].

The European Commission recently presented a "Road-map to 2050" to the European Council of Heads of State, which pursues and amplifies the already highly ambitious objectives set for energy saving of primary energy resources (a decrease of between 32% and 41% with respect to 2005–2006) and for the elimination of carbon (a reduction of 85% CO_2 emissions in energy-intensive sectors, including transport). These targeted objectives will lead to an increase in the "Energy" expenditures as a whole, *i.e.*, household budgets will be devoting up to 16%.

We can make two observations here: EU Members States made a large use of the freedom offered by the Treaty, to take certain basic decisions here, without consulting or even informing other States or the EC authorities. Germany's decision to opt out of nuclear power production by 2020 is an example. And we note that the same decision leads inevitably, at least in the short term, to an increased consumption of coal and gas and hence to an increase in Germany's imports plus an increased level of GHGs. Likewise, but paradoxically, in France, an over-rapid increase in use of intermittent energy sources would probably lead to a higher use of gas to offset intermittency, though to a lower extent than in Germany. But in both countries costs to energy end-users will rise.

In order to investigate trend paths for a future energy mix, the National Academy for Technologies of France (NATF) proposes a three tier methodological approach:

- a full study of the technicalities that underscore the issues; they are covered in this first contribution;
- a complementary study of costing, investments needed, comparisons "(added) value created/project costs". These points will be addressed in a second report, in a few months' time;
- possible choices among energy policy priorities.

On this 3rd point, it is not in the Academy's remit to be involved in final political decisions, but nonetheless our Fellows in the Standing Committee on Climate Change and the Environment would like to recall the following: an energy procurement/utilisation policy will necessarily be guided by partly antagonistic objectives and the relative weighting of these will largely determine the final mix:

- energy independence or autonomy, energy supply security, control of the balance of trade for each European Member State, by decreasing energy imports;
- the economics of the energy system as a whole, contributing to a large extent, as it does, to national wealth (GDP) and job creation:
  - indirectly but very strongly if the energy system proves efficient (price of the kWh for end-users and for enterprise);
  - directly but to a lesser degree, through job creation in the energy sectors either in the domestic markets of each country or in export activities.
- reduced emissions of GHGs among which CO_2, in the framework of the fight against global warming–which can only be global.

The choice of the time horizon year is important; it must be sufficiently far ahead to anticipate a policy decision of a given energy mix in a post-carbon age.

All the points indicated here should (and must) be subjected to economic arbitration by the Authorities but without neglecting the system's "externalised factors", in particular the cost of CO_2 in the economy.

Assembling and drafting a strategy consists of ranking the chosen objectives and sub-objectives and privileging those elements that top the priority list. Ranking comes down *in fine* to a societal choice, spread continuously over time. The two examples that follow show that two countries with large similarities to France, *viz.,* Germany and the USA have chosen clearly different energy procurement/utilization strategies.

Potential priorities are numerous.

Two interim comments here:

- recent changes in the world show that total depletion of fossil energy resources will not occur in the immediate future and therefore — contrary to a widespread confusion — it is not the driving force that leads to an energy transition; the real cause lies in greenhouse gas effects on the climate;
- any national, regional or local decision in terms of energy production or utilization presupposes that cost/advantage comparisons are made, these

factors enabling operators to manage the production means efficiently and to satisfy a given energy demand at least cost. These costs, of course, must be calculated correctly; in particular, this implies that the managers:

- take into account a price that incorporate savings made in terms of GHG emission levels;
- take into account the real costs, incorporating subsidies, and also technological progress gained through return on experience (ROE);
- introduce, where necessary, an assessment of and a possible compensation factor for damage to the environment;
- introduce costs that results from the compliance with binding regulatory decisions issued by France's National Nuclear Safety Authority (ASN).

The aim of this NATF document is therefore to present clearly the technical facts and data, the associate constraints, the industrial bases and the energy environment in which the drafting of France's strategy to face an energy transition will be made. It also has the purpose of issuing some recommendations to help frame any future policies.

Chapter 1

EXAMPLES OF ENERGY TRANSITIONS OUTSIDE FRANCE

In order to help readers understand the wide-ranging diversity adopted by various countries outside France, the NATF Standing Committee on Energy and Climate Change chose to begin their report with a rapid overview of two approaches, in the USA and in Germany, to the extent that these two countries show somewhat contrasted, if not almost contradictory, ongoing evolutions.

The approach adopted in the USA

In the USA, independence of energy procurement ranks very high among the national priorities, on a par with employment and revitalising the economy. We might even prefer to talk about energy autonomy, given the stress laid on the resources drawn from America's own territory and subsoil. The third priority is that of energy saving (energy efficiency) inasmuch as the Americans are fully aware that they lag Europe in this area. The day (1992) when President Bush asserted that

"*The American way of life is not negotiable*" is now behind us[4]. It is also the best way to move to a level of energy procurement independence. We often read that controlling the Strait of Hormuz in the Persian Gulf would no longer be necessary if oil imports were to cease. This illustrates the close connection between America's military strategy and access to energy resources. We note, however, that Europe and Asia will continue to need Persian Gulf oil. Would they be prepared to militarily control the Strait of Hormuz?

Addressing climate change and attaining lower GHG emissions come next in the list of priorities. This does not mean that nothing is done in these areas, but sometimes it does seem rather fortuitous. Rapid development of shale gas extraction and the associate low costs have changed the 'energy mix' of fuels used to generate electricity. The fraction of coal in the mix, some 45% in the recent past, has dropped to 30%, *viz.,* to approximately the same level as gas. The price of an electric MWh[5] produced using coal in April 2012 stood at 31 $US/MWh while the same produced with gas as fuel cost 17.8 $US. It is not certain that the price indicated will stay at this low level. It is due to the fact that production of wet gas leads to condensate by-products that can also be valorised and the price of which is maintained at a high level by the prevailing global oil market conditions.

The price for gas will continue to rise when demand increases sufficiently; moreover, we observe that the number of drilling equipment operating in known gas fields has decreased, because of the less attractive price for the product, from approximately 800 to less than 200 installations over a 2 year span. However, the changeover from coal to gas as the choice of fuel to generate electricity is a sustainable fact. And because of this, the GHG emissions by the USA have decreased significantly, more indeed that would be due solely to the ongoing economic crisis. Nonetheless, let us not, however, over-rejoice; the quantity of coal extracted in the USA has dropped by a small amount (approx –4%), but the steam grade coal was exported to Europe, mainly to Germany (+22%) at a price of 90 $US/tonne delivered

4 A decision was taken in August 2012 to review vehicle fuel consumption standards (CAFE standards). It was the first time since 1975 that the USA changed their automobile standards; indeed the values chosen approach those used in Europe.

5 *Cf.* definitions for the units used in the document, *in fine*.

CIF ARA (Amsterdam, Rotterdam, Antwerp)[6] and to Asia at 100$ US/tonne, slightly higher because of the distance factor. A year ago the price was 120 $US/tonne. Global GHS emissions therefore are continuing to rise, in line with the quantities extracted (and burned). Indeed every bit of coal mined will be burned somewhere. Whether we consume coal here or there on Earth makes no difference, if the quantities mined continue to increase.

Today's coal-burning power stations are approaching their operational end-of-life, *i.e.,* will need to be rehabilitated (or replaced) in the coming decade. Certain States indeed are demanding that the stations be upgraded to accommodate modern technologies that are now well-proven and used in Europe and in France. But, economically speaking, this sector is simply not ready to make the required investment outlay.

Moreover, it is important to note the consequences of developing extraction of non-conventional gas or shale oil, on employment and on economic growth. In the gas sector, taking this as an example, 60 000 jobs were at stake in 2010. The drop in the cost of energy (the price of electricity at the outlet has also been forced to drop) constitutes a very favourable factor for the competitiveness of enterprises that use energy abundantly and has contributed to a re-industrialisation process in the USA. It also has led to an improvement in household budgets[7].

Finally, we note that the development of a non-conventional gas sector is a major advantage for the American petro-chemical industries, their main raw material being ethane (produced with methane) whom price has also been lowered. Thus we see a new upsurge in US production of ethylene, which had been declining because of alternate competitive sources available in the Middle East. European petro-chemistry, in contradistinction uses mainly naphtha oil the price of which is connected to that of crude oil, whereas the prices of other oil products are, *grosso modo,* determined by the international market-place.

[6] *Cf.* http://www.bloomberg.com/quote/API21MON:IND for the current steam coal CIF ARA pricing.

[7] *Cf.* also the development of "America's Natural Gas Highways" that has enabled inter-state trucks to be refuelled with LNG rather than diesel oil.

The energy transition in Germany ("Energiewende")

We cite the following elements from the CAS study in reference below[8]. The four principal strategic orientations — as decided by Germany in 2010–2011 are:

- development of Renewable Energies REN (objective: 35% by 2020, 80% by 2050);
- decreased total energy demand: –20% in 2020 and –80% in 2050 (for electricity: –10% by 2020 and –25% by 2050);
- increased energy efficiency (savings) (so-called 'energy intensity')[9]: –2,1% *per annum*);
- decreased GHG emission levels GES (–40% by 2020, –80–95% by 2050).

Following the major nuclear accident at Fukushima (March 2011), the German Parliament decided to exit more rapidly from nuclear power production, their horizon for this moving from 2036 to 2022. A major role was assigned to gas (natural methane gas and biogas) to compensate not only for the gradual decommissioning of the nuclear power stations but also to counter the intermittent characteristic of RENs (wind power and solar PV, mainly). The role played by gas in the German energy scene is important, whether the methane is imported from Russia, or comes from European shale beds or is produced in biogas facilities. Currently, the price of gas in Europe stands at 12 $US /MBTU), *i.e.,* four times higher than the American price (3 $/MBTU), with our comment that we feel the latter is under-priced. The German spot market for liquid natural gas LNG lies between these two values (8 $US/MBTU). German biogas is, for the time being, 3 to 4 times more expensive than for LNG.

If we analyse figure 1, we note that the total power capacity installed in Germany is 214.8 GW, *i.e.,* 2.7 times higher than the peak demand (equal to 80 GW) which should drop by some 10% by 2020. This is clearly lower than the peak observed in French demand, 100 GW. The reason is that heating in Germany is assured by gas and/or coal whereas in France heating is often electric. Electric energy in Germany is consumed mainly in the industrial sectors. If we group the primary

[8] Published September 2012 (CAS: French Government Agency for Strategic Analysis — Centre d'analyse stratégique).

[9] Amount of energy to be consumed to secure 1 € in the GDP.

German electricity production figures
Capacity installed for 2013 (in GW)

Lignite (brown coal)	18.4	86.4	86.4
Coal	39.2		
Gas	28.8		
Hydro STEP (pumping)	9.9		9.9
Others	6.2		
Wind Power	49.2	103.2	
Photovoltaic	54.0		
Biomass	9.1		9.1
			105.4

Figure 1.

sources by their typology, we have lignite (brown coal), coal and gas which amount to 86.4 GW, *viz.*, close to the peak demand, and 96.3 GW if we add hydro-electric production to follow load changes and rapid demand variations. Wind power and photovoltaic sources represent 103.2 GW, *viz.,* of approximately the same order of magnitude. **Investments in RENs will not decrease the investments needed for fossil energy procurement and use.** The programme calls for installation of 12.8 GW by 2013 (coal and gas), plus 10 GW more by 2020, viz., the same quantitative production as will be lost when the nuclear plants are decommissioned.

We can note that biomass, *i.e.,* mainly biogas only represents 9.5 GW whereas by 2050, the German texts assign to it central role in matching production and demand and this calls for an installed capacity of around 60 MW. The electric production plants are the same, no matter what the source of methane (CH_4), whether it is conventional, non conventional or bioengineered. Biological production of CH_4 by processes that do not use agricultural produce is not, as yet, industrially available. Over and above the economic issues that are central, the capacity to produce the required quantities of CH_4 in Germany has not been demonstrated: Germany's methane mix could very well vary as a function of various external factors.

Another thought here is that gas is maybe not necessarily appropriate as a backup for intermittent energy production. Combined cycle gas turbines are designed to operate on a regular basis, somewhere between 5 000 and 6 500 hours/yr. They are on stand-by (not closed down) ready to start production as soon as the sun stops shining or when the wind speed drops below the wind turbine kick-in threshold value. In Germany, many power stations are only operated 3 000 h/yr, or even much less. The operators of these stations ask for a price rise for their production. According to the OECD, the increase in the fraction of the energy mix for intermittent RENs tends to push prices up steeply.

In Europe, we have a symmetrical situation compared with what is happening in the USA. Coal is cheap and gas is expensive. Germany therefore imports American coal and increases its consumption of steam grade, *viz.,* high quality, coal. This situation could last for a fairly long period and would encourage other European countries to make a maximum use of their own coal burning stations.

Germany's stance in terms of GHGs is not totally clear. And, in the meantime, the emissions continue to rise.

Chapter 2

POINTS TO BE CONSIDERED IN RESPECT TO AN ENERGY TRANSITION IN FRANCE

France will be determining its energy transition policy in 2013 and, in order to do this, will have to take into account the technical considerations, the limits and constraints of the changes, the industrial parameters, all of which are addressed in the following chapters.

France will also need to consider the investments and costs incurred by each path envisaged. These points will be addressed in a second NATF academic report in the months ahead.

ACTING ON ENERGY CONSUMPTION RATHER THAN ON ENERGY PRODUCTION

By 'acting on consumption', we refer to the level of efficiency and low-profile energy consumption in a number of forms: we can avoid wasting energy (better insulation, energy recuperation…) and increase the efficiency rating of all operations that use (consume) energy. The question also (and perhaps above all) is how to understand the nature of the end use and to check if the solution chosen to satisfy this need is adequate and efficient. In the transport domain, for example, over and above seeking to identify efficient modes of transport, we must address the question of the urban environment and its organisation, of the local land planning policies, of work patterns, entertainment, teaching establishments and the need for private or collective mass transport. This also implies collectively organising the demand, such that the resultant is not just the sum of the individual needs, but rather a first synthesis applicable to a given, local setting.

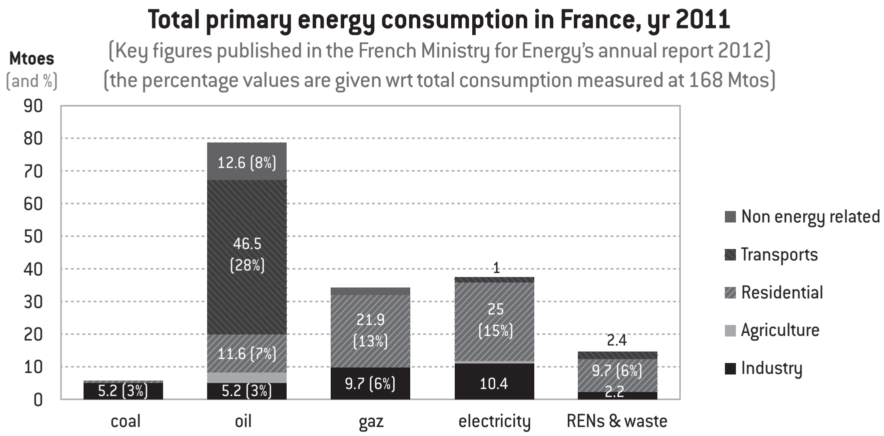


Figure 2.

To have an idea as to the potential energy gains or savings, we must examine the three major uses for electricity, *viz.,* industry, transport and cities and housing.

Industry (25% of the total)

Two main categories of industry can be identified:

- the manufacturing industry sectors that produce/assemble equipment and consumer goods, using 70% electric power sources and we can note that this fraction will increase. To preserve competitivity of these sectors, they must continuously improve and upgrade their products and their assembly/fabrication processes. The electric consumption overall should decrease, unless France's much awaited and lasting "reindustrialisation" takes place at last;
- the major energy consumers, *viz.*, the cement kilns, the steel-makers' furnaces, petroleum product refining, chemical sectors… These industries do

continuously improve their methods and processes and here again, overall consumption should decrease, unless the pro active policy to build more housing leads to positive consequences for these sectors. We can also note the recent efforts to recover fatal energy losses (heat losses) that could affect the measured energy production/consumption balance sheets.

By way of a conclusion, in terms of industrial consumption, at this stage we can observe that by horizon 2025, there is not, in fact, much room left for energy saving. In contradistinction, if political decisions are taken to revitalise industry and the housing sector, they may lead to an increase in energy consumption in the sectors mentioned above.

Transport (33% of the total)

The transport sectors are the main consumers for fossil fuels.

Referring to road transport, the gains in fuel consumption in the more recent road vehicles are close to 1.5 to 2% per year, which represents an average drop of between 25 and 30% over the period 1995–2012. However, not all the vehicles on the road are recent and overall fuel consumption has not decreased in the same proportions. The important point here relates to a possible and significant change to adopt electric private cars (currently they account for 40% of energy consumed in transport).

The change over to electric vehicles, even at the horizon 2025, will be on a small scale mainly because of the costs of installing networks and recharging posts [sockets]. But in the decade 2040–2050, the electric vehicles on the road will principally be composed of fully electric urban and suburban private cars and hybrid rechargeable vehicles fitted (potentially) with biofuel engines (which is another important change) or biogas engines after a transition *via* LNGs.

Management of the electric power production needed for these changes will *per se* be a primordial problem that remains to be solved. Over and above the question of the quantities of extra electric power needed, we shall have to reason in terms of extra production capacity. An analysis of private electric vehicles and hybrids shows that:

- in 2020, the forecast is for only 400 MW (averaged over a year) for about 400 000 all-electric and hybrid vehicles;

- in 2040–2050, the demand will rise to between 4 to 6 GW for approximately 4–6M all-electric and hybrid vehicles. The total capacity to be installed could prove much higher if the decisions to build the networks and power posts are taken and implemented rapidly.

We must bear in mind that the number of vehicles on the road also evolves according to population (currently we have a positive population growth rate in France).

Considering that, by 2050, a factor 3 in the drop of CO_2 emissions does seem plausible, the factor 2 for the drop in electric power consumption will be very difficult to attain. We assert that 40% is more realistic as a target, *i.e.*, 13% of total projected energy consumption in France at that time.

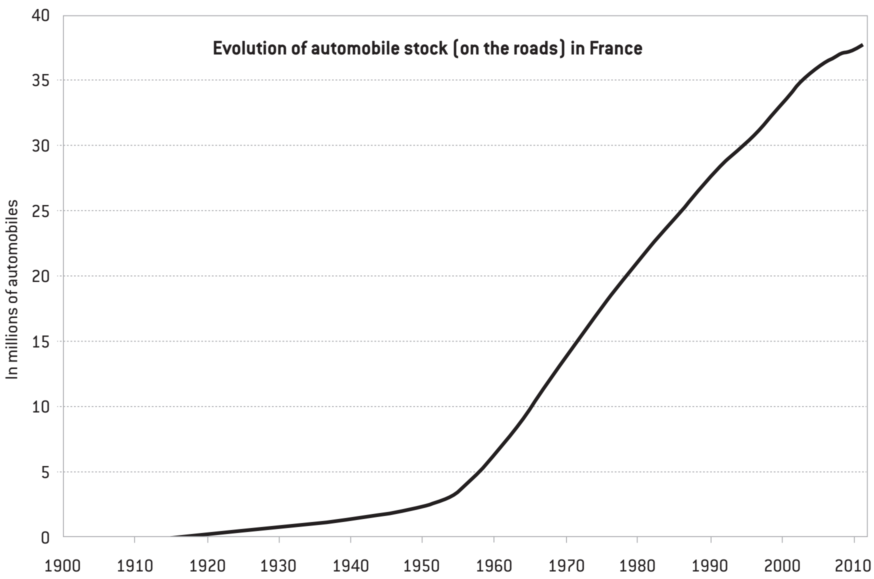


Figure 3.

Cities and housing (42% of the total)

In the housing sector, the evolutions in the future will depend on the results of three impacting factors:

- progress made in energy production efficiency levels (equipment, lighting, regulation…);

- energy savings through implementation of improved insulation measures;
- development of new energies, in particular thermal solar power.

Older housing constitutes 90% of the segments in which energy saving and new energies can be achieved.

The objective advocated by ADEME for yr 2020 is that we reduce by some 38% the financial outlay for energy consumption in buildings (housing, office space ...). We feel at NATF that 28% would be a more realistic figure here (12% of the total energy consumption in France) and only possible if strong policy decisions are made in that direction. By 2050, if we were to extrapolate, the saving level would be around –15% total French energy consumption.

Whether we actually attain the objective above or not will depend on the results of studies currently under way to reduce the costs of construction and rehabilitation of housing, etc., and also on the financial measures or incentives, addressed in particular to individual home-owners or multi-proprietor constructions, flats, etc.

A "bonus" of 7% reduction in energy expenditure in buildings can be obtained by developing heat networks and calorie capture processes (in incinerators, waste effluent water ...)

If the efforts suggested here are implemented and pursued, we can reasonably look forward to observing a 50% energy saving level in the housing/office space sectors (representing 23% of France's total energy expenditure).

To draw another conclusion, with a probably fairly high error margin (we recall that we are indulging in an academic, prospective exercise, not formal forecasting), we can state that France's energy consumption should drop by some 15% by year 2025 and by approx. 30% by 2050.

These three main areas are designed to use a specific type of energy vector which structures the corresponding industrial sectors, *e.g.,* diesel engine cars, electric locomotives, gas-fired or electric furnaces. This concept of energy vectors largely analysed and defined by NATF (*cf.* Publications *supra*) is necessary here. An energy vector is the physical form assumed by a given energy to satisfy a given need. They are the vectors that are distributed and sold to the end-users: petrol at the petrol station, gas to the boiler, electricity to the outlet socket.

Vectors are 'structured' or organised in networks, which enable the users to access them and to make spatio-temporal adjustments. A vectors energy demand/use analysis allows us to take account of downstream competition — what use will be most profitable? — and upstream — what source will be the most prolific or abundant? — Competition in this light may be economic (what is the final cost to the end-user or the level of remuneration for the producer?); it may be ecological (what is the quantity of GHGs emitted using this energy?); it may be strategic (what may be the impact on the country's balance of payments and what are the risks of the procurement chain becoming fragile; or again may be socio-economic (what jobs does the sector create?), or industrial (who are the French leaders in the sector?) Doing a vector analysis is an interesting approach to fully understand what an energy transition entails.

The most rewarding approach is to make a systemic, global analysis and firstly in a global energy procurement and use study of cities (taken in a wide connotation). In France as elsewhere in the world, the populations are increasingly becoming urban dwellers and indeed it is in this framework that most energy is consumed[10].

What priority considerations should we consider?

Ranking priorities is the responsibility of politicians and the potential range of such priorities is wide open. Should we, for example, focus on reducing CO_2 emissions, or should we seek to secure our energy independence and, subsequently, try to improve the country's balance of payments, or should we be trying to encourage job creations, or the development of new industries whose priority will be to export goods and/or services?

[10] Over more than one year, recently, our Academy visited several major cities in France (Nanterre, Rennes, Toulouse, Belfort, Bayonne), spending a full day each time, with the elected local authorities, the community and area service representatives and the citizens, for the purpose of analysing with their input the local urban situation from an energy procurement/consumption policy approach.

The final price to a household or industrial consumer and end-user for energy, as we see it, should be subjected to a careful analysis. This point is very important: those industrialists who are major energy consumers place the price they have to pay above the price for labour when it comes to choosing their industrial sites. As far as household consumers are concerned, a high cost of energy delivered to the home is that amount no longer available in the family budget and reduces its non-energy related consumption.

If we were to ignore the question of energy procurement independence, whether it is France or Europe as a whole, would constitute a serious error inasmuch as it is the *leitmotiv* of all the major players in the world. France chose, as of the close of WWII (1945) to invest first in hydro-electric facilities (dams), then in nuclear power generation. The country likewise decided to abandon coal mining (a process which took 50 years) — to ensure its energy independence. It was in this way that the railway lines and locomotives were electrified, household heating too as well as many industrial ovens and machinery. These historic facts explain why France has a peak in electrical consumption some 20% higher than Germany (absolute values 100 GW/80 GW). The national choice in favour of electricity as the prime mover presents the double advantage of decreasing the amount of energy resources one needs to import, as well as that of CO_2 emission levels. Should we go further in this direction? The idea of energy independence also contributes to the development of renewable energy sources. In France, this means principally the erection of wind turbines, on land and off-shore; solar photovoltaic electricity and biogases. There is also room in the mix for marine energies (wave and tidal), geothermal sources, etc.

The gradual installation of intermittent renewable energy sources will lead to a major change in the way we produce electricity. Indeed, it should not be seen as a factor of perturbation, but as a welcome opportunity to see the global electric system in France evolve.

This relatively recent development of intermittent renewable energies does, nonetheless, raises the question of their impact on final cost to customers, also the cost of infrastructures and industrial tools as needed to ensure development in this field.

Development of intermittent 'renewables' also raises questions about job creation. Energy is an area that calls for fairly large teams of highly qualified personnel to build new infrastructures more or less in keeping with the scale of the power capacity installed, to operate the equipment and ancillaries, to work on the networks, for maintenance purpose, etc. Fundamentally, in terms of job profiles and numbers, there is hardly any difference between building a methane (LNG) handling port facility, an EPR nuclear power station or an off-shore wind farm. Development of world leaders in each case is a far more complex issue. France does have leading companies in hydro-electric, nuclear and petroleum product installations, and these must be developed. But you do not necessarily have to be a world leader in a given product line to succeed in the export business of your product. If you are a market leader for a strategic component (the electric generator for a given type of wind turbines, or other example, the glass or integration process for PV frame assembly, formulating additives to extract shale gas) can prove just as profitable and less 'exposed' than holding a dominant market position in the market-place. There are, consequently, two main areas for development of jobs related to energy production: those connected with local energy production in France, and those that correspond to energy demands (of a different nature) in local markets outside France where certain French export companies can compete with the majors. These two parallel industrial opportunities should be developed simultaneously.

It is primordial to remember that the economy of the energy system and its efficiency (kWh price for the domestic end-user and for industrial/commercial companies) contribute, but to a very large extent, to assuring national wealth, to the creation of jobs in numerous areas of activity and in particular the industrial sectors that consume energy.

Analysis of energy consuming sectors and the role played by heat networks

The **city** or the **urban area** is the appropriate scale to analyse the three primary sectors where energy is consumed: mobility, heating and (street) lighting, domestic and industrial equipment.

Energy related expenditure for **mobility** depends a lot on the physical space occupied by the conurbation, this being in turn dependent on the possible pleasure of living in the city centre and the financial possibility of finding housing (purchase or rental); again, this depends on the housing policies enacted by the city authorities. Are there schools, or educational establishments in a wider meaning; are there sports grounds and amenities? Are there community centres… ? All of which have a direct impact on the price of housing, property and land and hence, paradoxically, tend to push families with children further away from the centre. For energy consumption reasons, it seems likely that future urban centres will be densely populated; they must be able to offer pleasant surroundings and life-styles, in other words "a really nice place to stay".

The energy vectors for transport uses may be liquid fuels (diesel oil, petrol and biofuels), gas phase fuels (methane, hydrogen) and electricity. When consumers choose their vehicles and the fuel, it has large impacts on the associate industries that have a high degree of inertia. What is important is the amount of energy consumed for a given service. Heating at home and hot domestic water are produced using gas burners, or by electric heaters/immerser appliances, or by fuel burning boilers. Lighting relies on electricity. The efficiency of light appliances has progressed considerably in recent years. LED lighting appliances consume very little energy and this now allows us to have better lit, safer cities for least cost (LEDs are just arriving in the public lighting sectors). They are only just beginning to be adapted to this situation.

The fraction of **heat production** in the global balance sheet justifies that special attention is paid to this form of consumption. If the final objective is to produce heat, then it will be more appropriate to heat domestic water using thermal solar energy rather than to install PV photovoltaic panels to power electric water boilers, hence the importance of thermal solar installations. By 2025 with this approach we can save 20 TWh/yr[11]. The particularity of heat as an energy source is its high inertia: we can heat water or coolant tubes for a certain time and then recover the heat at some later time. This is not the case for electric heating since we must instantaneously balance production with the demand and consumption. The inherent advantage of the inertia characteristic lies in the fact that the heat can be produced either when demand for electricity is low or the nuclear production offer is in excess, or when the wind blows, or the sun shines and can be consumed much later. This is one of

[11] Requiring 40 Mm² thermal sensors, for a roof area potential of 2 800 Mm².

the efficient ways to accumulate and store energy. The inertial factor also enables recuperation of underground heat (geothermy) or the heat in waste domestic water effluents. These technologies can be developed to fit the scale of the city.

Lastly, we observe that both **home appliances and industrial equipment** run mainly on electricity. Computers (laptops, desktop and larger office models) are accounting for an increasing fraction of the electricity consumed. Rapid development of high processing power levels also leads to an increase in the overall quantity of electricity consumed. Large-scale data processing centres and so-called data bank processing/archival centres[12] require several hundreds of MW power. Almost all this power is transformed into heat and could be recovered for use in heat distribution networks; an analysis would be in order to ascertain whether the called power can be modulated downwards during peak demand periods or raised when fatal energy is available (*via* intermittent sources).

By 2020, **electric vehicles** could number somewhere between 400 000 and 1 million in France alone and that would represents some 7% annual sales, *i.e.*, of the same order of magnitude as the projection for hybrids. The electric consumption in France for these vehicles would be between 2 and 4 TWh, *i.e.*, between 2.5 and 5% of the projected electric consumption in homes. The automobile industries reckon that the recharge will be obtained mainly by slow amperage connections (7 to 11 h) by simply plugging the vehicle into a simple home 220 V socket. Rapid recharge leads to physico-chemical problems in Li-ion batteries not forgetting the difficulties of high instant power demand (as an example, electric vehicles at the Velizy — Paris suburbs — shopping mall would require 5.4 GW!). In contradistinction, if we take a two-hour stay of the vehicle on site, this would call for only a 450 MW during the mid-day lunch period. Admittedly, it represents a lot of power but can be met inasmuch as mid-day is a low consumption segment. Battery exchange protocols (fully charged for depleted) offer some possibilities. The batteries connected for a long period to the electric distribution network can serve to build up energy storage capacity that would then be integrated in the decentralised storage sites managed by local 'network' operators.

[12] Large-scale data processing/archival centres represent between 1% and 2% of the world's electricity consumption for 2010, with a 50% increase of this consumption between 2005 and 2010.

The role of networks

There are gas (transport and distribution) networks; electric (transmission grid and distribution networks); heat networks — leaving aside transports networks for the moment. The national networks are integrated into a European system that enables inter-state energy exchanges and carry provisions of clauses for mutual assistance if needed, to comply with energy market economics.

The **gas network** is designed to transport gas from the producers, to store it and to distribute it to the end-users. Gas used in France comes for 1.6% from national wells, by gas-pipelines from Norway (32%), from the Netherlands, Algeria, Russia, etc. and is unloaded from three LNG ports (liquid natural gas) that comes to Dunkirk, Montoir de Bretagne and Fos-sur-Mer) in cold liquid phase. LNG represents 28% of imports. It proves to be a more flexible form of energy source compared with (gaseous) gas imports by gas-pipelines which is subject to long-term contracts with the producing countries.

Electric networks (HV transmission grids) spread over all Europe and interconnect with the North African grids. They will develop to a considerable extent to accommodate the development of intermittent power sources (wind, PV, marine, etc.). In France the transmission grids lie in the responsibility of RTE which posts on Internet the real time consumption of electricity and then production, source by source[13], the balance sheet for imports/exports of power, the quantities of CO_2 emitted. Each Internet connected citizen can follow in real-time the electric status of metropolitan France. Why, we may ask, should development of intermittent (renewable) energies lead to a development of networks and network extensions? The simple answer is that the larger the size of a territory we are trying to connect, the more it is subjected to climate variations and changing meteorological conditions, and hence the higher probability it will have to receive, globally speaking, the necessary wind and solar input. This leads to share to some degree the intermittent power production for the purpose of making best use of the generation, transmission and distribution infrastructures. To take an example, average photovoltaic production, amounting to 1 100 hours/year peak power equivalent (for a total of 8 760 hours in a year) in Marseilles is less than 900 hours in Paris or, for that matter, the average in all Germany.

[13] *Cf.* http://www.rte-france.com/fr/developpement-durable/eco$_2$mix/production-d-electricite-par-filiere

On land and on average, wind power production is available 1 800 hours/year in France. It is better in coastal areas and clearly much better off-shore (ranging from 2 500 to 3 000 hours). The end result underscores the weight of the geographic factor. Renewable energy in essence is geographic: it can be either very profitable or not at all, depending on the geographic siting of the production plants.

However, we can readily observe the local societal opposition when it comes to building a new line of pylons for electric transmission. Two regions in France, Brittany and Provence-Alpes Côtes d'Azur (the French Riviera) have a special energy status. There is only a low power production capacity in these Regions and a limited grid situation which leads to stringent energy use, but generally well accepted by the regional consumers at peak hours (so-called Ecowatt[14]).

The electric network (just like the gas distribution networks) is submitted to closely controlled operations procedures, *via* centralised dispatching and control centres using highly sophisticated system management , forecasting and intervention protocols.

Local networks allow operators to 'mutualise' consumption and even, in certain cases, production of electricity and, more commonly, heat. Management of energy saving opportunities (short-term energy shaving[15]) and energy storage (heat and/ or electricity), in a framework of urban districts, is easier. This approach can lead to a decrease in total energy consumption and to procure energy at best price (as per current regulations this is possible for industrial consumers but not, so far, for private home-dwellers). It is, however, an area that holds promises for new developments, a potential for export opportunities en for creation of new jobs. Several networks of this type exist in the Paris region, or in and around Lyons, etc. These networks enable better exploitation of intermittent energy sources, provided the latter represent only a reasonably small fraction of total local electricity production.

[14] Britanny: *cf.* http://www.ecowatt-bretagne.fr/pourquoi-ecowatt
Paca: http://www.ecowatt-provence-azur.fr/

[15] Electric load shaving — which can be imperceptible — is adapted to the type of equipment. For example, electric heating apparatus does not react if the electric power cuts are short. Industrialists can participate in load shaving *via* contracts, in which they have preferential tariffs. This does not, in fact represent an economy, since the consumption is only deferred, but it does provide for better management from economic and technical points of view.

Heat networks are local (*i.e.*, the piping can reach points out to some tens of kilometres). They may use hot water produced in a central boiler installation using many different types of fuel, notably renewable (burning urban and agricultural wastes, wood or intermittent energies). They may also use geothermal energy from warmer lower layers (the Dogger layer in the Paris basin) or can recover residual domestic heat using exchangers in the sewers, and in more general terms, all forms of so-called fatal heat, *viz.*, from industrial cooling circuits, notably used to cool electric power production stations.

Chapter 3

POSSIBLE PROSPECTS FOR THE FUTURE FRENCH DEMAND FOR HYDROCARBON FUELS (INCLUDING NATURAL GAS)

Ever since yr 2000, **French domestic consumption of oil and petroleum products** has been oriented downwards (with a sharp drop between 2007 and 2010 and a +2% rebound between 2010 and 2011). In 2011, taking into account the corrections due to climatic variations, the primary consumption of oil and petroleum products was 82.6 Mt, 11.1 Mt of which were consumed in non-energy production uses and 4.9 Mt in energy related uses, *viz.,* fuel to run the oil-burning electricity power stations, plus some consumption for internal uses in refineries. The drop in the energy balance sheet was particularly significant in industrial sectors and residential uses. The fraction in this balance for uses in transport (46.5 Mtoe) is growing and represents today about 70% of the final consumption of petroleum products. This figure is characterised by the trend to equip private vehicles with diesel engines (due, in particular, to a preferential Government tax on diesel fuel compared with petrol) and by an upturn in road goods transport trade. The percentage of diesel fuel in the total fuel market is now 82%. This long range trend is largely the cause of the difficulties encountered by the national refineries. Production of petrol is in excess for petrol and in deficit for diesel fuel. Consequently, the net imports of diesel fuel and jet fuel rose to around 20 Mt, while net exports of petrol and naphtha were 5.4 Mt. Imports for crude oil entering the French refineries were stable at 64 Mt, while cracking capacities were lowered with the closing of several sites (Dunkirk (Total) in 2010 and Reichstett (Petroplus) in 2011), reduced capacity at the Normandy refinery (Total) in 2010 and the outage of Petit-Couronne (Petroplus) in 2012 and a doubt as to the future of the Berre site (LyondellBasell). This situation is not specific to France and the fact is that European refining is over-dimensioned. Sales of diesel fuel — representing 32% of fuel sold in Europe in 2000 — have increased to 52% in 2010, with a surplus petrol production estimated at 40 Mt/yr for 2011 and a diesel fuel deficit of 60 Mt.

These trends will doubtless continue in the future with an imbalance between petrol and diesel fuels, despite numerous projects to install hydrocrackers (to handle more than 20 Mt/yr in Central Europe in particular). Moreover, the excess production of petrol will have to find new markets outlets other than the USA who are now approaching a balance (development of biofuels and a drop in demand due to price leverage which is more striking in the USA because they apply less Government taxes to fuel at the pump).

Finally, it is often considered that there is an intrinsic advantage to having the petroleum product refining coupled to the petro-chemical industries. However, we can comment, as we did earlier, that European petro-chemical sectors now have a degraded competitivity level, in particular when compared with the equivalent industries in North America where the principal raw material, *viz.,* ethane, is available at prices far below those for naphtha that we refine in Europe. French resources in this area may be re-evaluated because of recent discoveries of deep offshore fields in French Guyana (South America) and even shale oil layers under the Paris Basin, where there is already a conventional oil extraction industrial activity. The combined potential of the last named sources could amount to 16 M barrels/yr.

There is also an important development underway to produce biofuels. Those we use today are mixed in with traditional fossil fuels: currently (and since 2010) at French filling stations diesel fuel incorporates 7.5% biofuel in volume and there is 10% volume ethanol in petrol. However, the limit is now reached given the agricultural land space available, *viz.,* that can be used in France to grow oil-bearing crops. The European regulatory framework forecasts a proportion of 10% biofuel throughout Europe, along with severe constraints in regard to protection of the environment for first-generation biofuels. It encourages research and progress towards second generation biofuels that would derive from processing of non foodstuff plants or from agricultural foodstuff plants wastes (straw, vegetable tops, leafs…) and not (as at present) from raw material plants that are also used for foodstuffs (*e.g.* maize seeds, beetroot…), or foodstiff production wastes.

The time taken to develop processes and their associate technological implementation, as needed to produce second generation biofuels, is turned out to be much longer than envisioned initially. Such fuels will only reach the pumps after 2020. Without significant industrial results thus far, it is difficult to assess the economic relevance of these developments. They will require implementation of non food-stuff biomass at costs compatible with a sane economic global approach. The availability for such biomass in France is already largely compromised by the production of heat, use of wood for increased electricity production and timber. A large scale effort needs to be undertaken to valorise forestry products and resources.

In 2010, consumption of gas in France was 40 Mtoe (or 465 TWh), *i.e.*, a little less than electric energy consumed (570 TWh). Consumption in tertiary, residential areas, represents 60% total. The fraction used for heating depends to a large extent on the observed winter average temperatures. Industrial gas consumption is rising through policy decisions to replace traditional coal burning or domestic fuel installations. Production of electricity represents about 9% of gas consumption; this latter figure is increasing thanks to newly commissioned "combined cycle" power stations, *viz.*, having a much higher global efficiency than "classical" gas turbine (more than 60% compared to less than 40%).

Stored gas in France represents some 50 TWh. Thanks to these reserves, there are no problems to meet peak hour demands, which do exist. For example, February 6–7, 2012, when the peak demand for electricity was higher than 100 GW, the demand for gas reached 150 GW.

Natural gas is a fossil. It is in fact simply methane gas, CH_4, which when released into the atmosphere is a potent greenhouse gas (HGG). When it burns, it produces CO_2. It is imported to France and therefore has an impact on the country's balance of payments.

Two evolutions can be foreseen, as follows:

- the first is to exploit the **shale gas layers** existing in France. In doing so, France would reduce its imports and be in a better position to control the risk of supply difficulties on the world market. But it would not reduce, in contradistinction, the country's CO_2 emissions. French industrialists master the techniques of rock fracturing and also are capable of carrying out deep drilling operations. They also know how to measure and to control shale gas/oil extraction operations. They would undergo internal and State level inspections. A field assessment of the potential here is absolutely necessary. The decision to exploit the shale oil/gas layers can be taken later, as a function of the cost of operations, the import market price levels, the quantities that can/could be exploited, the social acceptance and the simple taking into account of the energy procurement needs of future generations[16];

- the second evolution lies in production of biogases. The main biogas is methane currently obtained by decomposition of plant cellulose. This form of methane is chemically similar to that of fossil methane gas. To the extent that the carbon atoms of this methane are extracted from the atmospheric CO_2 by photosynthesis as and when a plant grows, the balance production/consumption is totally neutral *i.e.,* it is ruled has having no effect on the atmosphere and the climate. Moreover, it is 'renewable' as are all forms of plant production around the world, provided it is done within the constraints of climate change. Future production protocols for biogases will be assigned two objectives: one — not to enter into competition with food production aims; two — to be offered at a competitive price level. Today the buy-back price for biogas in France is established at 12 centimes €/kWh, *i.e.,* 3 to 4 times the price of traditional gas supplies. Contrary to what we may have thought in recent years, the price of fossil gas tends to be stable and is even decreasing in the USA.

It will also be noted that a different set-up is used in Germany: production of biogas there uses pig droppings combined with field maize crops. France, in contradistinction, has chosen to encourage the use of intermediate crops specially chosen for energy valorisation between two main-line crops plantations (for food stuff). In this way the required carbon is produced without entering into competition with human food sources. The production here is also associated with the use of animal droppings and effluents. Under these conditions, the "digestate", *viz.,* what is left in the digester after fermentation, still contains a fair proportion of organic nitrogen

[16] Included in the notion of shale layers we have coal and the possible capture of methane in the Lorraine Region (notoriously known to French miners as 'grisou' with the danger of it exploding in mining operations "coup de grisou").

and therefore can be used as an excellent crop fertiliser. If the prospective study made by ADEME for 2030 sets a truly impressive target value of 6 Mtoe/yr for France, compared with <1 Mtoe in 2010 — we note that Germany was already producing 8 Mtoe/yr in 2010! — the industrial scale installations for this form of dedicated agriculture are only in their initial, exploratory phase today. To attain the target set above, France would have to commit 25% of its arable land-space (outside those specific to food-crops) and 5% of French grazing fields. Consequently, and taken together, this represent a sizeable challenge for the agricultural community.

Another noteworthy difference is that France aims to inject the biogas produced, after purification, directly into the gas transmission and distribution network. National gas suppliers have in recent years slipped up a bit in terms of quality standards and this now authorizes direct bio–CH_4 injection. In order to do so, it appears that large-scale bio-digester plants are needed, the limiting factor being the space for spreading the digestates in fields. Consequently, the approach envisaged in France is completely different from that in Germany, with some 6 800, relatively small, installations already at work throughout the country. These installations are mainly used to produce electricity (15 TWh in 2011) despite a fairly low efficiency.

Yet another approach, currently under development (demonstrator GAYA — GDF-SUEZ) is designed to produce biogas by thermo-chemical methanisation which consists of gasifying biomass to produce both carbon monoxide (CO) and hydrogen (H_2) which are then recombined to form methane (CH_4). This novel technology has now entered a pre-industrial phase in several countries (Canada, Austria …). Its main advantage is to be able to use biomass from many different sources: agriculture, forestry and even household organic wastes. Cost of producing CH_4 this way would be comparable with present subsidised biogas prices.

Let us end this section by noting that the production of electricity, of heat or use of chemical reactions are in fact the same, whatever the source of the gas and to a certain extent its exact composition. This largely simplifies the policy options that could be taken in the long run.

Chapitre 4

ANALYSIS OF FRENCH DEMAND FOR ELECTRICITY AND POSSIBLE EVOLUTIONS

Daily electricity consumption is posted every day by RTE on its web-site and this information is fully and freely available. Demand is measured in MW (or in GW, *i.e.*, 1 000 MW) which refers to the power level. **To determine consumed energy, you have to multiply the instantaneous power level by the time span during which the demand is to be measured.**

Analysis of electric energy consumption in France and peak power periods

Electric energy consumption in France shows seasonal variations, mainly because of heating requirements, dependent on the day in the week and on the hour of day/night and as well as on variations of industrial demand (week-ends, night time, holiday periods). The daily low peak can be observed around 4 a.m. and two high peaks around 12 a.m. and 7 p.m. Maximum consumption occurs in the winter period. Ambient average temperature also plays a role. If the temperature moves ±1°C, the inverse impact on demand is about ±2.3 GW.

In order to satisfy this demand, production means available are brought on line as a function of the installed power capacity[17] and of its availability at the time of the demand. For the year 2012, the electric production power levels installed in France are:

Nuclear power stations	63 GW
Hydro-electric installations	26.8 GW
(of which 12.7 GW come from run off from the river flow and cannot therefore be modulated (or only to a small extent)).	
Coal, gas, diesel fuel fired stations	27 GW
Wind-turbine generators	7 GW
Solar Photovoltaic (PV)	3 GW

Figure 4 is a screen copy of what any French Internaut can see on the RTE site: www.rte-france.com/fr/developpement-durable/eco2mix. It gives an instantaneous picture of production of electricity in France and the sources (as per list above); this is a most important graph.

The same is available for English speakers at www.rte-france.com/en/sustainable-development/eco2mix/electricity-demand

Let us analyse figure 4: at any given moment in time, the summed power demand of all consumers must be satisfied. Most of this power is provided by the nuclear power stations, with a noteworthy drop during the night-time (–7GW) and an even more significant during the week-end (–14 GW), when there is less electric powered transport (such as train, tram, trolley-bus) and industrial demand is lower. The fraction of nuclear power is around 60% when demand is high and around 80% when it is low. During the peaks, mid-day and early evening, it is the hydro-electric stations that complete the power production which moves up from 5 GW to 14 GW. This 5 GW power level corresponds to run-off from the rivers hydropower plants production (regular flow but non modifiable). The other 9 GW come from low level dams and

[17] The installed power level is the sum of the power rating of all equipment physically installed and connected to the grid. The associate investments are assumed to be paid for and may or may not yet already be amortised (depending on life span).

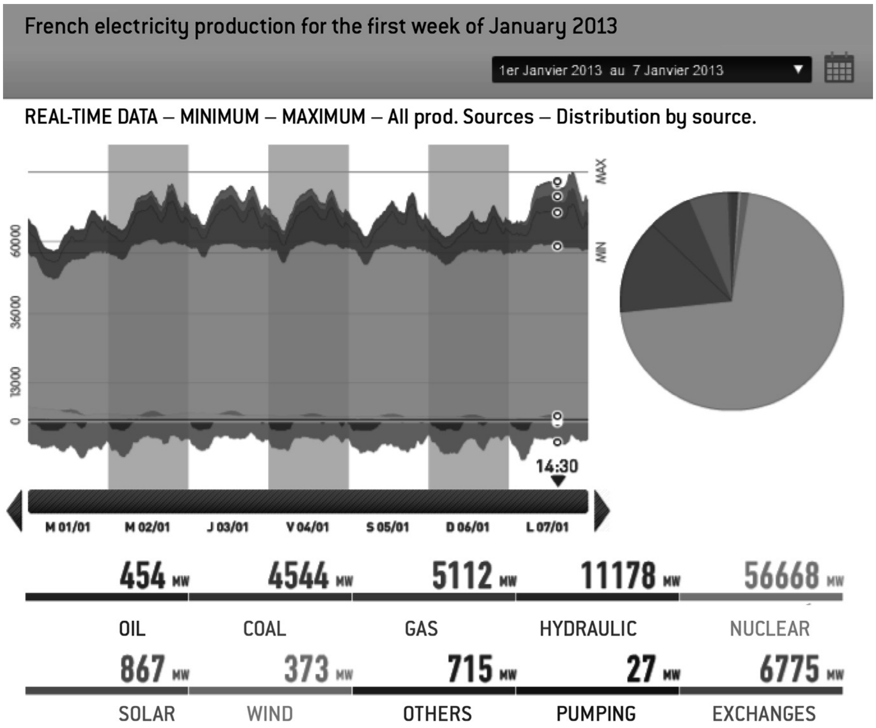


Figure 4.

Pump Storage Plants[18]. We can see in the graph that about 3 GW is used during the night to pump water to a higher storage dam for later generation use. Wind power is variable, from a high 4 GW (about 60% of the installed power capacity) to a low 0.6 GW (9% of the installed power capacity). Photovoltaic production is included

[18] STEP: acronym in French for pump storage plant used to pump water up from a lower reservoir to higher (dam) reservoir positioned several hundred metres higher up. Pumping takes place when energy is cheap, even free in North Germany for example when there are strong winds (driving the turbines at maximum rate). When demand increases, the water is released from the higher dam passing through the hydro-turbine generators. The storage at full power corresponds to several hours at most (between 3 and 6 hours). Only two Step installations in France, Grand'Maison and Montezic (out of 7) have higher storage capacity, *approx.* 30 h, given their large physical dimensions (in m^3); the other 5 are lower capacity sites.

among "OTHER" sources, as is so-called co-generation (simultaneous production of heat and electricity); solar PV production represents on average about 1 GW (33% of installed power capacity) around 1 p.m. (PV is non negligible between 11 a.m. and 3 p.m. if the sun is visibly shining). Co-generation amounts to 4.5 GW electric production, over and above the heat output. Production of electricity from coal-fired, or gas-fired power stations (exceptionally oil-burning) provide the extra power demanded. Coal-burning stations are used more than gas-burning generators, given that the price of coal and gas in Europe are such that it proves more economic to produce electricity by burning coal (accounting for some 5 GW) than burning gas (*approx.* 2.7 GW). But we must bear in mind that GHG emissions from burning coal are much higher than those from gas, but the price-tag for carbon on the ETS market do not compensate at all the differential. Exports and imports here are used to adjust supplies and final costs.

When France had a demand peak of 100.5 GW, on Feb.6–7, 2012 at 7 p.m. (both days); 7 GW were imported, whereas under normal circumstances France is generally an electricity export nation.

In the summer-time, demand is much lower. In August, it varies from approx. 30 GW at night to 45 GW at the mid-day peak.

The previous graph and the next two tables show the extent to which nuclear production is primordial[19]. The structure of the consumption of electricity in France and the 'low profile' prospects for its development (growth) do not justify building any new nuclear capacity in the short term. The production units however are

[19] French nuclear reactor power stations represent high quality installations. They have enabled France to achieve and maintain a low price for electricity for the consumers. The sector has contributed to the development of industries in France, to the country's energy procurement independence (the quantity of uranium consumed is small and supplies are widely diversified between Russia, Kazakhstan, Australia, Canada, Republic of Niger), and also to the overall GHG emission level. The countries' 58 reactors are operated under the controlling authority of the National (Nuclear) Safety Agency (ASN) and are subject to regular inspections and improvements in order to comply strictly with the latest specified requirements. If one were to be 'reasonable' then the decommissioning of the older units should be decided in a framework of overall optimization, leaving the nuclear power station operators to assess whether the cost of implementing the demands of ASN (which body is an independent authority) can be offset by nuclear power production over a longer period of time.

Demand peak of 100.5 GW, on Feb.6–7, 2012 at 7 p.m.	
Energy source mix: Nuclear power stations Hydro-electric installations Wind-turbine Coal and diesel fuel fired stations Gas Co-generated electricity Solar PV	 63 GW 13 GW 0.8 GW Feb. 6 and 3.6 GW Feb. 7 (*i.e.*, 56% total wind generation installed capacity) 5 GW 3 GW 5,9 GW 0 GW
Imports (electricity)	7 GW

Figure 5.

not optimised inasmuch as there are too many reactors devolved to meeting the base-line demand[20] and which, consequently are under-utilised and not sufficient dedicated power plants to handle peak demand levels. For a long time to come, there simply will not be any need for new base-line capacity in France. However, the strategic position held by the nuclear industrial sector in France, combined with the high potential for an export market of French nuclear and associate civil engineering know-how and the awareness of policy makers that we are in an "after oil" situation in the long term, all of which should be seen as conducive to maintaining and developing French skills and commercial advantages in this field. Two major axes can be privileged:

- definition and development of several short term reactor designs, with varying levels of power capacity. They would need to comply with a high safety specifications, such as those for the EPR design and installation, and at the same time all possible lessons from return on experience (ROE) from the first EPRs should be taken into account (Generation III+);
- development of a more advanced technology, that would enable operators to burn and eliminate very long life radioactive by-products of nuclear element transmutation (Generation IV).

The hydro-electric installations are likewise of high quality and as is the case for nuclear sites, they are submitted regularly to stringent, continuous control.

[20] Base-line power is that needed to meet base-line demand, *i.e.*, around 40 GW (average for a summertime day load). Any demand in excess of 40 GW is only present a fraction of the year and this is no longer "base-line" demand.

Matching production and demand today calls for modulation of the power output to the grid, knowing that nuclear electric production in France can be changed gradually but over a wide range of power levels. High fall hydro-electric installations can be rapidly brought on line and what is more, excess production from other sources can be stored (by STEP)[21]. Coal and gas are used as intermediate adjustment variables.

Production of electricity from intermittent sources (wind and solar PV) involves yet another adjustment of overall production. Network management is therefore directly dependent on climatic conditions and forecasts: ambient temperature for demand, and strength, mapping of winds for wind-turbine generators and sunlight for solar photovoltaic panels. If we take into account the proportion of intermittent production in today's energy procurement mix, the production levels can be adapted fairly easily to match demand. Improved machines and a more balanced geographic distribution would also allow for an increase in the intermittent sources without disturbing the management of the network as a whole (grid control). However, the fraction of intermittent[22] energy supplied must not exceed a certain percentage of total local power capacity, the risk being that the 'system' as a whole may collapse into a blackout status. The reason is the low inertia factor for wind generators and total absence of inertia for PV panels ands this does allow them to contribute to network stability at all.

How can we follow demand and technically offset the intermittent feature of certain renewable energies?

'Guaranteed'[23] wind-power, with the French prevailing climate, is approximately 10% of the power installed. It would be 10% better for off-shore wind farms. Wind power is significant in the winter season inasmuch as winds at that time of year are

[21] These are imported fossil fuels that emit GHGs and affect (negatively) the country's balance of payments. Using them should be marginal (limited). However, non electric energy consumption is largely majority; a delta on GHGs due to electric production using fossil fuels is low in the general, total emission context.

[22] Solar thermal production does not create problems in respect to network stability.

[23] Power level available 90% of the time.

steadier, more regular. However, even in winter when anti-cyclonic high pressure zones occur or between low pressure depressions, there are calm, windless periods that can last for several days at a time.

Solar photovoltaic panels do not supply any significant power during the early evening peak. The percentage of guaranteed total power available is less than 5% of the nominal power rating. Other sources of energy are therefore needed to meet the evening demand peak.

What we also know is that the installed power capacity for nuclear power production will only vary marginally in coming years, since the Flamanville EPR station, rated at 1.65 GW will be replacing two 0.9 GW reactors (Fessenheim I and II) due for decommissioning at Fessenheim on the Rhine. The average age of the reactors in France is 27 years, which is relatively young, if we consider that the equivalent US reactors, the same family of reactors as those in operation today at Fessenheim, have received their authorisation to continue operations till 2037 and even 2047.

Hydroelectric installations (dams and ancillaries) play an important role. In those countries with lots of hydro-power "on tap" so to speak, Austria, Switzerland, Norway… the supporting 'intermittent' power source (beyond base-line needs) is solely the fact of hydro-electric stations. In France, the availability of hydro-power was built up between 1970 to 1990 by installation of 6 new Step installations, bringing the total to 7 with a combined installed power capacity of 4.9 GW.

There is a need to install other STEP installations and these should be planned in France, as has already been done in Switzerland and Belgium[24].

New power capacities are on the drawing board or under installation, in gas (*approx.* 2 GW), in photovoltaics and wind-turbines, notably off-shore wind farms where three

[24] Building storage facilities is not economically justifiable under current French regulations for sales and procurement of electricity. There are a number of suitable sites in France for STEPS facilities, generally speaking, that could use an existing reservoir in a deep valley and building another reservoir on one of the valley sides, a few hundred metres higher than the water level in the lower reservoir. We could also envisage marine STEPS on steep coastlines (*e.g.*, cliffs) close to the sea. A production of several GW can be envisaged here, on a basis of 7 to 8 hours continuous turbine operation. The Coo-Trois-Ponts Hydroelectric Power Station is a pumped-storage hydroelectric power station located in Trois-Ponts, Province of Liege, Belgium.

investors have been granted operating licences for an installed capacity of 1.93 GW in 2012. There are, in addition, various hypotheses and proposals for new solar photovoltaic stations or land-based wind-farms, for several GW nominal rated output.

Let us now make the supposition that total photovoltaic power and wind-turbine power capacity is 45 GW by 2025, which we note is less than is already installed in Germany today.

Intermittent production will amount to approx. 70% installed capacity when there is a bright sun and strong winds. If, in south France, the well-known 'mistral' wind is associated with bright sun and clear skies sun, when we have strong winds in oceanic regions the skies tends to be overcast. The spread will vary from a minimum 2 GW when there is no sun in the winter peak hour (7 p.m.) and there is a light wind (often the case in very cold, high pressure periods) and a maximum 30 GW when there is a bright sun with strong winds simultaneously over several regions.

Maximum power demand is equal to a little less than 30 GW at night and 45 GW in the day-time. Thus, even if all the power sources (other than wind and PV) are in outage, the sum of these two intermittent power sources should not exceed the value of 45 GW, given that above this value and once the storage facilities have been "filled", production would necessarily need to be exported — and only if there is a foreign demand for power.

Several solutions coexist to forecast and handle power production:

- Nuclear electric power production can be managed in a more flexible manner, so as to handle demand drops from 40 to 20 GW and demand rises from 20 to 40 GW approximately every twelve hours (morning and evening).
- Coal or gas production of electricity is flexible as it stands. Coal and gas emit GHGs (except in the case of biogases *cf.* supra) and they are largely imported (unless we start to exploit shale gas sites).
- Energy can be stored. If we are looking at needs for a few hours only, then the Step reserves can be brought "on line" for a current maximum of 4.9 GW. This power level limit could be increased. If we consider wind-power, the windy spells and the calm periods generally last several days. STEPS here can handle small hour-by-hour variations but not lasting change in production demand. Nuclear power output can be adapted to match variations over several days. Mass storage technologies and associate distribution questions constitute a major area for research and development.

Maximum power demand in France can reach 100 GW in winter time. When the early evening peak occurs, it is dark over France. Wind power generation therefore does not allow the national grid operators to ignore other forms of installed power, but it does allow them to save gas and/or coal when sufficient wind power is available.

By 2025, the electric energy basket could comprise:

Nuclear power	63 GW (current)
Hydroelectric power	30 GW (hypothesis),
	12.7 GW of which are from live water installations
Wind power	27 GW (hypothesis)
Solar photovoltaic	18 GW (hypothesis)*
Coal, gas, diesel fuel	27 GW (current)
Co-generation, etc.	10 GW (hypothesis)

While it remains true that we need overall power production redundancy, the conclusion is different when it comes to emissions and consumption of fossil energies. Indeed, the power that can be produced using intermittent renewable energy installations aims at saving on coal and/or gas burning activities thereby reducing GHG emission levels. A balance sheet needs to be drawn up showing consumption savings subsequent to bringing intermittent sources 'on line', compared with emissions and extra consumption as needed to meet the evening peak occurrences.

How much would a system operating on this energy mix cost?

Investing in installation of intermittent energy installations and infrastructures does not obviate an equivalent investment outlay in 'on demand' power installations, *i.e.,* those with an inherent high, operational flexibility factor. These flexible sources indeed can be renewable, if we look at possibilities in

* Peak power of France's photovoltaic equipment is estimated at 75% nominal panel power rating, the reason being that sunlight varies during the Sun's day's transit and it does not shine all the time (adverse weather conditions).

hydro-electric or biomass production. For the time being, better flexibility in nuclear power production can help solve load matching issues. Moreover, in order to use intermittent energies properly, we must install or prepare reinforced transmission grids that allow energy produced to be exchanged with other regions (with different climate or local weather conditions), centralised storage facilities, such as hydroelectric reservoirs, or decentralised). Above all, you need excellent management of demand to proceed with power shaving operations, or alternatively demand increases depending on the production from the intermittent sources. Network or grid operators have access to temperature, wind, sunlight forecasts, and have the possibility to bring 'on line' extra power from (a) given source(s). Operators will continue to improve the management protocols they use. Investing in grids proves very expensive and need decades of procedural, admin., regulatory work just to plan and install one 400 kV HT line of pylons. Installing new storage facilities will require a least a decade of planning/installation before their impact becomes significant. Modulating demand in an overall vision is a long-term undertaking, lasting several decades but there are today protocols that allow selective saving/shaving of demand, off-peak consumption (to produce hot domestic water or deferred household appliances such as clothes or dish-washers, for example). So-called 'smart' meters in a framework of a global vision for urban or regional consumptions can introduce a significant modulation of demand at short notice. Today, the installed power sources in France are managed satisfactorily by RTE. Consequently, moving to an energy mix comprising 10 GW renewables (RENs), *i.e.,* somewhat less than 10% total installed power capacity, is not a problem.

Let us now suppose that there will be a regular growth in the offer of intermittent energy sources. We saw earlier that France has about 18 GW available for a rapid intervention, if needed. Wind-speeds that vary in cycles of several days at a time can be offset by raising the nuclear output production to compensate, and the same holds for fossil energies (gas, coal, fuel, as we await biogas installations) or gain using the hydro-electric stations when the demand variations are rapid. Also, we recall that hydro-pumping can be used to transfer PV energy production to the early evening peak demand. It was, indeed, this line of thought that led to the proposal to limit new energy capacity from intermittent sources to 45 GW for the coming decade. The final decision in this respect will have to be taken with due consideration for economic factors.

What will be the impact on the pricing of electricity?

Intermittent energy sources and their infrastructures lead to high investment outlays but, in contradistinction, they do not call for any fuel purchasing. Operational costs are low (although higher in the case of offshore wind-farms) and the operational life expectancies of a generator (and ancillaries) is measured in several decades. Once the writing-off period is over, they will have a positive impact on prices, similarly to what has happened with hydro-electric sites. To pay-off the REN sites, we would turn to the savings made in terms of gas and/or coal and also the buy-back value of carbon permit coupons issued under the ETS European carbon market.

Additional (ancillary) investments (networks, storage, demand management protocols) are investments for the future, that will take a considerable number of years to amortise, but they have to be made and developed as a function of French investment capacities. An 'equitable' form of remuneration will be required for the thermal energy (coal or gas burning) stations as and when they are called in to back-up low level intermittent operations (in terms of hours) and even natural outage periods. We see today that several gas-burning power stations in Europe are in mothballs (*i.e.*, stopped) because the cost today is too high but they will be needed again in the future. The entire European pricing system needs to be reconsidered —if and when intermittent energy sources arrive on line with large quantities of energy, as a percentage of total energy demand — if only to remunerate equitably the service rendered to consumers by using thermal power generation to guarantee the electric supply as per demand.

In order to be sure that an intermittent electric production such as solar PV is competitive on an open market, we must take it that the electricity supplied comes with a sufficiently high level of guarantee, for example that there is a storage system for excess production from PV if again this is technically feasible. We must then add to the initial investment outlay (for PV production) an additional investment to build, for example, a hydro-pumping "STEP" station near a solar photovoltaic facility or near a wind-farm.

Let us exemplify this with three examples:

- in Spain, Iberdrola possesses 4.5 GW in wind-farms located in an advantageous site (*viz.*, windy) in South West Spain. The company took note that the quality of the prevision of the output of its turbines was 25% over 7 days and 15% over 24 h. To make sure that they would not be commercially penalised if the wind speed drops, Iberola built a hydro-pumping storage facility at La Muela. The company can then propose its energy on the spot market without taking any undue commercial risks;

- in California, the state's energy mix includes well-known wind-farms, photovoltaic arrays and add in a dose of thermal solar energy, whom the thermic inertia of it enables the electric energy delivery to be postponed to meet the peak evening demand. Part of the solar PV installations is not used, simply because sunshine in California is abundant;
- Morocco has recently contracted with an investor to build a large-scale solar farm (160 MW) near Ouarzazate, with a relatively low price tag: 14.5 c€/kWh. The technical choice was in favour of the thermal solar option, because, on one hand, it is a technique with which the National Office for Electricity (ONE) is familiar, but more so, on the other, because the solar energy inertia allows them to meet the peak evening demand. The cold source is the water contained in an existing reservoir and therefore there is no additional cost to the investment outlay to build the solar arrays; ONE also contracted out a 300 MW wind farm at Tarfaya, South Morocco on the Atlantic coast-line. The investment level here is given as 500 M€. The forecast load factor is 45%. Local climate and geographic conditions are conducive to a successful investment.

Storage is one of the techniques used to handle the intermittence characteristic. Electro-chemical storage is currently limited in power ratings and duration but has been amply studied and published in numerous research papers. A sodium-sulphur battery rated at 1 MW was installed by EDF (the French electricity utility) at Saint-Denis, La Reunion (French department in the Indian Ocean, close to Madagascar). It is this island isolation factor that makes the installation economically viable. Other forms of storage are the hydraulic storage and the thermal storage, this last one being particularly useful if the end-consumer needs and consumes heat *per se*.

We saw that gas can also be used to offset intermittence shortfalls. If the storage capacities exist already, they can be seen as amortised and consequently the overhead costs are lower.

In those countries that possess a long-standing tradition in hydro-electric installations (such as Switzerland), intermittent energies are used to economise the water reserves in the dams (which represent a permanent store) and also to reload the 11 hydro-pumping reservoirs (1 400 MW)[25]. There are no overhead costs for intermittency. This is not the situation in France, despite our country having a number of excellent hydro-electric sites.

Despite its high quality hydro-electric park France needs to develop other, differing strategies, *viz.*, when the intermittent energy supply is high, or even in excess of demand, we could heat water in immersion heaters ands run high-inertia heating systems without overheads. Voluntary (contractual) consumer shaving at peak demand hours can also be associated to reduce operational constraints. The "smart" networks will be called in to contribute to this systemic reactivity.

Intermittent energy integration will therefore be expected to take a systemic vision into its stride, with accompanying measures relating to demand/supply of energy and the storage possibilities to limit prices increase and consumption of fossil fuels, with their well-known constraints.

For these reasons our Standing Committee on Climate Change and the Environment at NATF advocates a reorganisation of demand management: energy efficiency targets should be framed in terms of local climate data and fatal electricity available, development of specific and or diffuse shaving policies and equipment, time deferral protocols for decentralised energy storage, as and where constraints become noticeable. There are technologies today that exist or are undergoing development. It then remains to define the policies of attributing costs (or incentives) for the investments needed in the mid-term.

This decentralised approach allows us to develop local systemic visions with unambiguous economic consequences depending on the policy decisions taken. This clearly prefigures an energy transition.

[25] This power level will reach 3.5 GW by 2016. Swizerland and Norway hope to become the green batteries of Europe.

Chapitre 5

CONCLUSION AND INITIAL METHODOLOGICAL PROPOSALS TO HELP PREPARE FRANCE'S ENERGY TRANSITION

A number of remarks and proposals come out from the analysis presented in the preceeding chapters.

- As we underscored earlier, an energy transition must compose with three partly antagonistic objectives:
  - energy autonomy, secure procurement and a control of the balance of trade by decreasing energy sources imports;
  - energy system economics, which contribute largely to national wealth and job creation, whether indirectly but strongly—if the energy system is efficient (price of the kWh to home users and to corporate sectors), or directly but to a lesser extent by creating jobs in the energy domain for the domestic market or for exports;
  - reduction of GHG emission levels (notably CO_2) in the framework of the fight against global warming (indeed the latter can only be global).

Transition relates to production means (power generation stations, supply transmission grids and distribution networks), to consumer outlets (in homes, vehicles, factories, offices…). This is a long term challenge which calls for continuity of policy decisions and consensus.
The objectives must be clearly defined and arbitration when necessary must be explained satisfactorily, using the cost-benefit status analyses and taking into account all externalised costs.

- Controlling demand is a primordial objective, every bit as important as adapting the production means to meet demand — the latter has been over-privileged in recent decades. Better energy efficiency at point of consumption decreases total consumption and also imported fossil energies.

Smoothing peak demand periods allows you to decrease installed generation capacity and consequently the total investment outlay.

- Evolution of energy demand trends in France up to the horizons 2025 and 2050 for the three main consumption areas (industry, transport and cities/housing) in fact obey highly differing logics. Improvement of 'levers' for specific energy efficiency in each sector must be sought and implemented.
  - In industry (25% total consumption), the prospects up to 2025 are stable (low reduction or low increase).
  - In the transport sectors (33%), breakthroughs are possible with sales of all-electric private vehicles (not very significant by 2025 but far more by 2050) and use of next generation biofuels. The reduced energy consumption objective may attain –40% by 2050, compare with current consumption levels.
  - In housing (urban areas, homes) (42% total), decreased consumption could take striking proportions, thanks to a triple impact:
    - from energy efficiency improvements (equipment, appliances, lighting, regulation…);
    - from energy savings (insulation materials and techniques);
    - through development of certain renewable energy sources such as solar thermal installations and re-use of fatal heat energy losses. The objective here could attain –33% by 2025 and –50% by 2050.

Weighted appropriately by the percentage values attributed to each of the three sectors defined above, **the decrease in consumption of total energy consumption in France could reach –15% by 2025 and –33% by 2050.**

- Renewable energy sources (RENs) need to be developed, to the extent that they will one day replace fossil energy sources. We must, however, distinguish between intermittent sources (wind, sun) and other RENs where the availability factor can be guaranteed (hydroelectric sites, biomass, geothermal ressources…) to quote the mainstay RENs. The intermittent characteristic of wind and sun (weather dependent, *viz.*, wind strength, sunny spells or otherwise) or astronomic (day-night, seasonal), is characteristic of today's energy transition implementation, and will remain true tomorrow. Some innovative solutions are needed: networks, storage, use of other sources that can be rapidly brought "on line", demand management (including possible new tariffs), etc.
  - This naturally intermittent feature of winds and sunlight does not represent *per se* a technical obstacle to their development, all the less so that these technologies picked up in France later than in some other European countries. If we pursue the trend observed over recent years, a rapid rise in intermittent loads up to 2025 is possible, but must not exceed the average summer demand for electricity, *viz.,* 45 GW, failing to do so would lead to a need to export, at a time of year when it is not requested. Total wind-power and solar PV by 2025 in France could amount to 27 GW for wind and 18 GW for solar PV (currently the solar PV capacity installed end 2012 is 3 GW).
  - Wind power and solar PV will need to be backed up to offset "long" intermittency factor, using nuclear power to do so (with a delay forecast around 12 h) when outage occurs during high demand periods; Germany decided, in 2012, to definitively abandon nuclear power generation and accompanied this decision at least as a first stage by compensating for wind and/or sun outage using fossil fuels (coal and gas). France can avail of a noteworthy advantage in maintaining its nuclear power potential which not only allows the country to drastically limit the imports of fossil fuels to produce electricity, but also reduces to a considerable extent the emission of GHGs thereby complying fully with the commitments taken, in respect of the Kyoto protocol, etc.

To partly offset "short term" intermittency or random outage phenomena, the Step hydroelectric reserves can also be used (this would raise the current storage capacity from 26.8 GW to 30 GW by 2025), provided that French regulations in this area in regard to purchase and sale of electricity are revised. Lastly, for excess demand, the combined cycle power stations (gas-burning) and other thermal power stations (coal, diesel fuel), already installed and commissioned (with current capacity at 27 GW) will allow a balance to be struck between supply and demand.

- We must be aware that this redundancy of installed power to compensate for the intermittency factor of wind and solar power generation will have an impact on the price of electricity. In particular, a partial outage of nuclear or fossil burning power stations, as and when wind and sun are available, will lead to rise in the hourly cost (due to the arithmetic drop in the number of productive hours). It is then necessary to make a balance sheet for consumption savings and CO_2 emissions due to use of intermittent RENs during the day-time, *versus* the corresponding emissions and extra consumption that result from the early evening peak consumption period.
- Development of non-intermittent RENs is therefore to be encouraged: biomass represents an important renewable energy source, all the more so that France has sizeable potential here, compared with its European neighbours. Arbitration among the various possible uses of biomass (heating and cogeneration of electricity, biofuels, biogases) is both necessary and complex. Cost of production is central to the debate. As far as use of land-space is concerned, there are solutions that do not add competition with respect to foodstuff uses.
- Likewise, where heat networks are concerned, the vectors that correspond to the urban dimension that draw on "fatal" heat losses and natural geothermal sources should allow us to distribute the energy directly as heat, rather than convert the energy into electricity.
- Assessing the potential reserves of shale oil or gas in France, and initiating research programmes in biogas and biofuels are seen as strategic priorities.

Our Standing Committee at NATF advocates that on the basis of the foregoing observations and conclusions, **energy scenarios for France should be built**, for the country as a whole but also Region by Region to anticipate on national and local strategic policy decisions and to assess possible effects and associate costs using systemic modelling techniques and protocols. In particular, the scenarios for development of wind-power and solar or thermal PV arrays and thermodynamic equipment — precisely because of their intermittency — must de drawn up in a systemic manner alongside the scenarios for gas (and in particular biogas) energy consumption and development, decentralised and centralised storage (new 'Step' hydro-pumping installations).

APPENDICES

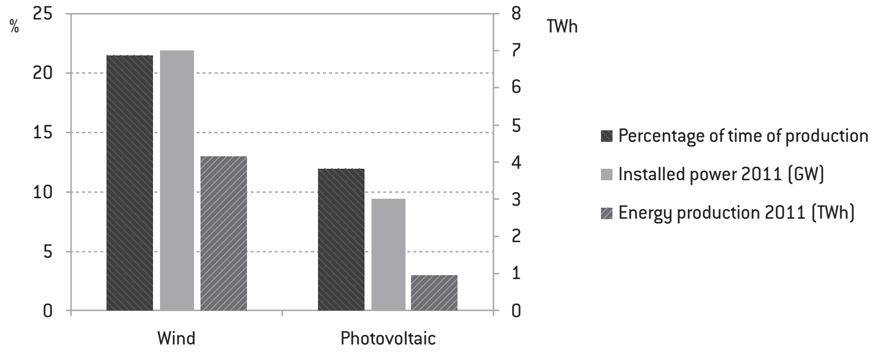
Abbreviations and acronyms

Units :

MW	megawatt (10^6 W)	power (not to be mistaken for energy)
GW	gigawatt (10^9 W = 1 000 MW)	power
TW	terawatt (10^{12} W = 1 000 GW)	power
kWh	kilowatt-heure	*energy* consumption resulting from using 1 kW power for 1 hour
MWh	megawatt-heure	*energy* consumption resulting from using 1 MW power for 1 hour
TWh	terawatt-heure	*energy* consumption resulting from using 1 TW power for 1 hour
MTep	million tonnes oil equivalent	Unit of energy equivalent to that produced by combustion of one million tonnes of crude oil. Equivalent to 11.63 TWh

It is important to distinguish installed electric power capacity (measured in GW) and the electricity produced or consumed (measured in GWh or TWh). There often is a confusion here: the installed power must be able to meet "peak" demand periods, while the measure of the consumed electricity over, *e.g.*, a one year period is the sum of the electric power demand, multiplied by the associate time factor.

Two examples of the distinction between installed power and yearly energy production



So, for 2025 as well as for 2050, two forms of energy mix must be defined: one is the mix corresponding to the installed power, the other is the produced energy mix, summed over a year.

Acronyms

ASN Autorité de sûreté nucléaire [French Agency for Nuclear Safety]

CCCG Centrale à cycle combiné gaz [combined gas generator station]

CIVE Culture intermédiaire à valorisation énergétique [intermediate energy valorisation crops]

ENR Énergie renouvelable (intermittent or not); in English, RENs

EPR European Pressurized Reactor (Generation III+)

ETS European Trade System (Europe's carbon emission coupon market)

GES Gaz à effet de serre; in English GreenHouse Gases (GHGs) such as CO_2 and methane CH_4, etc.

LED Light-Emitting Diode (electroluminescent)

LNG Liquid Natural Gas

MBTU Millions of British Thermal Unit (unit of energy = 293 kWh or 0.023 toe)

RTE French electric transmission network operator (a subsidiary of the national EDF utility)

Step Station de Transfert d'Énergie par Pompage (Hydro-pumping station)