The electricity of France
RTE data
September 2010 –August 2011

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Abstract

We present recent data on the time evolution of the consumption and production of electricity by various means which is now publicly available on the web site of RTE (Réseau de Transport d'electricité). For the first time, some detailed information is provided on wind energy. We analyze its relevance as a contributor to the French electricity system and its potential ecological impact.

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I) Introduction

We begin this presentation of the landscape of French electricity by introducing and discussing two laws dealing with electricity as it is used in modern societies. They do not concern electric energies when the amounts are small (say the capacity of the battery of a modern cell phone or a flash light). These are not also physics laws with the same high standing as those enunciated by Maxwell, Faraday, Ampere or Kirchhoff. Their author is not known. It is probably best since they are only approximate laws. As a matter of fact they control only what we may call "social electricity"; that is how our societies produce and consume electricity in large amounts for their industry or the running of the home appliances in their medium to large cities.

Before stating the first law, we introduce a first approximate lemna : "Electric energy can't be stored at adequate levels". Here "adequate" means 10GWh of more, that is the production of a typical nuclear reactor over 10 hours or that of a large offshore wind farm (say the London array) for the 24h of a windy day. This lemna applies to condensators (the only existing direct storage of electric energy) as well as to indirect storage systems whether chemical (batteries and why not hydrogen), futuristic mechanical (flywheels, compressed gases, …) or existing mechanical (hydraulic pumping stations). Only the latter systems are presently operational for energies which are close to what can be considered meaningful. For instance, altogether the total power of the French pumping stations (in the mountains mostly) built over several decades is close to 5GW and their capacity is 100GWh, that is about 1.5h of winter French consumption. Along with those in Switzerland, Austria, Norway and Sweden, this is one of the largest storage capacities in Europe. On the other hand, i) these are costly and ii) many technical and social factors hinder their further expansion.

Given, this lemna, we can state our first law : "At any time, the electric energy production must exactly match the electric consumption". The consequence of this law is that a permanent balancing of production versus consumption is required. This means that either the production or the consumption (or both) has (have) to be controlled. When the balance is not ensured, beyond a certain level of mismatch, the frequency shift becomes unbearable. To avoid a general collapse of the grid and the ensuing blackout, some geographical zones (for instance in France, Brittany or Provence) have to be disconnected.

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Another approximate lemna prepares the second law. For present Europe, it says: "Electricity can't be transferred at adequate levels". Transporting electricity implies losses: typically 6% for every 1000km. Using DC rather than AC may slightly improve this value but only by 1 to 2% (we consider SC as too futuristic). Thus, one avoids transport as much as is possible. Presently, cross border High Voltage (HV) lines are not many. For instance there is only a 1GW line connecting France and Spain – after 20 years of "discussion construction" a second GW line will open this year -. The connection potential with Germany is of the order of 4GW. While it takes between two to five years to build a gas-fired, coal-fired or nuclear plant, today in our countries, it takes about 10 years to built a HV line (only one year is needed for the physical construction itself). Aerial lines meet strong public opposition while underground lines (such as the new one to Spain) cost 5 to 10 times more. In the end such costs impact the electricity bill. It will take several generations before the "European copper plate", the dream of renewable energy aficionados becomes a reality (if it ever does).

Now the second law says: "Over a typical year, in about every country, electricity consumption varies by a factor two to three". Moreover, since Europe corresponds only to two time zones, these variations are almost in phase. Once it is associated with its lemna, the second law has the consequence that an excess capacity of controlled production is necessary in almost all countries. Building and maintaining plants which are only used a fraction of the time has a cost which ultimately is also added to the electricity bill.

II) RTE (Réseau de Transport d'Electricity) data

Over the last ten years, no significant dispatchable (= which can be controlled) power plant whether hydraulic, oil, gas, coal or nuclear has been started in France. In the mean time, electricity consumption has increased by 10%. Ten percent is not much, but it has been enough to wipe out the safety margin corresponding to the difference between the sum of national dispatchable power and the maximal consumption power occurring in a year (typically a winter week day around 19h). During cold waves in the winter season, France must now import electricity.

On the other hand, over the last ten years a significant amount of fatal (= which can't be controlled) power has been installed. The country has now 6.3GW of wind turbines (1/10 of the installed nuclear power) and more than 1GW of photovoltaic solar panels. Moreover, following the "Grenelle de l'Environnement", the government decided that by 2020, the French wind fleet will total 25GW and the solar parks 5.4GW.

Before presenting the actual data on French electricity, it is appropriate to say a few words on how the flow of electric energy is organized in France.

On the left side of figure 1 one sees the organization as it was designed at the outset of the second world war and how it still existed about 10 years ago. This simple-minded chart is the production of engineers who figured out that to ensure a perfect balance between production and consumption of a product (electric energy) which could not be stored, it was best to establish a perfect coordination of the production, transport (voltage above 50kV) and distribution (voltage between 50kV and 220V) into a vertically integrated structure. It was called EDF (Electricité de France).

Fortunately, confronted to such an efficient but dull structure, economists stepped in and prepared the much more interesting scheme drawn on the right side of Fig.1.

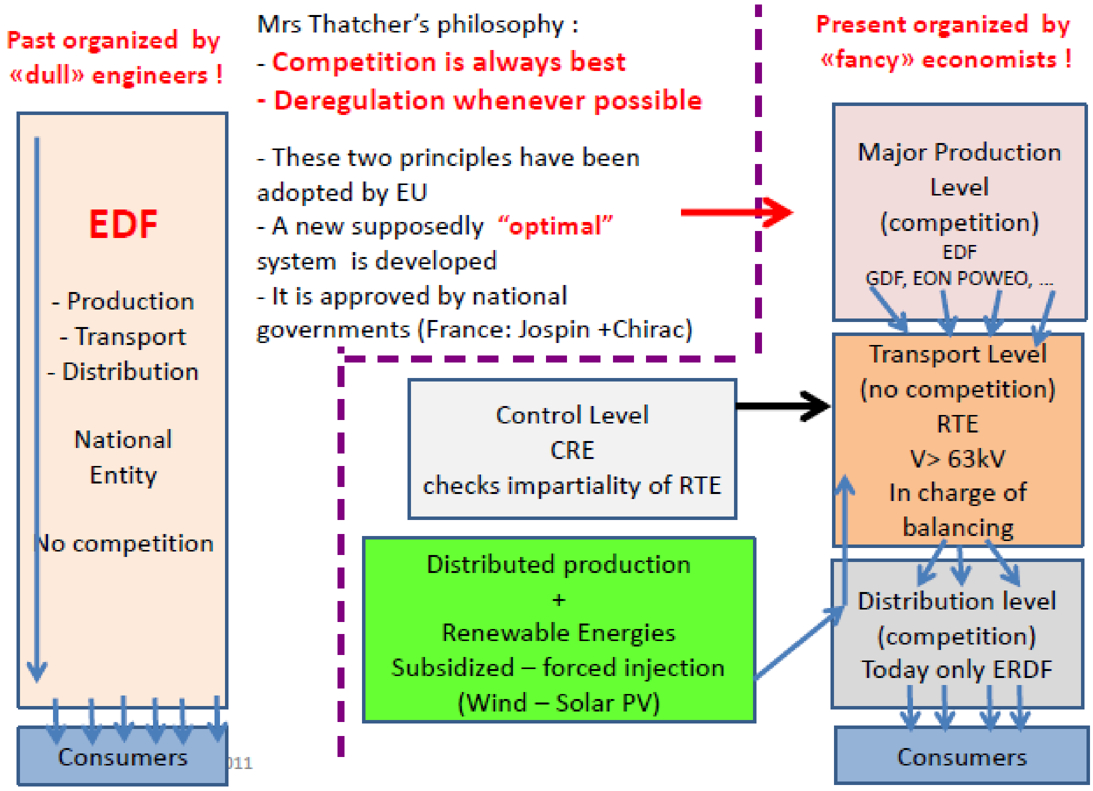

Fig.1 Organization of the French electric system, in the past (left side) and presently (right side)

Now, although electricity production is highly non "elastic" (an economic notion), the basic principle regulating its market is the same as the one valid for soap bars, cars or mobile phones: competition should be enforced whenever possible because "competition is always best for the consumer". The fact that this statement has been consistently contradicted by facts whenever electricity was concerned has not deterred European and after them French politicians.

Presently, it is only accepted that the transport level remain under the control of one operator in a given geographical zone (even economists could understand that it was impossible to impose the construction of several competing HV grids). Apart from transport, in addition to the vertical segmentation (production, transport, distribution), there exists now a horizontal segmentation (= competition) in both the production and the distribution sectors (although fortunately, ERDF is still in charge of almost all the distribution). Instead of the global optimization that was formerly attempted by the engineer's scheme, the system depends presently on the fact that the many firms competing within each strata work for the common good instead of twisting the system towards their own interest and that of their shareholders. To make sure (?) that this happens it has been necessary to create a new body the "Commission de Régulation de l'Energie" which has to check the fairness of all participants at each level. The system has obviously led to the creation of new jobs (probably counted as a positive contribution to the economy), although not a single additional GWh has been produced to the service of the nation. Everything is based on the assumption that the sum of competing private interests adds up to a collective good, something which is far from being proven, even for markets much more flexible than that of electricity.

In addition, to this market-economy inspired organization, layers of government intervention have been added to make the system even more confusing. For instance, EDF is forced to sell one quarter of its nuclear production (100TWh) to its competitors at a price (42€/MWh) which is about 33% below the average European price. In addition, EDF (only EDF, not its competitors) must buy the renewable energies at prices which are two (onshore wind) to four (offshore wind) to ten (solar PV) times that of its own production (nuclear plus hydraulic) cost. Not only is this national firm (80% owned by French citizens) penalized financially, it also receives the technical challenge to accommodate its own production to the fluctuations of these fatal energies. Indeed the injection of renewable production has priority over any other production irrespective of its cost. Only a fraction of this extra-cost is ultimately transferred to the customer electricity bills via a tax named CSPE (Contribution au Service Public de l'Electricité). The rest (approximately 40%) must be shouldered by EDF alone since its competitors in the production sector are spared this burden.

Thus, we, in France, benefit now from an organization much more interesting (if not more effective) than that which in the past has built the production system which allowed the French customers and industry to benefit from one of the lowest European tariff. One may also wonder which of the two systems depicted in Fig.1 would be the most efficient to set up and manage the much heralded "smart grids" (which its fans expect will solve most problems raised by the fatal productions and will lead to huge energy savings although the justification of such hopes is still awaited) into which information and energy must be flowing unimpeded and transparently at high speed both downward and upward from individual "customer-producers" to the large scale electricity producers across distribution and transport networks.

RTE is the French national grid operator. It is in charge of the transfer of electricity over HV lines (orange box in Fig.1). Recently it has opened a web site (eCO2mix) which provides detailed information on the various electric productions in France. The time granularity is very good (quarter hour). Thus, in the present text, we will be able analyze 35040 lines of data (365*24*4) corresponding to all quarters hour from the 1st of September 2010 0:00h to the 31st of August 2011 23:45h. Each line informs us on:

- 1 Electric consumption
- 2 Coal-fired plants
- 3 Gas fired plants
- 4 Oil-fired plants
- 5 Nuclear
- 6 Hydraulic
- 7 Wind
- 8 "Others" (to be presented below)
- 9 Import-Export balance
- 10 "Electric" CO2 emissions

Over a year the French consumption has been 491.8TWh and the production 538.9TWh. Table 1 analyzes the global contribution of each production.

Coal %	Gas %	Oil + Peak %	Nuclear %	Hydraulic %	wind %	« Others » %	Consumption %	Import-Export %	Production %
3,09	3,20	0,25	86,01	8,48	2,08	6,48	100	-9,58	109,58
2,82	2,92	0,23	78,50	7,73	1,90	5,91	91,26	-8,74	100

Table 1 Contribution of various production means. On the first line, percentages refer to the total consumption (491,8TWh), while the on the second line they refer to the total production (538.9TWh) which includes export.

It is seen that the installed wind power (6.3GW) which amounts to 1/10 of the total nuclear power produces 1.9% of the French electricity to be compared to 78.5% for nuclear energy (although as we shall see nuclear plants must sometimes reduce their production to accommodate surges of wind power which have a priority of injection). About 9% of the French electric production is exported.

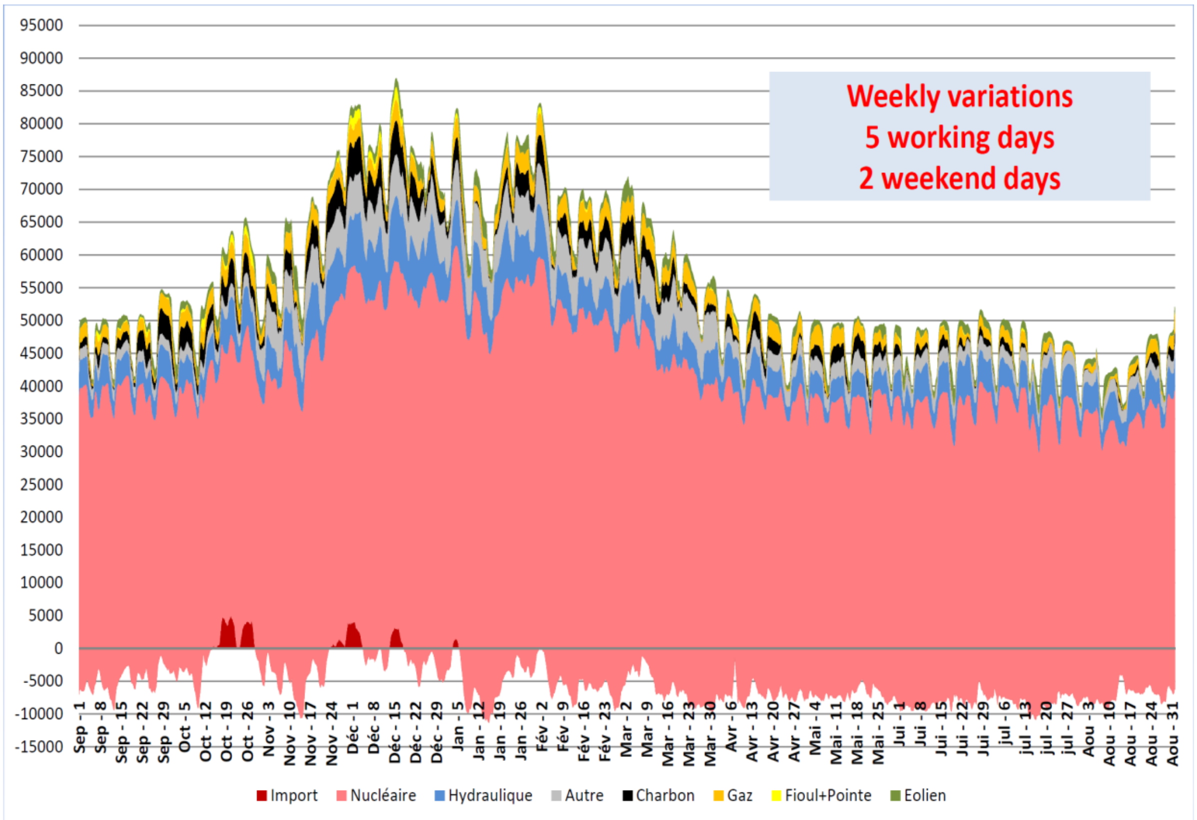

Fig.2 Time evolution of the various productions over a year. The initial data has been averaged over 96 consecutive 1/4h (one day) in order to eliminate daily fluctuations.

The upper envelope of the curves in Fig.2 shows the national consumption (note that the 'sliding" averaging over 96 quarters hour eliminates extreme peaks and lows when they last less than one day; see Fig.3). While the averaging performed in Fig.2 suppresses the daily fluctuations, it preserves the weekly fluctuations of the consumption (5 work days and a weekend).

The lower envelope of the pink zone shows the import-export curves. It has been necessary to import electricity in the middle of December when the consumption reached a maximum. Otherwise, France has always been exporting. This has been especially true since the middle of March when the German government decided to shut down 8 nuclear plants. Since March 20th, as compared to previous years, France has exported an average of two more GW which directly or indirectly (through Switzerland, Belgium and the Netherlands) has reached Germany. Indeed, the German decision has led to an increase of the cost of electricity on the German market, leading to a reverse of the situation which existed before and consequently of the direction of the energy flow. This is another instance of government intervention in the electric energy open market promoted by the EU.

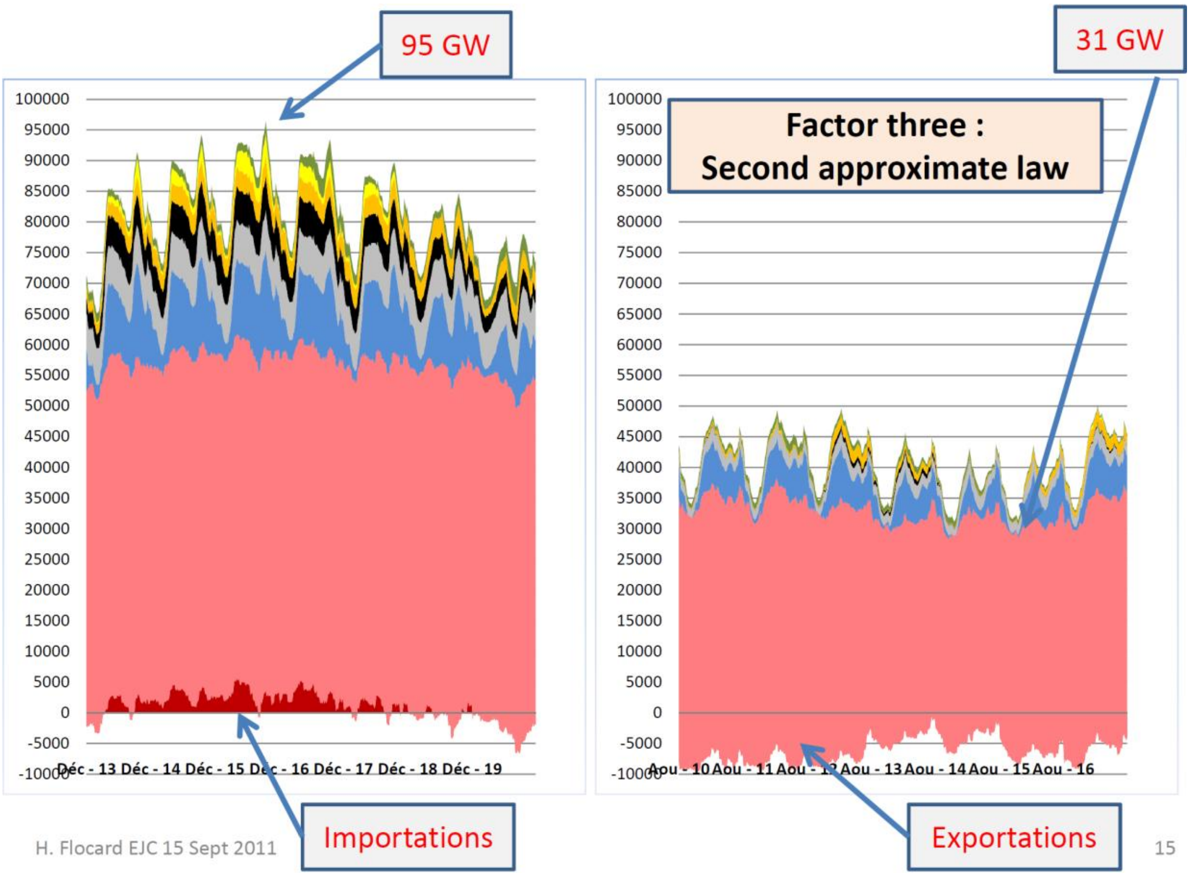

Fig.3 Evolution of various production and consumptions for the winter (left) and summer (right) weeks which correspond to the maximal and minimal consumptions respectively. The vertical scale (MW) is the same.

Fig.3 shows the daily fluctuations of the consumption: a first peak is visible around 9h in the morning when the nation activity starts and a second peak around 19h when people launch home appliances (TV, videos, washers, dryers, dishwashers, …). Every night the consumption is low. This figure is also an illustration of the fact that the electric power request can vary by a factor three over a year (31GW to 95GW).

Figs.4 to 7compare the time evolutions (smoothed over the duration of one day) of the French consumption to several dispatchable productions and to the import-export balance. Except for that of nuclear energy, the scales for the production and balance have been significantly expanded with respect to that of consumption. Fig.4 shows that the early arrival of winter (mid November) caught the nuclear production by surprise. Thus, imports were needed in December (note that the wind production being very low due to anticyclonic conditions could not be of any help; the stability of the grid was saved by the German coal and peat plants). It was not the case during the January cold wave since all French nuclear plants were operational (again wind production was low). Figs 5 and 6 show that hydraulic and fossil energies did a good job at helping nuclear energy. So did the balance (and German fossil-fired plants; Fig.7)

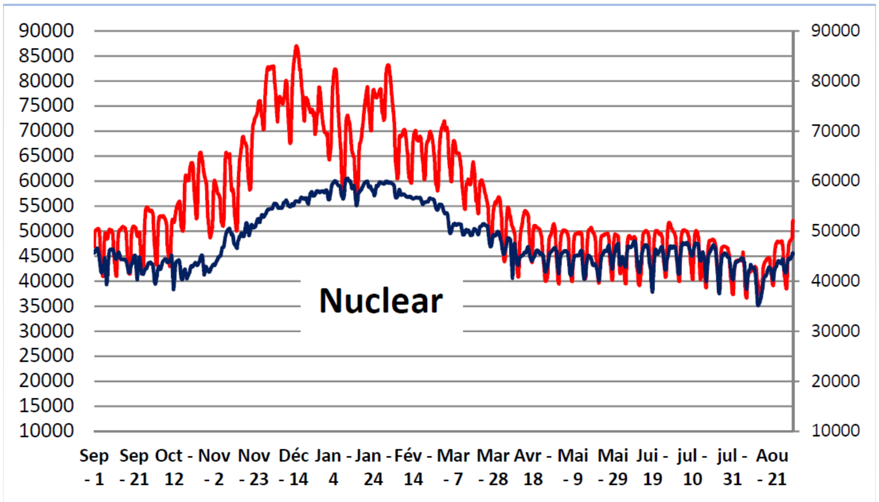

Fig.4 Comparison of French electric consumption (red curve, left scale, unit MW) with nuclear energy production (blue curve, right scale, unit MW)

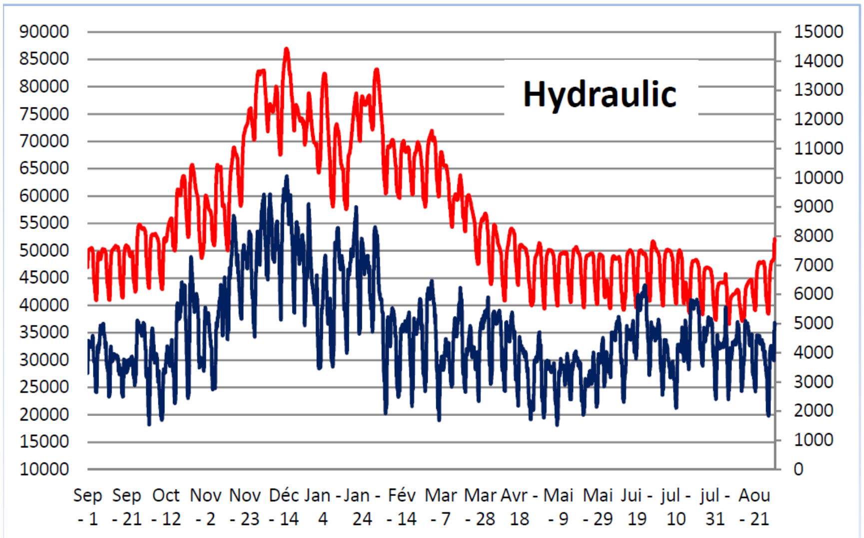

Fig.5 Comparison of French electric consumption (red curve, left scale, unit MW) with hydraulic energy production (blue curve, right scale, unit MW)

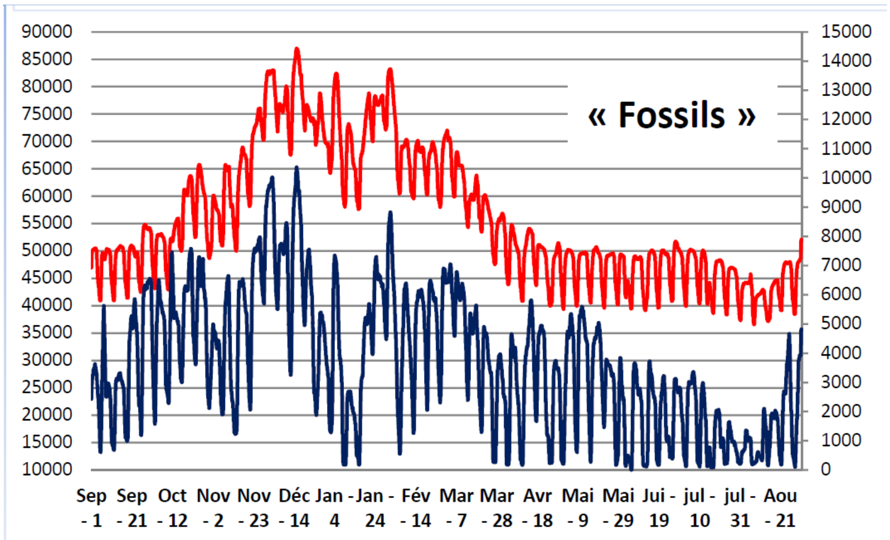

Fig.6 Comparison of French electric consumption (red curve, left scale, unit MW) with fossil fuel (coal plus gas plus oil) energy production (blue curve, right scale, unit MW)

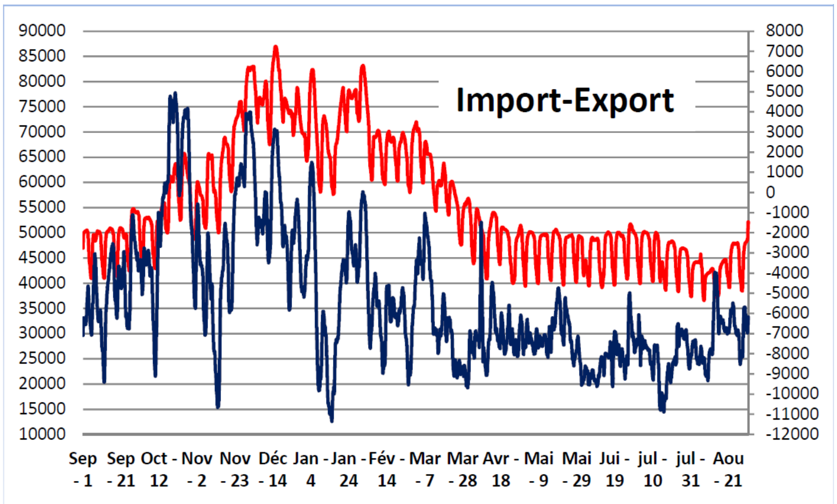

Fig.7 Comparison of French electric consumption (red curve, left scale, unit MW) with the import (positive values) export (negative values) balance (blue curve, right scale, unit MW)

To complete the construction of the French consumption as the sum of productions (note that neither RTE nor ERDF are presently able to give us an information on the instantaneous energy loss), we still have to consider "Others" and "Wind". Before analyzing the latter in more details in the next section, let us consider "Others".

It turns out that for this sum of various productions whose evolution is displayed in Fig.8 the adjective "fatal" also applies (once the small contribution from biomass electricity is discounted). For some productions such as solar photovoltaic, small hydraulic, Rance tide plant, just as for wind the fatal character is determined by Nature. On the other hand, the blue curve in Fig.8 displays a clear step structure which reflects that "fatality" can be introduced differently, by means of sufficiently large subsidies. Here one observes that cogeneration plants responsible for the step structure of the curve are only subsidized from November 1st to March 31st. In this case, the fatal character is the consequence of a government decision. Suppressing the subsidy would lead to a better match of this production to the French needs (and presumably to a lower CSPE tax paid by consumers).

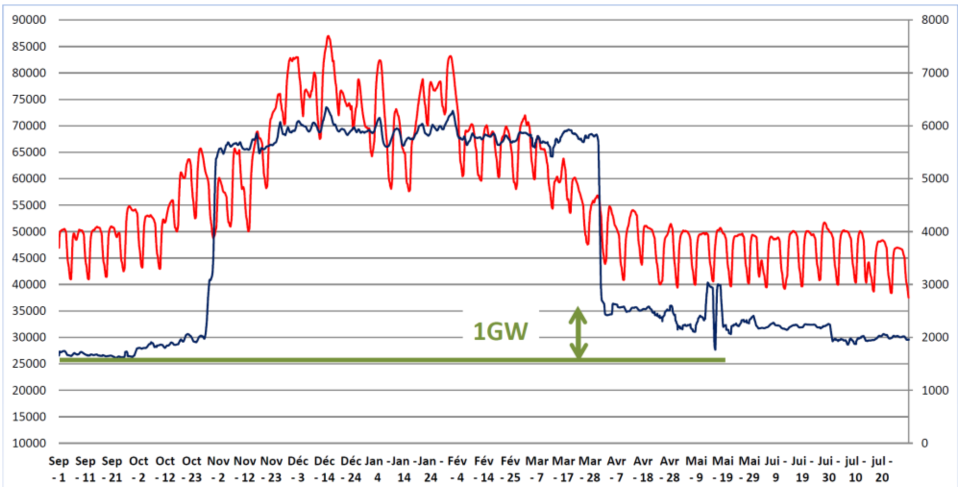

Fig.8 Comparison of French electric consumption (red curve, left scale, unit MW) with the "Others" production (blue curve, right scale, unit MW)

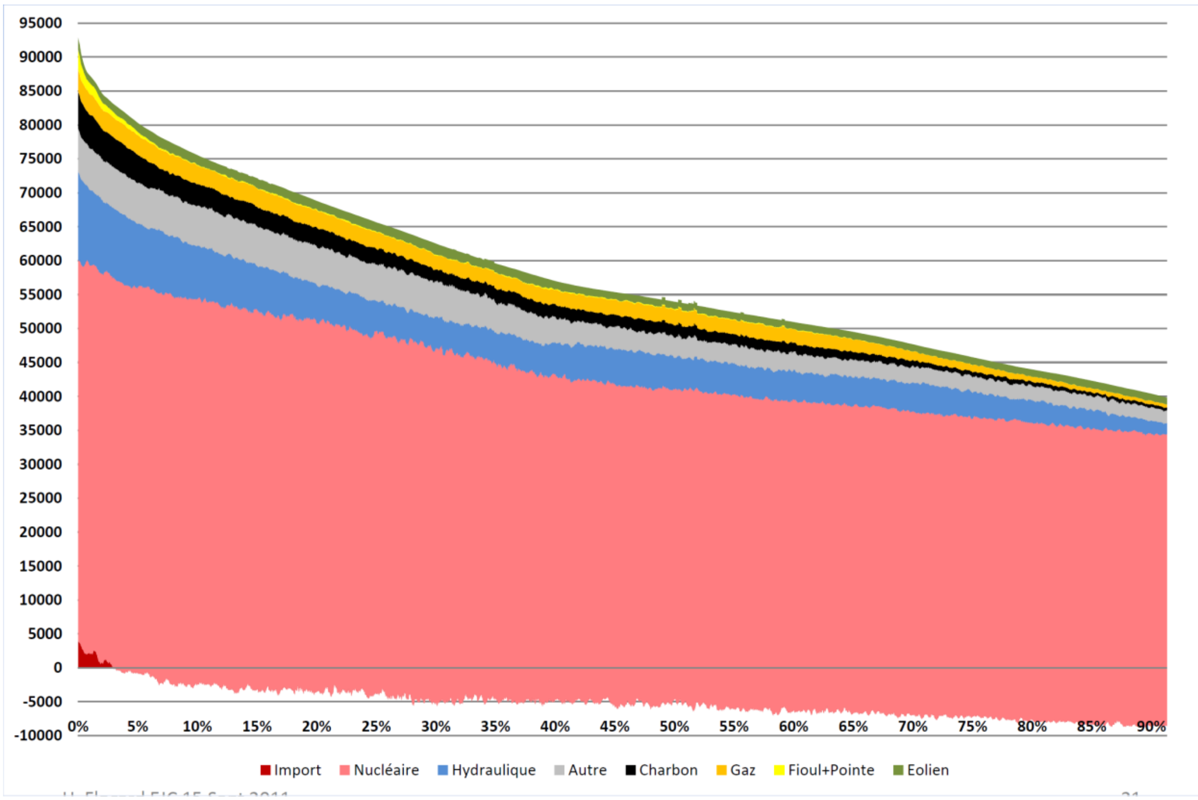

Fig.9 Contribution of each mean of production to the monotone of French consumption (vertical scale MW). The abscissa which could have been made to range from one to 35040 quarters hours in a year has been rescaled to 100% for commodity.

Another representation of the same results can be made as the “monotone” (Fig.9) in which all quarters hour are sorted according to decreasing electricity consumption. The small dark red zone in lower left corner indicates that high consumptions are associated with imports. By contrast export is at a maximum when consumption is small. It can be seen that all dispatched energies increase their production when requested by consumption (the vertical width of the colored zones increases from right to left).

Fig 10 illustrates the fact that during the winter period (from November to February) the electricity consumption is negatively correlated with temperature. The negative slope of the linear regression indicates an average increase of the daily consumption by 35GWh when the temperature is one °C lower. This value is equivalent to the production of one more EPR nuclear reactor (1.5GW) whenever the temperature decreases by one degree Celsius.

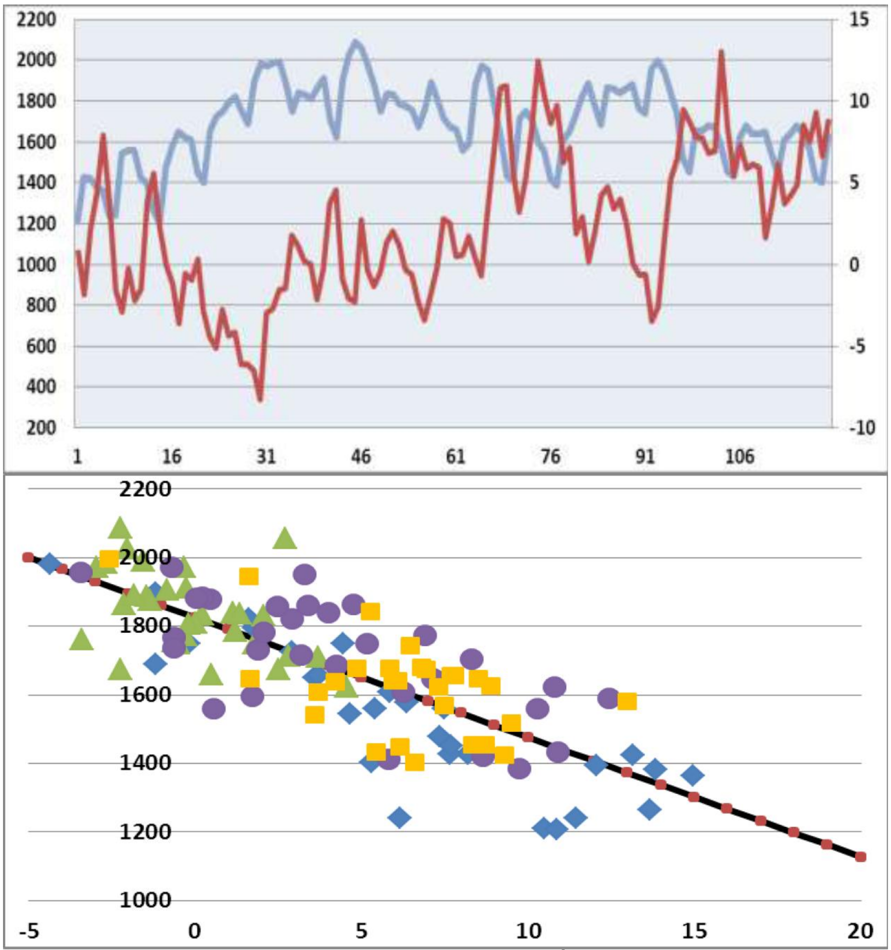

Fig.10 Upper part : evolution from 1st of November to 28th February of the daily electric energy consumption (blue curve, left scale, unit GWh) and of temperature of the Ile de France (Toussus le Noble weather station) (brown curve, right scale, unit °C). Lower part : correlation plot of the same data (same units). Color and shape symbols distinguish the days of each of the four months.

III) French wind production

For the first time, since it has been decided to subsidize wind energy, thanks to RTE website, it has become possible to confront its production to the promises that were made by its promoters. Figure 11 tells us what the situation of France is as far as wind potential (left map) and installed power (center map) is concerned. The table on the left indicates the installed power on September 1st 2011.

Today (31st December 2011), the nominal power of the turbines installed in continental France is 6.35GW. Its annual growth rate is about 1.4GW. The two maps and the table show that turbines are not necessarily erected where there is wind. As a matter of fact, the level of subsidizing has been selected high enough (80€/MWh, plus indexation on inflation and labor cost) and guaranteed over a sufficiently long period (20 years) to make wind speculation profitable even in the less windy regions of France and to induce banks to give loans at reduced rates. This situation makes wind one of the best and safest (state guarantee) financial bet (only solar PV is best). The return on private equity can surpass 20% a year, something that even speculators (and crooks such as Madoff) can't guarantee. This is a remarkable feat for a non economical product, especially if one takes into account that all this is supposed to take place within a free-market economy. It is obvious that engineers left to themselves would never have dreamed up such a wonderful scheme.

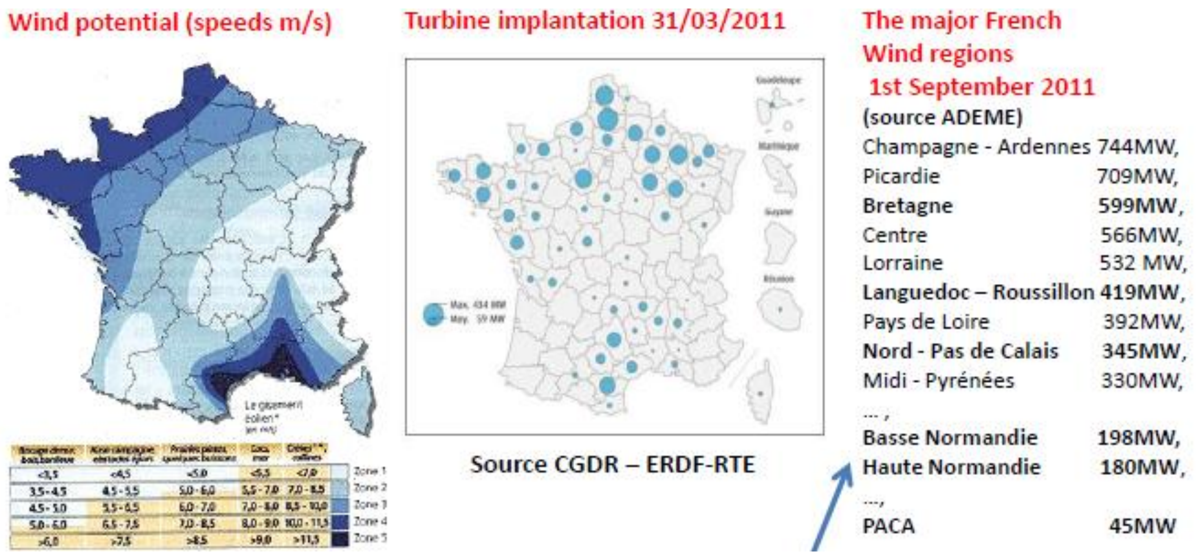

Fig. 11. Left map : wind potential over France from the windiest (dark blue) to the quietest areas (light blue). Center map : the diameters of the circles are proportional to the installed power in each “department”. Right table : installed wind power in the French regions.

Fig.12 shows the wind efficacy over one year. At any time this quantity is defined as the ratio of the power delivered over the installed power (this curve takes into account the fact that the power of the French wind fleet has increased by 1.4GW over one year).

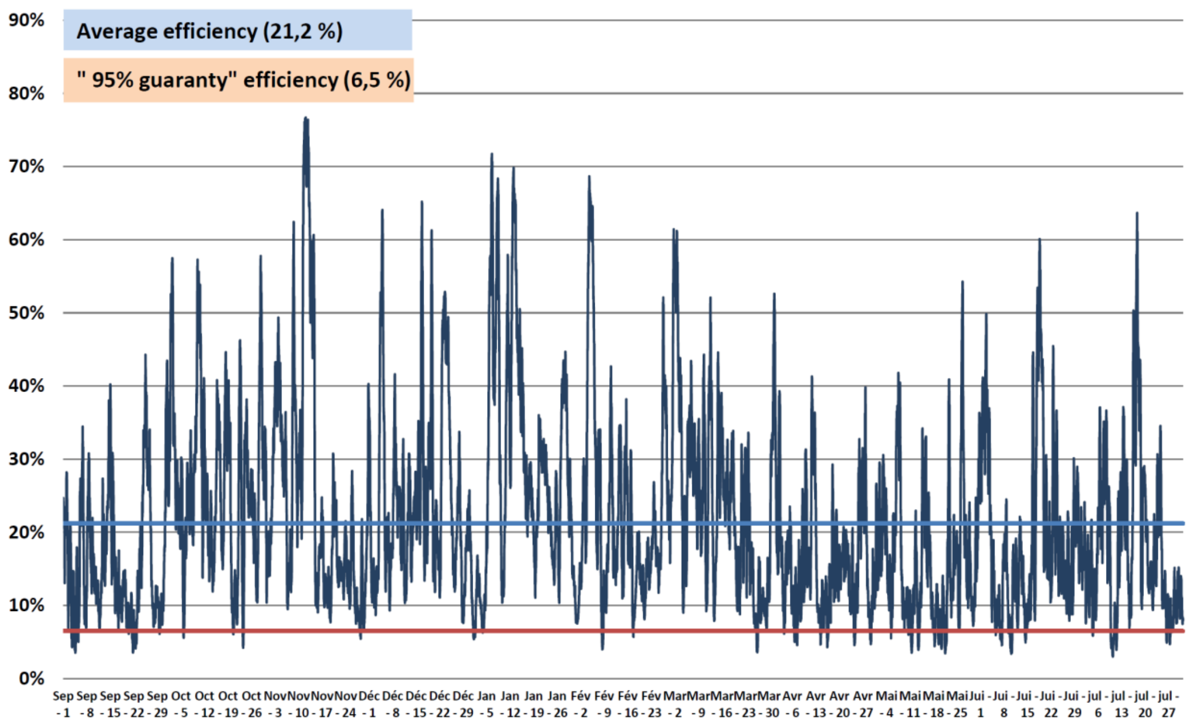

Fig.12 Efficacy of the wind production from September 1st 2010 to August 31st 2011. The horizontal blue line (21.2%) gives the average efficacy over one year. The horizontal brown line shows how much of the installed power can be guaranteed at the level of 95% (that is 95% of the time, one can expect wind to deliver at least such a power).

Thus the French wind turbines deliver their nominal power on the average slighty more than one day out of five (21% efficacy). Only 6.5% of the installed power can be guaranteed for 95% of the time. Note that, although at first sight, 95% may appear as a high level of guarantee, in our modern societies it is not. Indeed, one must compare it to the 99.95% level that jointly RTE and ERDF are compelled by law to ensure (non distribution of electricity should not exceed 3h per year for the average French customer; presently, on the average, non distribution is about 80 minutes).

Fig. 13 presents the same data in terms of a distribution of efficacy. The figures 12 and 13 speak for themselves.

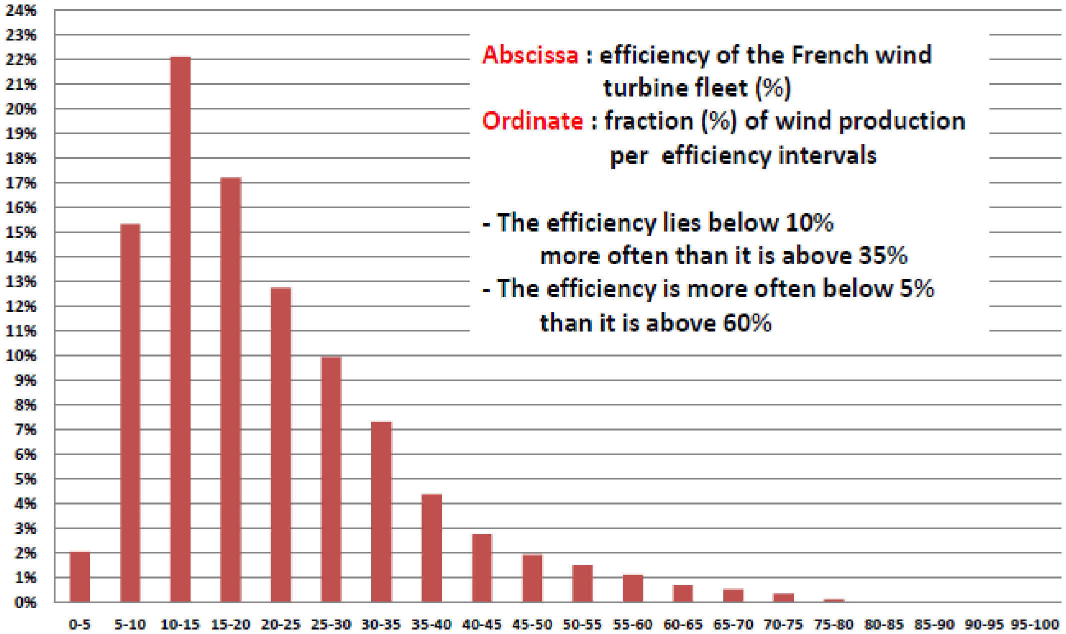

Fig.13 distribution of wind efficacy in intervals (5% width) of the installed power.

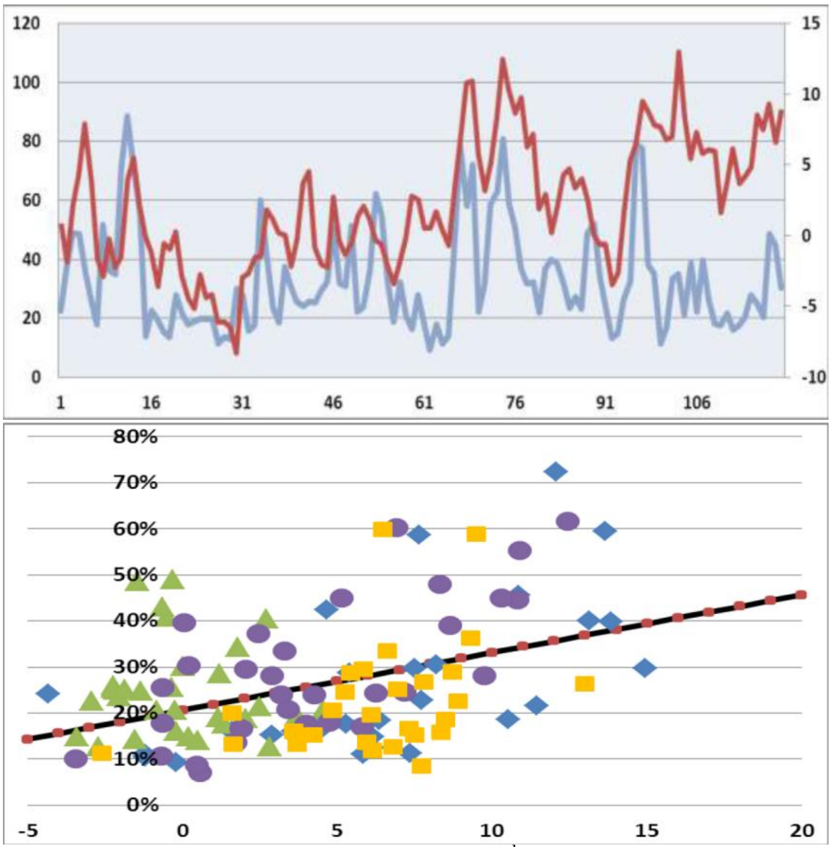

Fig.14 Upper part : evolution from 1st of November to 28th February of the wind energy production (blue curve, left scale, unit GWh) and of temperature in the Ile de France (Toussus le Noble weather station) (brown curve, right scale, unit °C). Lower part : correlation plot of the same data (same units). Each color corresponds to the days of one of the four months.

Fig.14 is constructed as was Fig.10. It shows that during the cold season, the wind does not blow much when temperatures are low (and consumption is high). The slope of the linear regression is positive In the fall and winter seasons, most of the wind production corresponds to the passage of Atlantic depressions which generally induce mild temperatures. On the contrary, when the cold Siberian anticyclone moves over western Europe, and when maxima of consumption are observed, the wind production drops.
It can be shown that there exist long distance correlations (still visible over 1000km distance) for this behavior. For instance when France most needed electricity between the 13th and 15th of December 2010, the production of the Scottish and Danish offshore farms was essentially zero.

The next figure plots the wind production along with the consumption monotone. It illustrates the same phenomenon. Although generally in winter time, thanks to the atlantic depressions which sweep over France, the average efficacy is better than the year average. The performance drops below this average value for the 5% times of maximal consumption when the country has to import electricity.

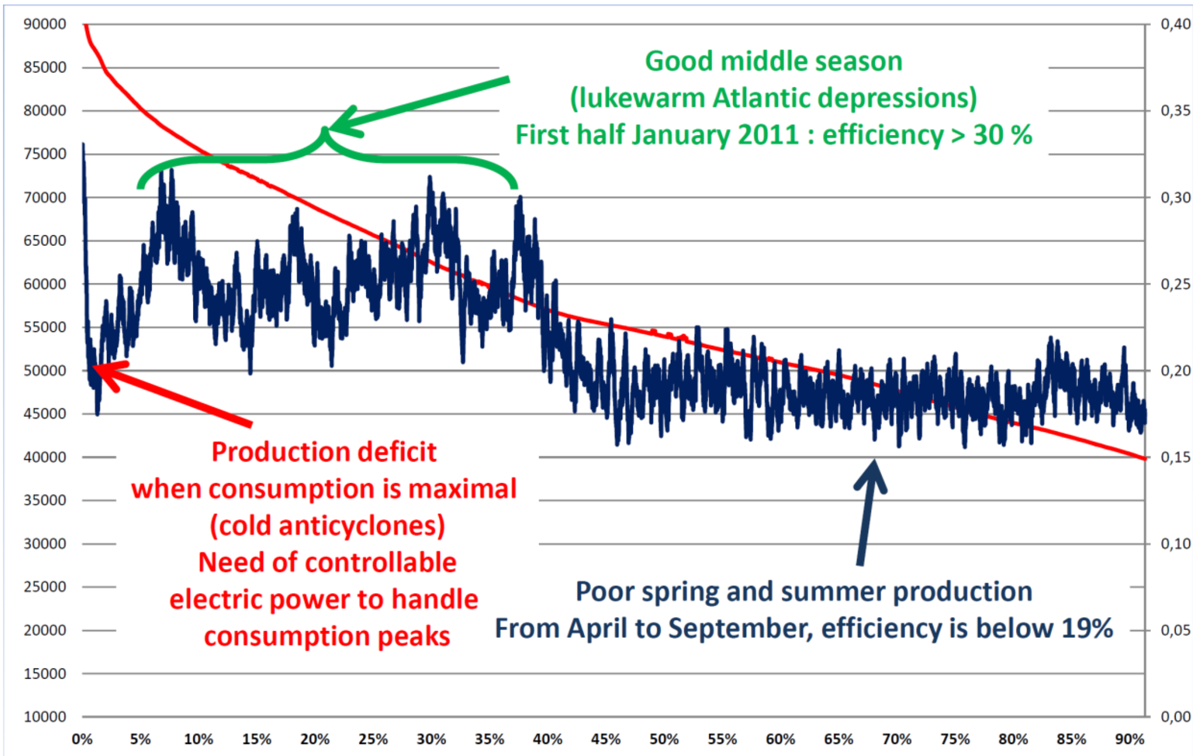

Fig.15 Monotone of French electric consumption (red curve, left scale, unit MW) versus wind efficacy (see text for definition) right scale.

Other pieces of wind data relevant for the management of the grid are the power gradients and the long episodes without wind.

The first information tells us on the need for an extension of the grid capacity. For instance, presently in Germany for lack of evacuating HV lines – NEDA estimates that 2000km more are already needed – wind turbines have to be turned off. Note that you do have to be sorry for the wind producers. Indeed, cleverly anticipating this phenomenon, they managed to extract from the German government, that under such circumstances, they would be paid for the electricity they DO NOT deliver (the same is true in the UK with, in addition, a market economy twist which allows that the not-produced electricity is paid more than if it was produced). Otherwise, the grid attempts to get rid of the unuseful wind energy on whatever market is open to the capacity of its HV lines. It can thus happen that the grid has to pay the customers willing to accept its electricity. For instance on December 8-9th 2011, on the EEX market one could “buy” German wind electricity for a **negative** price of minus75€/MWh. Of course, this extra cost (paying for electricity not produced or electricity sold at negative prices) is ultimately transferred to the willing (?) German customer. In France power gradients already often reached 500MW/hour so that when the “Grenelle fleet” (25GW) will be operational one can expect gradients in the range of 2GW per hour. This indicates the amount of high dynamic power which must be kept fully enslaved to wind power to counter its erratic production.

Another important item concerns the long duration episodes without wind for which backup power must be kept in store. For instance over the year considered, there were 44 episodes lasting at least 12h during which the efficacy was 10% or less – the 6.3GW of installed power could not guarantee more than 0.63GW. During these episodes backup power plants must cover the electricity needs of the Nation. Presently, nuclear plants can still perform the task. Whether it will still be the case, when the wind and solar parks have reached their full nominal power is doubtful, especially if political programs planning to stop 24 power plants (40% of the nuclear fleet) are enforced.

We have seen that wind electricity is expensive. In addition it involves costly (bur never mentioned by its supporters) externalities such as the construction of additional HV lines whose intermittent usage makes for poor economics. It also asks for the construction of backup plants which wont be used optimally. It certainly can’t be considered as an investment, since French customers will be charged a high price of electricity for the expected lifetime of the turbines. New subsidies will be needed for the next generation as it can already been seen with the offshore programs.

Wind does not match the electricity needs of our society (why should it after all, Man does not command Eole ?). It does not lead to many job creations in France since no wind turbine erected in continental France is homemade. Operation is generally done from abroad and maintenance relies mostly on foreign expertise sent from abroad when necessary (just as the wind turbines in Guadeloupe are operated by the French firm which has built them). Moreover, the subsidy spent on whatever jobs are created corresponds to money diverted from the economy, whether in the form of products that would have been bought by consumers if no tax had been levied on their bill or in the form of salaries associated with other jobs (teachers, policemen, researchers, nurses, …) if the government had decided to maintain the tax. Whatever “green jobs” are created they divert monies that could be used to create other jobs or services more profitable to French citizens. The wind energy program is adding a contribution to the national deficit without economic benefice to the nation since no additional GWh has been produced.

It can’t also be said that wind energy deployment promotes goals such as “decentralization of the production”, “energetic autonomy” or “small is beautiful” since, whenever possible, the trend is to erect bigger and taller machines – the height of a 10MW offshore turbine is that of the Eiffel tower and its blade span is wider than the wing span of an Airbus 380. This leads to more industrial concentration (the pioneering Danish firm Vestas is losing ground to giants such as Siemens not to mention the Chinese state supported firms which are snatching away the non european wind market and closing off the niche open to European builders). Although this may not happen before some time, there is also a “big brother” smartgrid looming on the horizon. It will require the construction of 20 000km of new HV power lines over Europe (European Climate foundation) and the creation of a comprehensive surveillance program of every level of consumption and production.

We will not mention here the opposition stemming either from people who reject the aesthetics of wind turbines nor claim that they are endangering birds or bats. Indeed, the same criticism could probably apply as well to HV lines (including those that will be additionally required by the deployment of wind energy). The only difference being that HV lines are useful to mankind.

What can thus explain the present French enthusiasm (among the public, the medias and ultimately the political class) for this peculiar energy that engineers had already abandoned when Alphonse Daudet wrote “Le secret de Maître Cornille”? As far as the author of this text could see – apart from a desire to embrace anything that is not nuclear – and more specifically French nuclear - and assist the promotion of imported gas – the motivation could be ecology: wind energy is claimed to prevent some CO2 emissions from the French electric sector.

Of course, since this electric sector presently emits yearly about 30Mt of CO2 and accounts for no more than 10% of French CO2 emissions which themselves account for about 1% of world emissions (30Gt), somebody used to the optimization of complex systems may wonder why this should be considered a high priority item – as compared for instance to a measure such as reducing maximal speed on superhighways from 130km/h to 110km/h which would immediately eliminate 10% of French emissions in a costless manner (it would also reduce our trade deficit) or to a policy aimed at improving housing insulation at the national level.

Nevertheless we have tried to estimate how much could be gained according to the most optimistic scenario one could imagine using wind electricity for reducing CO2 emissions (In particular we do not consider that wind intermittency will presumably require burning more gas to balance production versus consumption).

Today only 6.3 GW of wind turbines are installed. 25GW are expected to be there by 2020, that is one may well say, by tomorrow. We thus assume that over such a small time span no radical change will happen to France's climate, to the French economy or to the behavior of its citizens. We will thus consider twenty "France"s living under the same climate as that of the year analyzed here. The only difference is be that the wind fleet of each of these twenty "France" will be larger than the present one by one, two, .. twenty GW.
We will then make the following assumptions:

- the wind production grows in proportion to the installed power,
- wind electricity has always a priority for injection into the grid,
- wind electricity is used to eliminate CO2 emissions as much as possible,
- The "Others" production being fatal can't participate to balancing,
- "Import-export" (mostly export as we have seen) can't participate to balancing

As a consequence, i) the productions that can be dispatched will have to adjust to ensure balancing of production versus consumption and ii) wind power will be used first to reduce and possibly eliminate the production of coal-fired plants, then that of gas-fired plants and finally oil-fired plants.

The implementation of this scenario is done in three stages

- Stage 1: available wind power at time "t" is used to reduce or stop "Coal" then "Gas" and finally "Oil" electric production at the same time "t". We call this stage "instantaneous",
- Stage 2: if, following stage 1, there remains some "unused" wind power at time "t", one stops any flow of water from mountain dams at time "t" (hydraulic energy). The water preserved in this way, is now called "wind water". It is then used at later times to stop any "Coal", then "Gas" and then "Oil" electric production which would remain after Stage 1. We call this stage "hydraulic"
- Stage 3 : if, following stage 2, there remains some "unused" wind power at time "t", one pumps water into one of the available French pumping stations (5GW, 100GWh) until they reach their full capacity. The water saved through pumping is used at later times to stop any "Coal", then "Gas" and then "Oil" electric production which would remain after Stage 2. We call this stage "STEP" as it is the French acronym for pumping stations.
- Once this is done, if there is still some unused wind energy, balancing will require either the turning off of some wind turbines or that of nuclear plants or an attempt to export some electricity or any mix of these three actions. Whatever the choice, there is no CO2 emission reduction associated with this stage.

In order to calculate the maximum possible CO2 emission reduction we then make the following hypotheses which are systematically favorable to wind energy

- The grid can instantaneously handle any requested transfer of electricity: the production of a wind turbine near Perpignan can serve to immediately compensate the production of a coal-fired plant in Dunkirk.
- The two entities in charge of handling the injection into the national grid ERDF (for renewable energy) and RTE (for major power plants and dams) which Europe has insisted should be separated (Moreover Europe insists that ERDF should not be alone to handle distribution and be replaced by several operators) can nevertheless perfectly coordinate the necessary information transfers, their decision process and their actions. Note that this more or less implies perfect prediction of wind production.
- During electricity transfers, there is no energy loss
- Fossil-fired (coal, gas and oil) can adjust their production instantaneously to match any wind power fluctuation
- At any time, during Stage 2 dam reservoirs have the capacity to accept any amount of energy one wants to “put aside” for later use.
- During Stage 2 and 3, when hydraulic production is used both to balance production versus consumption (an obvious priority) and to simultaneously use previously “preserved wind water” to erase some fossil electric production, water turbine power is available to fulfill both missions at the same time.
- Pumping stations are used exclusively to help the CO2-emission-reduction wind policy. Note that this also highly uneconomical. Indeed pumping stations are an expensive investment and about 30% of the energy is ultimately lost. Thus, they are generally used to store cheap energy (typically the night production of nuclear plants) and to deliver it back when the price of electricity is high (peak hours). Here we chose to use it for storing expensive wind electricity.
- Owners of fossil-fired plants graciously accept that their plant be used in a non efficient and non economical way. In particular, to ”save the planet”, they agree to extra maintenance costs associated with the fluctuating use of plants. They also agree to the degradation of performances. Indeed the remarkable thermal to electricity conversion rates that such gas-fired plants can reach (above 50%) is only obtained when they are operated in a stable regime.

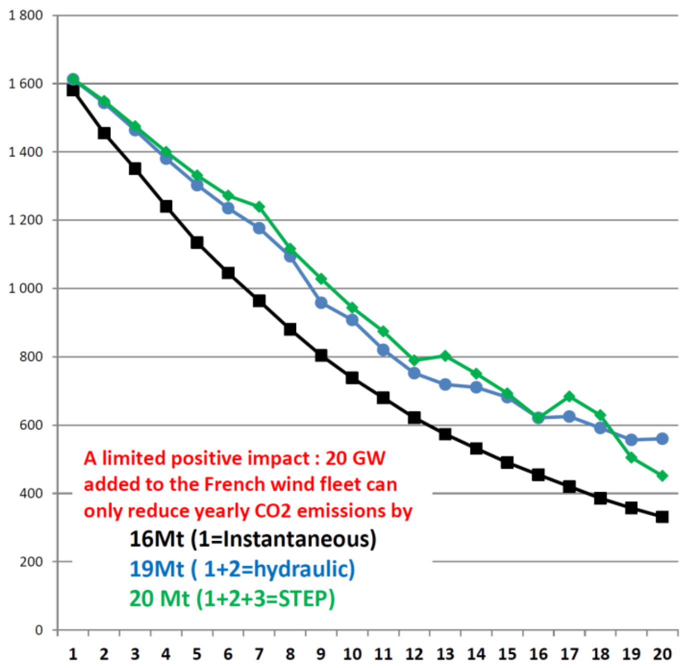

Fig.16 Maximal amount of CO2-emissions which can be avoided thanks to wind energy as the nominal power of the wind fleet increases. The black curve corresponds to the implementation of Stage 1 only (instantaneous). The blue curve to Stages 1+2 (hydraulic); the green curve to Stages 1+2+3 (STEP). The ordinates give the CO2 emission reductions in tons, while the abscissae indicate the numbering of the GW of wind power added to the present fleet.

Using all these hypotheses over the 35040 quarters hour registered by RTE we can now calculate two things

- How much the addition of one more GW of wind power helps reduce French CO2-emissions.
- How much fossil power can be removed from production by the addition of one more GW of wind turbines

The results are shown in Figs. 16 and 17. Fig.16 shows that that the addition of the first GW of wind power will at most save 1.6kt of CO2. The addition of the twentieth GW will only save 350 to 550t depending on how many stages are included in the scenario. The integral of these curves tells us how much the implementation of the Grenelle wind energy plan will reduce French CO2 emissions. If everything worked perfectly, one would at most eliminate 20Mt, that is two thirds of CO2 emissions of the French electric sector (thus 7% of French CO2-emissions). Note that RTE estimates that no more than 15Mt of CO2-emissions can be prevented (thus 5% of our CO2 emissions). Thus the efforts of one of the economic powers among the ten first in the world will yield results three orders of magnitude smaller than the scale of the problem (IPCC estimates that to control climate change it is necessary to reduce world CO2 emissions from 30Gt to 10Gt). Another measure of the usefulness of this effort is the cost of the CO2 ton. Given that investment for an onshore wind turbine is presently 1.5€/W (despite promises made as late as 2005 that it would soon be smaller than 1€/W) and for an offshore wind turbine close to 4€/W, one can estimate that the cost of the CO2 avoided ton thus avoided is in the range of 200€. This is about ten times more than the present price on the European market. If one wants to save CO2, a much better use of these 200€ can be made (building insulation, biomass, electric buses, etc.)

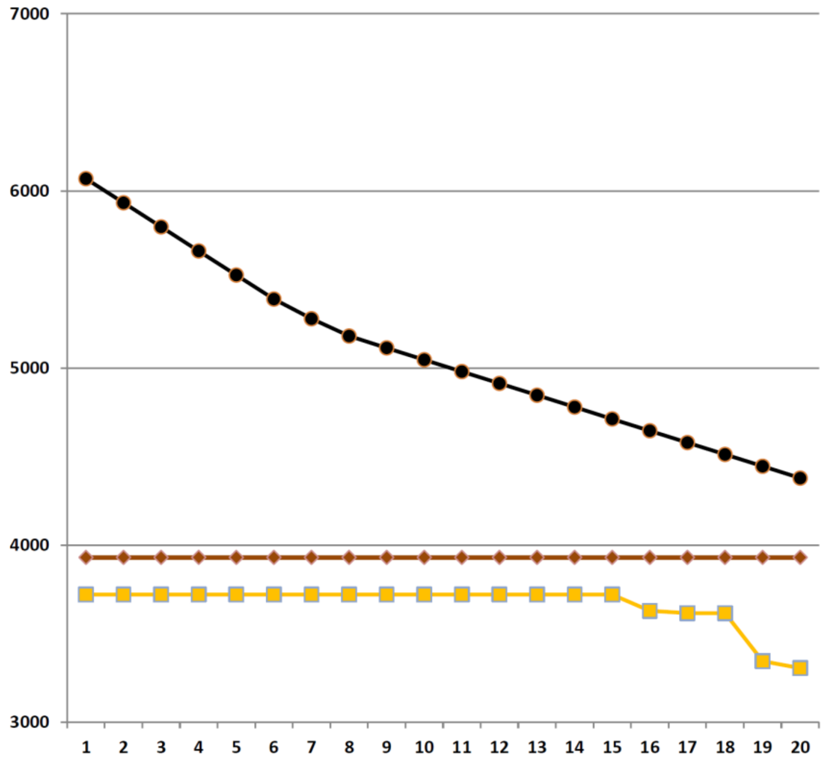

Fig.17 Fossil electric power (black=coal, yellow=gas, brown=oil) that must remain operational as the nominal power of the French wind fleet grows. The ordinate give the fossil-fired power in MW, while the abscissa indicates the numbering of the GW of wind power added to the present fleet.

Once the calculations involved in Stages 1+2+3 have been performed for an additional wind power of "N" GW (N ranging from 1 to 20), one can check that despite the maximal use of wind power made to stop them, some fossil power remains necessary during the year. This is what is plotted in Fig.17. Because reduction is performed first on coal-fired power, the first additional GW of wind power allows one to retire from production only a 130MW coal-fired plant. The twentieth additional GW allows the retirement of 110MW of coal-fired and gas plant. Altogether, deploying 20 additional GW of wind power (14 onshore + 6 offshore) at a cost of about 45G€ (14x1.5+6x4) will allow the saving of 20Mt of CO2 a year, the retirement of about 2GW of fossil-fired plants and the production of 42.6TWh (10.2x25/6). One witnesses a law of "diminishing returns": the more wind is deployed, the less is its positive ecological impact.

The construction of 4 EPR reactors, for 60% the cost of deploying the "Grenelle wind fleet" would have achieved more in every aspect (for these four EPRs, we take a nominal power of 1.5GW, a load factor of 0.8 and a 6GW price-tag assuming that the average construction cost will lie between that of Flamanville-III 7G€ and Taishan 3G€). Moreover these nuclear plants which would be operational for 40 to 60 years (instead of the 20 years after which wind turbines must be replaced - and subsidized anew) would be an investment for the future.

IV) Conclusion

It is fair to say that this tour of the French electricity landscape has not taught us anything that can be called surprising. Most of what we said belong to common knowledge at least for those having even a mild interest in the subject. Let us review the essential facts.

Ninety percent of the electricity is produced with nuclear plants and hydraulic dams whose construction was decided by our governments more than 40 years ago. The rest of the electricity consumption is covered by the production of coal-fired, gas-fired and cogeneration plants. The country exports almost 10% of its production. The cost of the production of electricity in our country and the final prices of the MWh either for the individual customer or the industry is one of the lowest in Europe. This production scheme also makes our country one those which, within OECD, emit the less CO2 per capita (55% of the emissions of a German or Danish citizen and the same amount than that of a mainland China citizen).

These figures must not mask the fact that the absence of construction of dispatchable power over the last ten years has endangered the autonomy which still existed at the turn of the century when the last nuclear plant started its production. During cold spells in winter time the country must now import electricity. Note that this never happened in 2011 because it was the warmest year ever since the beginning of the XXth century. One may consider this as a positive consequence of global warming.

In a remarkable attempt to overdo our neighbors in the European "greener than thou" contest, our government decided that by 2020, France primary energy coming from renewables would amount to 23%, while the average European request was "only" 20%. Other governments more attentive to the well being of their citizens negotiated for much less (for instance, UK is only committed to 15%). One wonders why France should do more in this domain than countries which, while raising a green flag before the media on any possible occasion, turn out to achieve much less than France in terms of small CO2 emissions per capita. It would have made more sense to ask these countries to shoulder most of the ecological load they were advocating as a mission for Europe to carry, at least till their score has been lowered to that of France.

Anyhow, based on this commitment at the level of 23% and on the unsubstantiated claims of productivity by various renewable energy lobbies (wind, solar photovoltaic, biomass…) the government has decided on how much installed renewable power of each type should be constructed over the coming decade. For the wind energy, the decision was that by 2020, French landscape would be covered by 19GW of onshore turbines (about 7000 machines) while 6GW of offshore farms would be looming on the horizon of our Atlantic and Channel shores.

It is a remarkable feature of our democracy that no figure on how these energies could usefully contribute to the overall production was publicly available when the decisions were taken. As a matter of fact this lack of transparency is a consistent characteristic of renewable energies. The only figures which become public are those distilled by the lobbies (generally well relayed by complaisant media) without any possibility for the public to check them.

In a sense, it is right to say, that renewable energies are the true “energies of the future”. By that I mean that it is essential for the strategy of their lobbies to have our eyes permanently fixed onto the bright future they are advertising rather than spend some time on analyzing how their present achievements match their past promises. I also mean that these energies will probably remain the “energy of the future” for as long as is possible in order to allow their promoters to pocket public subsidies. Along with other renewable energies, wind energy has invented the notion of “sustainable subvention” and even more remarkably have made us to collectively accept it as a normal state of affairs. When they ask for subsidies, the lobbies always insist on what they will be able to achieve once the financial public support has been obtained. Although sufficient experience is now available (wind energy was launched in Denmark more than 20 years ago), they never take the risk to confront the present reality with their annocements in the past[1].

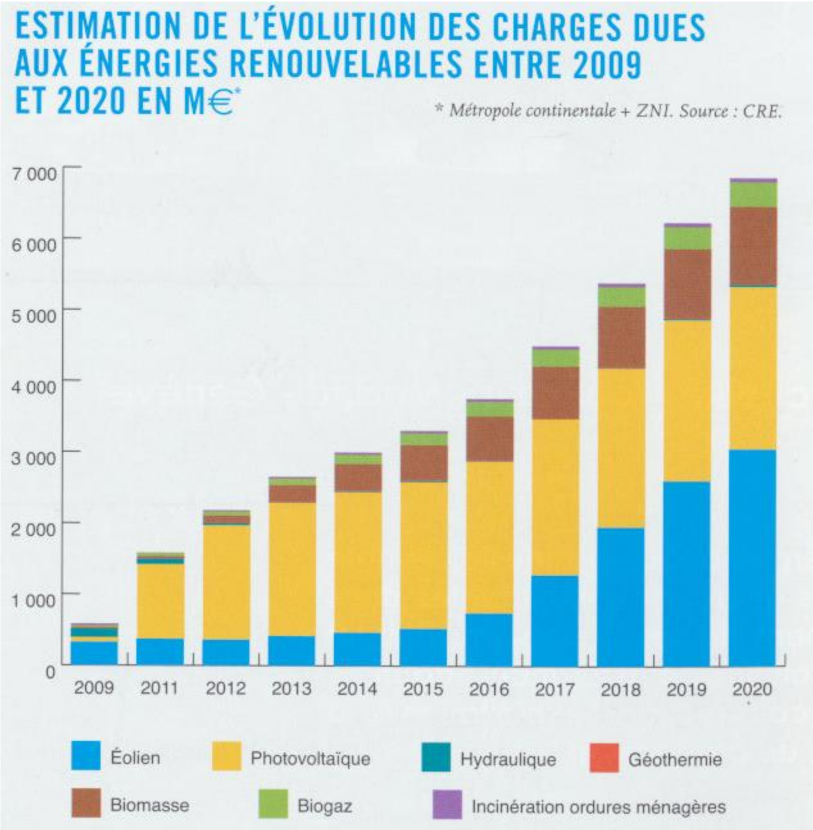

Fig.18 Evolution of the CSPE tax that French customers will pay as a result of the deployment of renewable energies.The calculation is that of the CRE (Commission de Regulation de l’Energie). The unit on the vertical scale is 1M€.

When a weakness becomes too obvious to be hidden, such as the difficulty to handle intermittent and poorly predictable production, there always comes a request for more support for some technology crutch described as a remarkable step forward although it generally amounts to making a square ped fit into a round hole. The argumentation basically amounts to; “ you wanted wind turbines, thus you also have to accept their drawbacks. Now you must be happy to pay for more HV power lines and backup plants”). This permanent “fuite en avant” which ensures a mediatic presence in the media by putting regularly on the table novel futuristic and non costed relief technologies, such as for instance hydrogen

[1] For instance, today (January 1st 2012), although more than 1GW of solar PV is operating within France, no public figures is yet available on the time evolution of this production and of its adequation to the needs of the French society. The curves that are presently available on the RTE site are pure inventions (sinusoidal curves scaled to match integrated values over one or two months).

production as a usage of renewable energy, is not only a trait of wind energy. It shares it with solar energy (think of Desertec) and nuclear fusion.

At least since a year and a half (July 1st 2010), thanks to RTE, some information on wind energy is available. It has been discussed at length in this document and the overall negative conclusions I draw from this analysis do not need repetition.

The last figure of this document (Fig. 18) is an indication of what the renewable Grenelle policy is going to coast the French citizens. Based on the assumption of a steady increase of the European electricity price and on stability of the subsidies served to the renewable energies in France, the CRE has calculated the amount of CSPE tax added to the French electricity bills. By 2020, support of wind energy will cost each year 3G€ (1/3 for 19GW onshore, 2/3 for 6GW offshore) and support to solar PV will cost 2.3G€. Altogether, the support to renewable energies will cost about 7G€ (something that will happen every year). This is essentially wasted money, money which every year, would have covered more than the 60-year investment into one EPR reactor.

What is clear is that the decision of the government concerning this and other renewable energies received the global (although unformulated) consent of a French population whose incompetence on the subject was astutely abused by the unlikely alliance of the wind energy speculators with antinuclear environmental organizations. In itself, such an alliance would make an interesting subject for a sociology study. In a sense, we, French citizens, asked for what is coming. Quite normally, our elected representatives made sure that we were going to obtain it. We will have to collectively handle the consequences of our choices and pay for them (Fig.18 corresponds only to part of the cost). As somebody once said: “Be careful about what you wish; you may very well get it”