GENI Global Energy Network Institute

Is 100% Renewable Energy Possible in France by 2020?

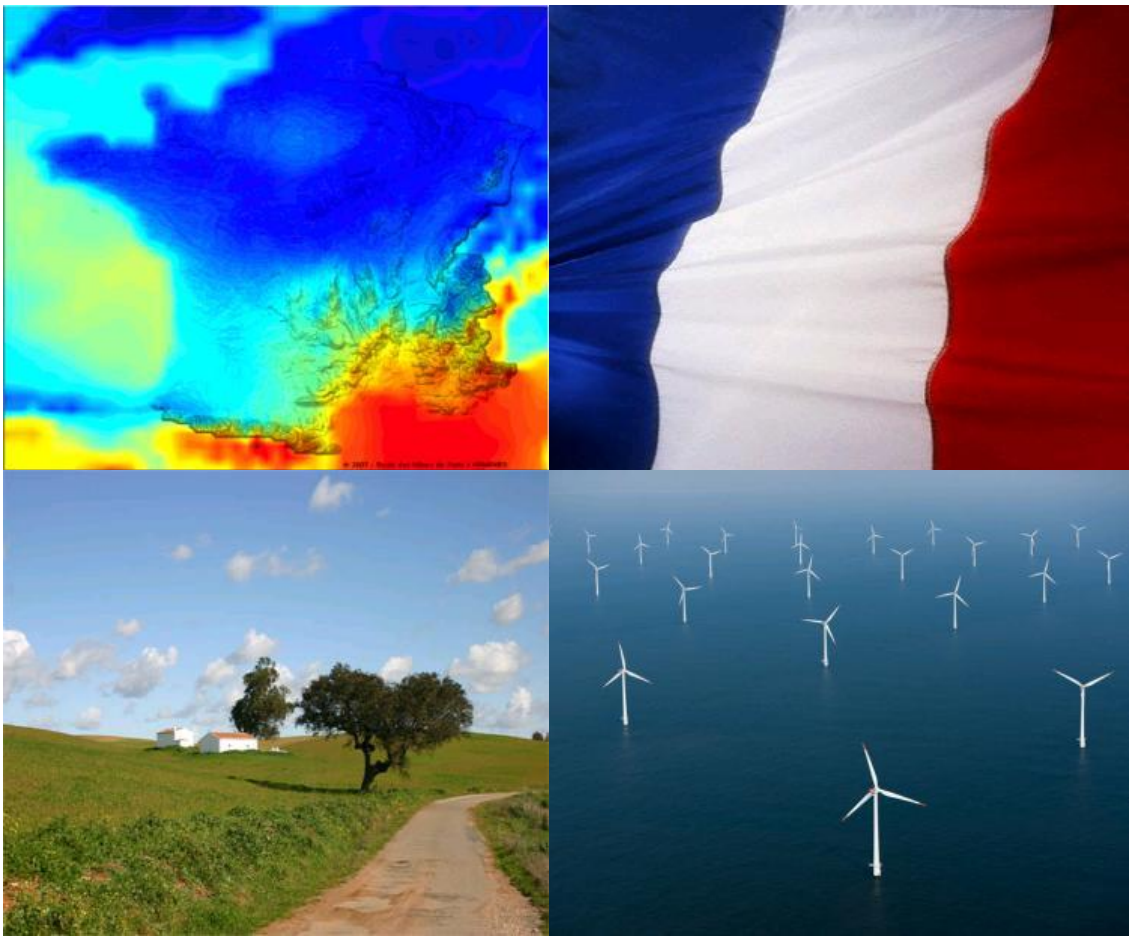

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Table of content

Figures Index

Abstract

This report focuses on the analysis of various groups reviewing the renewable energy potential within France. While those plans have focused on bringing the country to 23% renewable energy by 2020, this report takes a more agressive view. It raises the possibility of having France's electricity powered by 100% renewable energy at the earliest possible date.

In researching this possibility, effort was directed at two smaller questions, which together allow us to analyze the possibility of 100% renewable energy in France:

1. Do we have the capability of meeting the peak capacity daily with renewables?
2. Do we have enough renewable base energy to fulfill the total energy demand?

After research and review of many technical reports done within France, in response to these two questions we can say that 100% renewable energy in France is possible, but more likely in 30-40 years than in 2020. France's prime location and advancements in renewable energy technologies together create the capability to effectively harness abundant sources of hydro, geothermal, solar, waves and wind energy.

A major part of this report was made possible thanks to several EDF (Electricité De France, responsible for the distribution of all electricity in France) reports, like BAROELEC 2010. Other major groups or reports that helped in writing this paper include the EurObserv'ER, as well as several articles from French newspapers (Le Monde, Challenges, l'Express) intensively addressing this topic during spring 2011, mostly because of the Fukushima Earthquake and associated nuclear threat.

Quotes, ideas, figures, and tables are cited at the bottom of each page for ease of reference.

I/ France energy situation

1/ France current energy supply

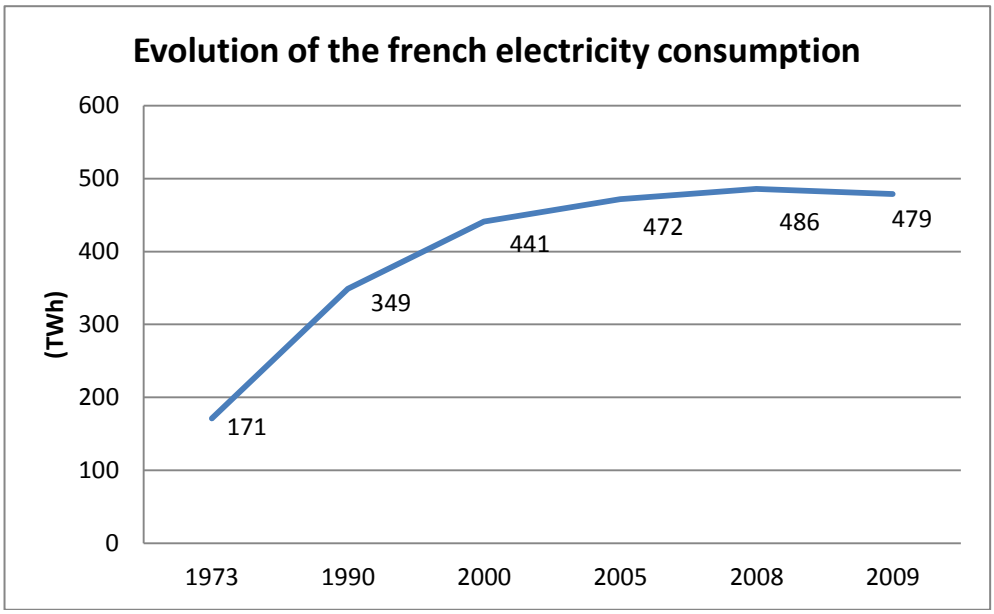


Figure 1: Electricity consumption from 1973 to 2009 **Source: statistics of electricity in France**

The total electricity consumption in France in 2009 was 479 TWh. If it tripled between 1973 and 2008, it looks to have reached a plateau close to 500 TWH in 2008, followed by a slight decline in 2009.

By 2020, power consumption forecasts significantly vary (+/- 20%) around 500 TWH, depending on the forecasted scenario:

Source :	in 2020 (TWh)
Tendanciel DGEMP 2004	635
DGEMP "facteur 4" 2005	520
Négawatt 2006	435

Figure 2: Forecast of electricity consumption France following three scenarios

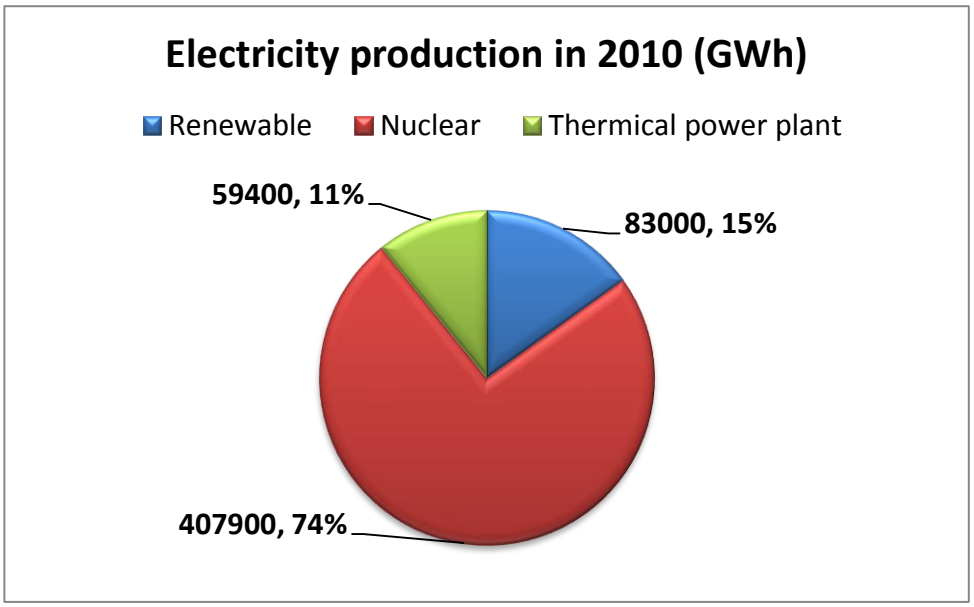


Figure 3: Actual electricity production in France, 2010 **Source: EDF**

	Electricity production in France, 2010	GWh	Σ (GWh)	Mtep	%	Σ (%)
NON renewelable	Nuclear power	407900	467300	33592	74,1	84,9
	Thermical power plants	59400		4892	10,8	
Renewelable	Hydraulic	68000	83000	5600	12,4	15,1
	Wind	9600		791	1,7	
	Biomass	4800		395	0,9	
	Photovoltaic	600		49	0,1	
	Net electricity	550300		45319	100,0	

Figure 4: Main electricity production in France, 2010

According to figures from EDF, the share of electricity from renewable resources increased by 11% between 2009 and 2010 in France. But still in 2010, only 15.1% of electricity is from renewable sources in France, against 84.9% of electricity from nuclear (74.1%) and thermal (10.8%, from fuel and natural gas) power plants.

France, now has 63 GW of installed nuclear power plants that provide 74% of electricity production. It is difficult to exceed this level of nuclear production due to the inability of nuclear reactors to adapt to the differences in consumption between day and night. In the 80s, the nuclear share had exceeded 3/4 of production, forcing the government to organize regulation for electricity not consumed during the night. Since then, there is a little more logic in organizing the French network of electricity. Nicolas Sarkozy's decision to authorize construction of two or three new EPR nuclear reactors that will add to the already excessive production base has been strongly criticized for this reason. The problem for France: neighboring countries now have a large capacity in wind farms, and France is having more difficulties selling its nuclear-source nighttime surplus. In 2008, France sold 46.6 TWh in the European market as wholesale electricity, a decrease of 8.8 TWh compared to 2007.

Compared to nuclear power, a renewable energy mix will represent a power capacity of about 22 GW, equivalent to about twenty nuclear reactors. The three main sources of green energy (wind, hydro, and biomass) will be used to replace these nuclear reactors one by one, depending on the availability of these green resources.

After the devastating earthquake in Japan on March 11, 2011 that caused the explosions at the nuclear power plant in Fukushima, France with its energy policy focused mainly on nuclear power is the subject of much criticism. Such a catastrophe is now not as hard to enviseage in France. The French government wants to evolve slowly towards more sustainable resources of renewable electricity which should speed up renewable energy projects and signal an energy conversion as soon as possible.

"No one could predict the consequences of human catastrophe, nuclear and financial that hit Japan. But after Fukushima, the world will never be the same. Particularly in terms of energy choices. Without stopping the call for nuclear, which has enabled France to keep its energy independence, it is conceivable that renewable will be a major concern and source for investment. A sign that never fails: in one month, "EDF Energies Nouvelles" (EDF New Energies) has gained more than 8%, when Areva (a nuclear company) lost 15%, and EDF lost 10%."[1]

[1] Marc Fiorentino, president of Euroland Finance, Challenges No. 246

2/ Nuclear power in France after the Second World War

It is difficult to speak about French electrical energies without addressing nuclear energy. It is still the main electricity supply source in France. Here is a brief summary of the history of nuclear power in France since its inception up to today :

- In 1945, General de Gaulle created the “Commissariat à l'Energie Atomique” (CEA) to develop the French atomic bomb. The first nuclear test took place in 1961 in the Algerian desert. 210 trials followed : until 1966 in the Sahara, then in French Polynesia (atoll Mururoa and Fangataufa).

- The first nuclear reactors appeared in France in the late 50s. The first French Central was built at Marcoule, in Provence and put into operation in 1956.

- But in the early 70s, in the context of the first oil shock, a major program was launched. This is the "Messmer Plan”. He wanted to generalize the use of nuclear energy in France and planned to build three reactors per year. This program has made France the world's most nuclear-armed counbtry.

- In France: In 2010, 407,900 GWh of nuclear energy was produced, or 74% of electricity production in the country (550,300 GWh). This represents 16% of electricity from nuclear power produced in the world.

- Today in 2011, there are 58 nuclear reactors operating on French territory. All are second-generation reactors (PWR : Pressure Water Reactor). But so-called third-generation reactors (EPR) should appear shortly. One is being built at Flamanville (near Cherbourg). Another project is in Penly (near Dieppe). The announcement of this second EPR reactor was made by President Nicolas Sarkozy in January 2009. Commissioning is scheduled for 2017.

- At the same time, ten reactors have been dismantled, including that of Superphenix in Creys-Malville. Abandoned in the late 90s, it was a fast neutron reactor. Another reactor of this type (Phenix, in Marcoule) was closed in 2010.

Unlike deconstruction, dismantling includes the destruction of all components, including nuclear reactors or explosive charges. It means the total and definitive cessation of all operations and involves the destruction of buildings and the treatment (including inerting when possible) and disposal of radioactive and hazardous waste (for reasons of chemical toxicity in avoiding illegal possible reuse).

Below a France map with all nuclear power plant (NPP) :

Figure 5: Map of nuclear power plants in France,
Source: Base map: File: Nuclear_power_plants_map_France-fr.svg, 2011

According to this map, the sum of the French reactors is 66.4 GW in 2011. All reactors do not provide the same power. Production can range from 0.9 GW to 1.6 GW for new reactors. As a unit, an "equivalent average nuclear reactor" is equal to 1GW. In 2011, the specialists consider that France is equipped with 65 "equivalent average nuclear reactors."

Strengths: Able to produce energy in large quantities, nuclear plants emit little carbon dioxide as their air emissions consist primarily of water vapor from the cooling system. The production cost is also very competitive.

Drawbacks: Nuclear is capital intensive and involves a major risk to human health and the environment in case of an accident. The management of waste material is complex and expensive, since it is necessary to store dangerous radioactive elements for long periods.

Production cost: 35 to 42 € / MWh

3/ An overview of renewable energies in France in 2010

Renewable energy is energy that is comes from natural sources and is inexhaustible in a time scale of our civilization. France has a high hydro and geothermal potential. It has the largest forest in Western Europe. The France metropolitan wind source is the second in continental Europe after the UK, with a broad and well exposed coastline, allowing offshore wind great potential.

France is the second largest producer of renewable energy in the European Union, mainly through its timber resources and hydropower (82.5% of the renewable energy production in France in 2009). It may be noted that the timber and hydropower account for more than 75% of the renewable energy production in France, despite a surge in wind power (40% growth in one year).

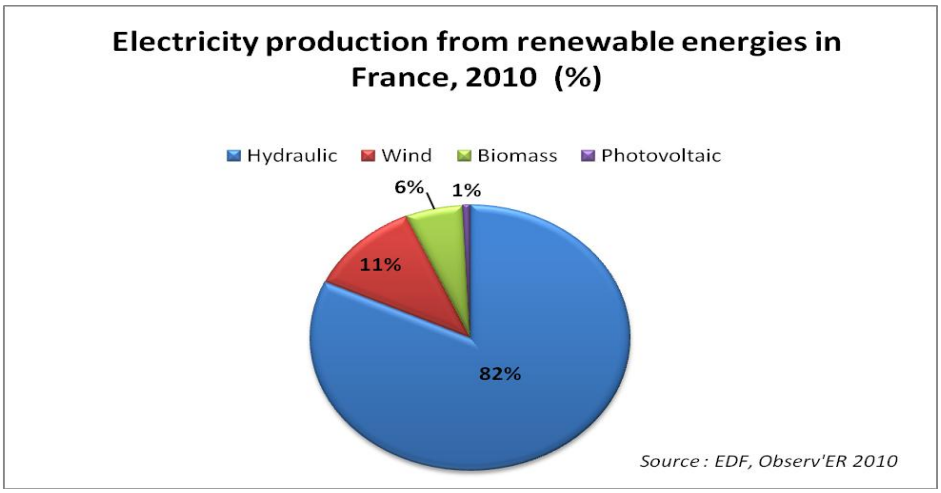


Figure 6: Electricity production from renewable energies, 2010 Source EDF

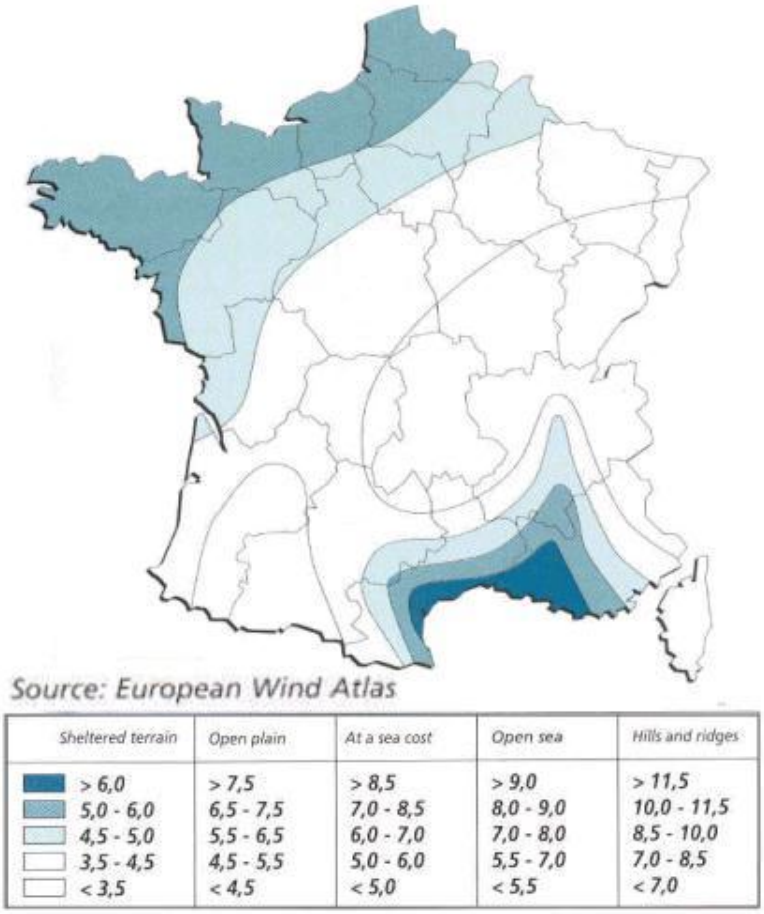
	Type of energy	GWh	%	Σ (GWh)	Σ (%)
	Hydraulic	61644	82,5		
	Wind	7891	10,6		
	Photovoltaic	212	0,3		
Biomass	Solid biomass	1642	2,2	4468	6,0
	Biogas	846	1,1		
	Waste incineration	1980	2,6		
	Ocean power	491	0,7		
	Geothermal	50	0,1		
	total	**74756**	**100**		

Figure 7: Electricity production from renewable energies in France 2009 Source EDF

a/ Wind power

With about 10,000MW of new capacity in the European Union in 2009, wind power has become the most active electricity generation sector in Europe.
Today, France has combined wind farm capacity of just over 5,000MW maximum instantaneous power (produced by about 3,500 towers). The annual production is about 10 TWh, for wind turbines running about 25% of the time, leading to a yearly production approximately equal to 2,000 hours rated power (maximum power of the wind). (8,760 hours in a year.)

A wind farm in France



Source: European Wind Atlas

Sheltered terrain	Open plain	At a sea cost	Open sea	Hills and ridges
> 6,0	> 7,5	> 8,5	> 9,0	> 11,5
5,0 - 6,0	6,5 - 7,5	7,0 - 8,5	8,0 - 9,0	10,0 - 11,5
4,5 - 5,0	5,5 - 6,5	6,0 - 7,0	7,0 - 8,0	8,5 - 10,0
3,5 - 4,5	4,5 - 5,5	5,0 - 6,0	5,5 - 7,0	7,0 - 8,5
< 3,5	< 4,5	< 5,0	< 5,5	< 7,0

Figure 8: The wind power in France Source: European Wind Atlas

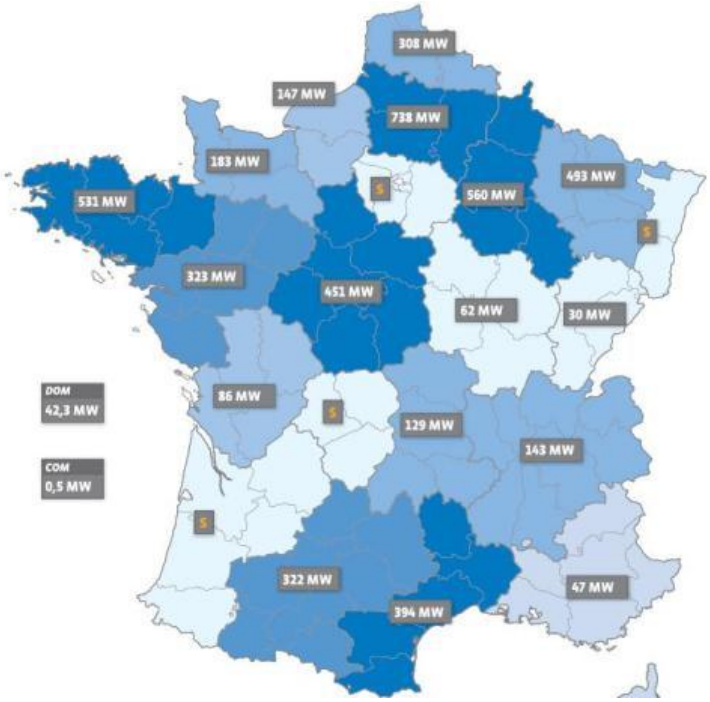


Figure 9: Map of regional wund power turbines in France (June 2010)

In the renewable mix, wind power will carry the bulk of the increase in renewable electricity generation in 2020 in France: 25,000MW of capacity is planned to be installed by 2020. To achieve this goal, the number of wind turbines present on French territory needs to triple.

"On July 11, 2011, the offshore wind tender expected for eight months is finally launched by the state. This tender aims to build about 600 wind turbines off the French coast by 2015, representing an investment of 10 billion euros that will cover the installation of 3,000 MW (the equivalent of three EPR nuclear reactors). By 2020, the government intends to increase the total power of the offshore wind energy to 6,000 MW (1,200 offshore wind turbines), representing an investment of 15 to 20 billion euros, if we take into account cost reductions to come, according to the Department of Ecology." [2]

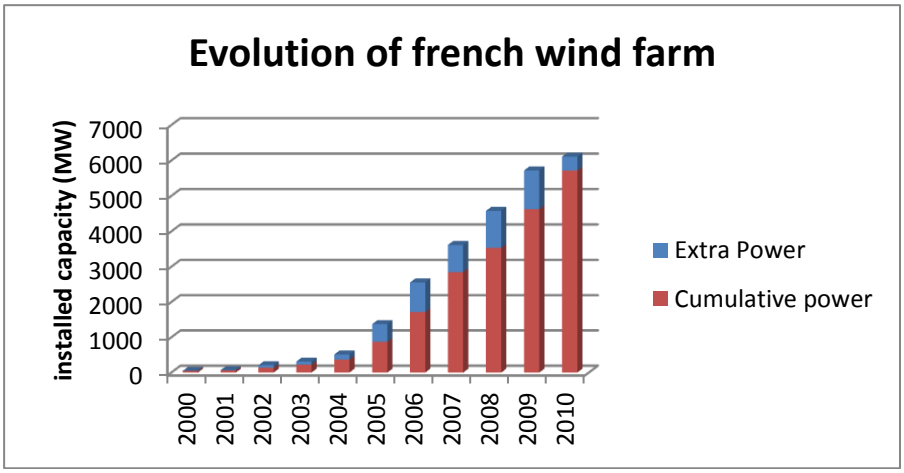
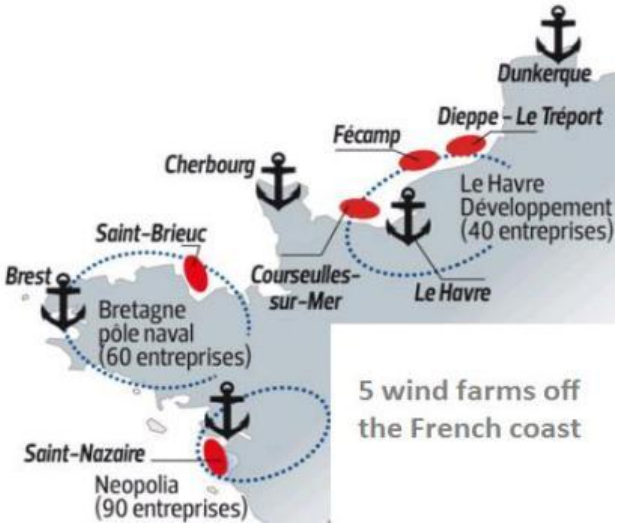


Figure 10: Evolution of French wind farm installed capacity

[2]Newspaper *Le Monde*, 11/07/11

Five "target areas" have been defined: "Dieppe-Le-Tréport", "Fécamp" (Seine-Maritime), "Courseulles-sur-Mer" (Calvados), "Saint-Brieuc" (Cotes d'Armor) and "Saint Nazaire" (Loire-Atlantique). A second phase of the same volume will be launched in April 2012.

This program in France aims to catch up with others in Europe. Despite its 5,800 kilometers of coastline for the country, France doesn't have any offshore wind turbines in spite of the fact that its European neighbors already have 950 towers in late June 2010.



The five areas for the development of offshore wind farms in France (red areas*)*

Besides offshore wind turbines, France plans to develop onshore wind power. To reach the 25,000MW goal in 2020, about 7,000MW new onshore capacity will be added to the 6,000MW already built.

The government's goal is to develop a real French industrial sector in the wind. For today, French companies are lagging behind the industry leading manufacturers: such as Danish "Vestas", American "General Electric", Spanish "Gamesa" or German "Enercon." Two large French companies have decided to join their forces to get the contract offered by the state: EDF EN and Alstom have announced an exclusive agreement to equip the ocean wind farms. GDF Suez is also vying for the contract. To win, candidate firms must satisfy two main criteria: providing a balanced price per kilowatt hour, both effective and acceptable by EDF which buys the electricity, and providing guarantees of *job creation* [3] in the territory.

At first glance, offshore is not as competitive as onshore: due to a construction cost of 3.5 million euros per megawatt, offshore wind easily surpasses onshore production cost, which costs 1.5 million euros per MW. The reasons for this are related to the difficulties of offshore installation - including the masts and turbine blades that should be studied to withstand the force of waves and current, as well as receiving enhanced protection against corrosion - and obviously more complex maintenance operations.

However, due to stronger winds off the coast and their technical characteristics (the tip of the blades is nearing the bottom of the mast), offshore wind farms are more productive: they can thus provide an average capacity of 5 MW, or 15 GWh of electricity per year, compared to the 3 MW wind turbines on land. Eventually, the offshore resource could become more profitable

[3] cf : II/2/ Linked jobs and turnover

than onshore. But everything will depend on the resale price of electricity. For now, the price has been set by the state at 13 cents per KW/h, against 8 cents for onshore wind.

The research aims to reduce costs and anticipated deployments, and new concepts (small wind turbines, horizontal wind turbines to optimize the wind to energy ratio thanks to new aerodynamic concepts ...).

These wind projects are still extremely complex to manage because of their visual and, therefore, environmental impact. They can cause harm to the landscape of some beautiful French regions that are often the pride of their inhabitants. These places may provide very important income through tourism. We can give the example of the threat that famous Mont Saint Michel may lose its UNESCO World site label if the wind turbines were visible in the area of the general site. This is not necessarily the case in less touristic areas, but many highly motivated groups are fighting against this type of wind farm project in France.

Strengths: This clean technology does not release carbon dioxide into the atmosphere and produces no waste. Its operation does not require the intensive use of water characteristic of nuclear power.

Drawbacks: The wind provides electricity intermittently and can be used in addition to another production system or with the support of a storage device (such as batteries). It is accompanied by a noise and visual pollution that only the offshore installation can limit.

Production cost:

	Cost to built 1MW (M€)	Resale price of electricity (c€/KWh)	Production cost (€/MWh)
Off shore	3,5	13	160 to 180
On shore	1,5	8	80 to 90

Figure 11: Wind power costs

b/ Solar – Photovoltaic Electric

Photovoltaic panels

In France, the photovoltaic sector represents less than 1% of national electricity production, but it represents a very high energetic and economic potential. France has set a target installing 5,400 MWp (Mega Watt Peak) of PV capacity by 2020. This will allow France to gain capacity similar to neighboring countries such as Germany, which leads in this sector.

Thermal : Panels have already been widely profitable and rapidly amortized, but research may enable further improvements.

Photovoltaic : The cost of photovoltaic solar panels is still relatively high, but has fallen sharply over the past 15 years. Research on various areas (cheaper cells with thin film layers or cells with higher returns) can expect significant improvements. The industry is growing rapidly in several countries (China, Germany, Spain, USA), which should help to reduce costs.

Thermal Solar : This technique is under development (the U.S. and Spain being pioneers) and seems very promising in the short term in very sunny areas. The Pioneer Themis solar power plant has been active in France from 1983 to 1986, but closed by the Chirac government for lack of profitability. The Odeillo solar furnace, a 1 MW laboratory, is still active.

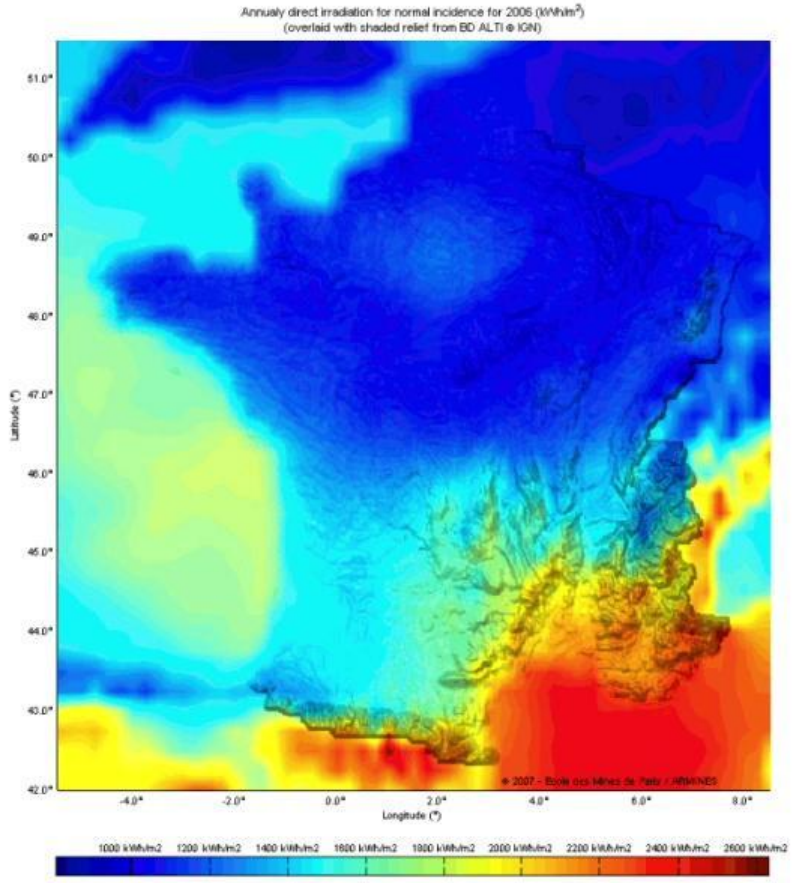


Figure 12: Solar radiation of France (kWh/m²/year) **Source : Ecole des Mines de Paris, 2007**

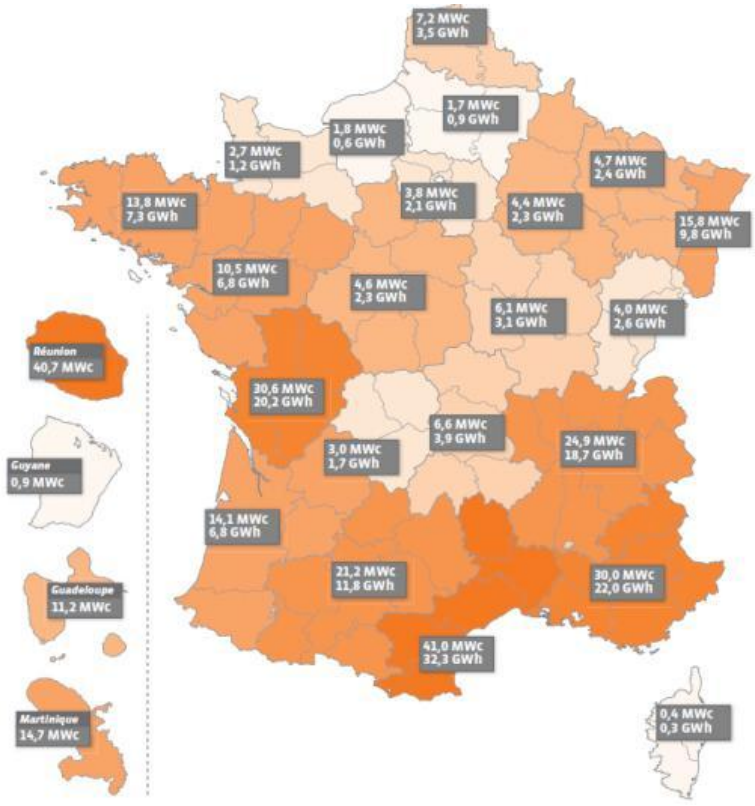


Figure 13: French map of the solar production power planned in 2010

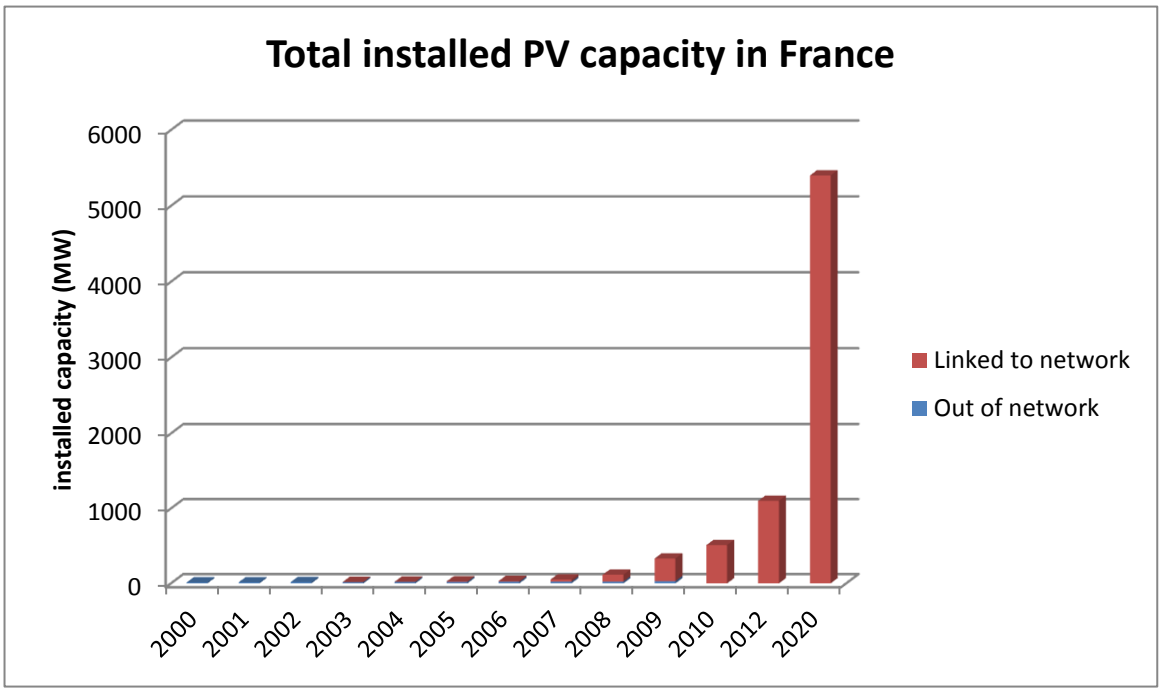


Figure 14: Graph of the French photovoltaic capacity

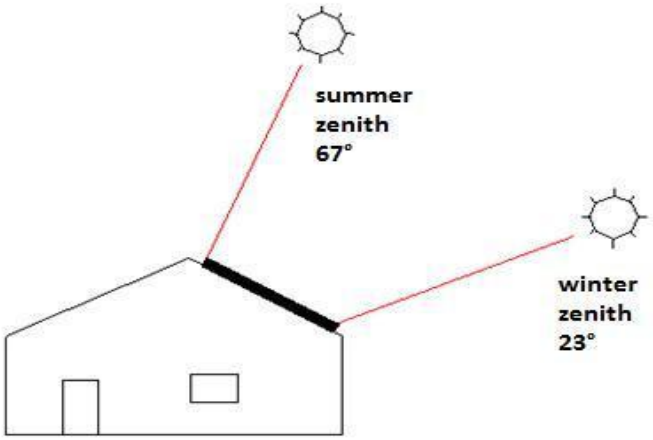


Figure 15: Inclination for of PV installation

The roof inclination may be low, because the production is focused for summer-season. The roof angle should be between 20 ° and 40 ° (optimum 30 °). The facilities usually comprise between 10m^2 - 30m² of photovoltaic modules. These modules must be oriented between southeast and southwest, but south exposure is not as critical than in the case of a solar heating system.

A solar photovoltaic installation for an individual pays for itself in 5-6 years, followed by 14 or 15 years of revenue through the resale of electricity to EDF (2,000 to € 2,500 per year, tax-exempt) throughout a 20-year contract signed with EDF.

Strengths: Research consistently improves the performance of photovoltaic cells. Installing them on the roofs of buildings avoids disfiguring the landscape.

Drawbacks: This technology does not generate power continuously, since it is subject to climatic variability and the reduction in sunny days during the winter in France. It is also the renewable energy that today displays the most carbon footprint because of the cell manufacturing that is very expensive in energy consumption.

Production cost: 300 €/MWh (solar farms), from 550 to 600 €/MWh (private residences).

c/ Hydraulic or Hydro Power

Power Dam Lake Tolla near Ajaccio, France

More than 150 years after its initial development, hydropower is the second largest source of electricity in France. The operation of this driving force was an important economic development for the country. In the early 1960s, over 50% of the electricity produced in France was from hydropower. It now has a new role in the fight against climate change. This renewableresource has had an image of a sector that would not change, will have a new growth dynamic: by 2020, with 3,000 MW additional capacity, it is expected to reach 28,500 MW of gross installed capacity. In 2009, hydro accounted for 87.1% of the French renewable power generation.

Large hydropower is already highly developed in France, and its environmental impacts (ecological fragmentation of rivers and disturbance of the fish fauna) could be reduced by monitoring and anticipating the flow and season change, and monitoring and management of sediment. This energy could be coupled with other resources (wind, solar, hybrid systems, including production and use of hydrogen). In the 1930s, an hydroelectric plant was built on the "Lac noir", in "Les Vosges." Hydroelectric "Durance-Verdon", which began in 1955, was completed in 1992. There are no longer large geographical sites easily suited to new development. The French rivers have already tapped the maximum development of dams.

The small hydropower could be developed further – as a run-of-river systems.

Strengths: This process is clean, renewable, with a low cost of production, and it uses proven technologies. The kinetic force of the water is recovered to be converted into electricity.

Drawbacks: Expensive to build, plants have a long pay-back period. The creation of large dams can have the effect of flooding agricultural land, displacement of populations and alterations in local ecosystems.

Production cost: 60 to 80 € / MWh

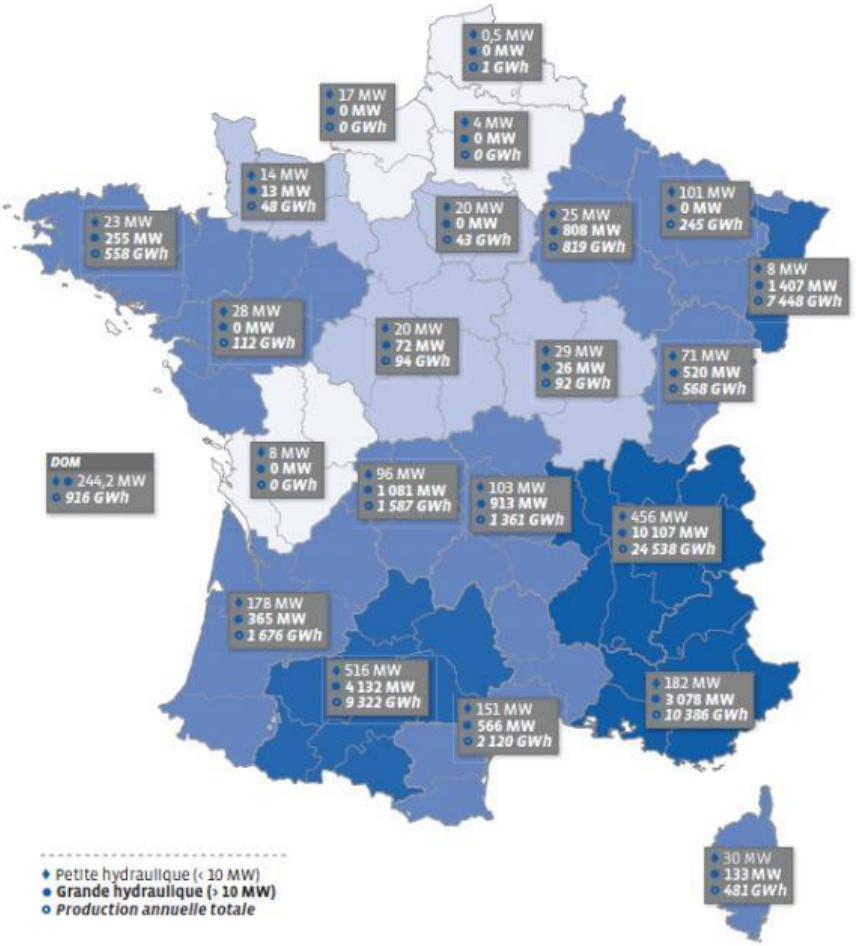


Figure 16: French map of the hydropower production in 2010

One can imagine small production improvements by upgrading the turbines to more efficient machines.

One very interesting aspect of this source of hydropower is to allow immediate response to electrical current demand, covering peak demand time periods (mid-day hours).

Another interesting aspect is the "re-turbine" which is to use the base of cheap energy (in France nuclear power as the main source of consumption) to lift the water back into the upper storage basins. It is method already used to smooth consumption: we open the floodgates to produce electricity when there is a peak need for current, and turbines return the water when there is too much gross power available (usually at night). This pumped storage is therefore a very effective way to store lots of energy with only a small energy loss in the process.

d/ Biomass

The generic term ‘biomass’ is a general term which includes the solid biomass, biogas, waste incineration and liquid biomass. In 2009, biomass produced 4,468GWh renewable electricity (6% of the production of renewable electricity in France).

Storehouse of wood for renewable electricity

Solid biomass industry:
In France, this is mainly used for heating rather than electricity. Electricity production from biomass in 2009 (1,642GWh) represent only 2.2% of renewable electricity.

Biogas :
Today, the bulk of electricity generation from biogas comes from non-hazardous waste (landfills). While the industry still has potential for development, the bulk of new deposits is related to the digestion of waste from the food industry, domestic waste and agricultural waste. With the upcoming release of new tariffs for the electricity sector, biogas should see a real take-off.

Waste incineration industry :
Almost all domestic waste in France is incinerated and used for energy production. Yet only half of this energy is produced from biodegradable waste and therefore considered renewable. Electricity generation is often the only solution for upgrading these facilities which are often located far from big cities. The value of this form of heat is limited to the presence of local demand by commercial needs. The goal of the industry is to increase energy recovery as heat by finding local, close-by industrial consumers and studying the connections to district heating.

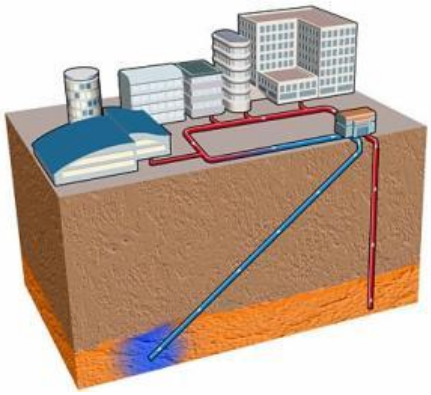
Strengths: The biomass is based on traditional resources which are readily accessible. It produces not only electricity but also heat for domestic and commercial needs.

Drawbacks: To create electricity and heat, biomass must be burned or undergo biogas processes, two transformation processes that generate greenhouse gas emissions. The extensive use of wood can cause deforestation.

Cost of production: 110 to 130 € / MWh

e/ Geothermal

With 16MW of installed capacity, high temperature geothermal electric power has not yet found a place among France's renewable energy mix. Things are going to change, because of the recent increase in buy-in tariffs, we should see a significant impact on investment in the sector. A sector that can draw on the work in "Soultz-sous-Forêts" (Bas-Rhin), a site of recovery of heat fractured rock, and the work carried out in Guadeloupe in a volcanic region.
The terget of installed capacity in 2020 is between 6,000 and 9,000MW.



Principle of geothermal system

Strengths: Thermal phenomena from the Earth's ground is not intermittent as wind and solar. Three types of geothermal heat deposits are: the very low energy (less than 100 meters deep), the low energy (100 to 1,500 meters) and high energy (beyond 1,500 meters).

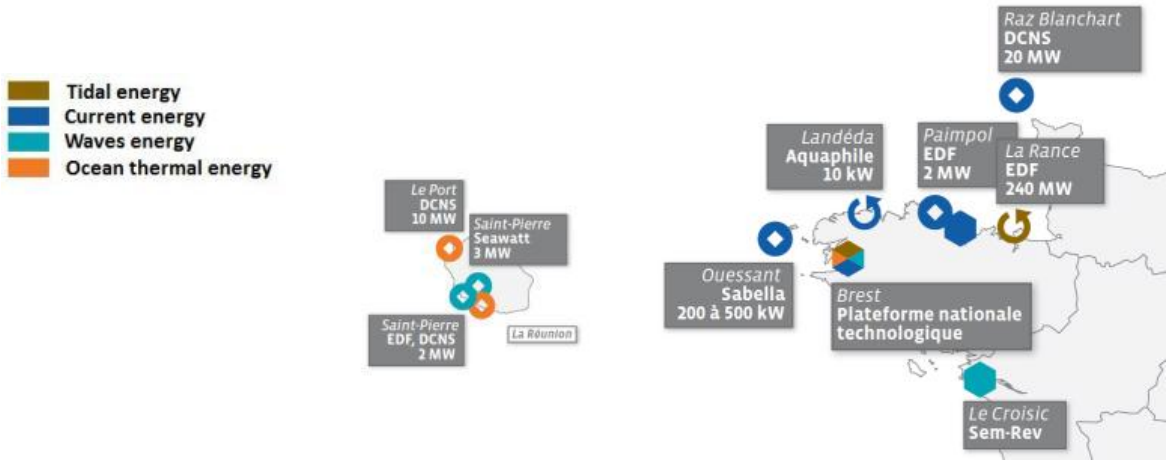
Drawbacks: To generate electricity, we must dig deep into the crust and use steam turbines. The heat can disrupt the ecosystem and create risks of micro-seismic activity.

Cost of electricity production: 120 to 150 € / MWh

f/ Ocean

France has major marine energy resources. However, this potential remains untapped industrially because the technologies have yet to prove themselves. Pioneered 40 years ago with “La Rance” tidal dam, France has subsequently abandoned the sector. The Rance tidal power plant, which uses the energy of the tide is the first of its kind in the world. Searev prototypes, to get wave energy, have been tested since 2003. New marine energy projects are in progress, showing a willingness and industrial interest. Industrial development could be achieved in 2020. For now, the goal of installing additional power by 2020 is 800MW.

Tidal turbine tested in Bretagne



Mapping of marine energy projects in France, 2010
Source: Observ'ER

Type of energy	Installed capacity (MW)	Production (TWh)
Tidal	400	1,4
Wave energy	200	0,8
Ocean thermal energy	200	1,4

Figure 17: Objective of developing marine energy power in 2020, EDF

4/ Electricity prices

a/ EDF (Electricité De France) prices

"EDF sells the cheapest electricity in Europe... at the moment and reluctantly. Yet it is an instrument of competitiveness. Until now, thanks to nuclear, the price paid by the customer, a little over 100 € / MWh, was 30% below the European average (see chart). Of this amount, approximately 60€ are recovered by RTE and ERDF, the transmission and distribution subsidiaries of EDF. The electric price 40€, is large sum given that the marginal cost of producing a nuclear power plant (including uranium and maintenance) amounts to only ten euros per MWh."[4]

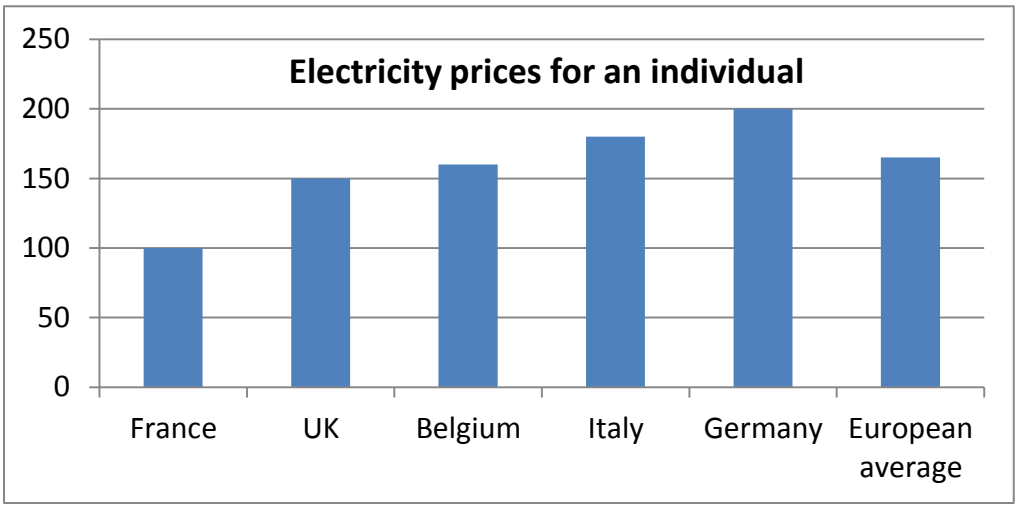


Figure 18: The French electricity bill is one of the lowest in Europe thanks to nuclear power

Despite recent price hikes, France is a country where the electricity bill for companies is the lowest in the world. According to an international study conducted by the NUS Consulting firm, a French industrial customer currently pays, on average, 6.70 cents Euro per kilowatt hour (c€ / kWh), half of what a German industrialist pays at 12.94c€ / kWh.

The current price of electricity in France for an individual is 12c€ / kWh: half of it being for the network and half to produce the energy. In comparison, the energy production costs are: 8c€ / kWh (+25%) for the Onshore, 18c€ / kWh for the Offshore, and 27c€ / kWh (x5 times more expensive) for photo-voltaic. The Onshore is nowadays by far the cheapest renewable energy.

About the Offshore project : the EDF client will be the adjustment variable. Stéphane Meunier, *Sia-Conseil* consultant, has developed a simulation for *"Challenges magazine"* : with the 6,000MW wind farm in 2020, an average utilization rate of 34% and wind in the event of a redemption price per MWh of 180 € (like in Germany), the annual bill of average users (600 € average) would increase by 52€, or just 4.3€/month.

[4] Challenges No. 250

b/ An "all renewable" budget for the consumer

What matters is not just the cost of energy; it is also a service. So the comparison is not only between different ways of producing energy or electricity, but also the question of distribution and consumption. If you have a very well insulated house which uses the best solar gain, your energy bill, regardless of the energy source you use, will be much lower. So in the economic point of view, it is energy savings (conservation) that is a priority.

If we compare the production costs of electricity, what we see first is that since the beginning of the construction of nuclear power plants in France, the cost of nuclear kWh has been increasing. The latest example is the estimated cost per kWh to be produced by the new EPR, which is higher than the cost from the previous nuclear designs.

It should also be remembered that some costs are not properly taken into account, such as the cost of decommissioning and the storage and protection of radioactive waste, which we know is an expense that will last over many decades and/or centuries.

"Conversely, the cost per kWh produced by renewable energy is much lower for hydraulics, close to the competitiveness of wind power and biomass, still significantly higher for photovoltaics, but the cost of it decreases currently by about 5% per year. So we can say that probably around 2020, due to the more than likely increase of the cost of fossil fuels and nuclear energy, competitiveness will be achieved for almost all renewable energy." [5]

[5] Le Monde 5/04/2011 : interview of Bernard Laponche, nuclear physicist, an expert in energy policy, former director of the Agency for Environment and Energy Management (ADEME)

c/ French consumption habits

Comparison of consumption of France with those of Germany and California:

"For two neighboring countries, France and Germany: electricity consumption per resident in 2008 is 6,000 kWh per year for Germany, and 7,000 kWh for France. In addition, German industry is more developed than French industry, thus a significant portion of electricity in Germany goes to industry.

Electric heating in France plays an important part in electricity consumption in the residential sector; this is unique to France. But even if we compare the consumption in this sector between Germany and France,"excluding thermal" (heating, hot water and cooking), consumption per resident in Germany is less by 20% - 30% compared to that of France.

Another example is California, probably one of the richest and most developed States on the planet. Electricity consumption per capita is 6,000 kWh per year, 16% below that of France. This shows that there is great potential for saving electricity in France. For example, in industry, if the use of high-performance engines would be generalized (70% of electricity consumption in industry is from engines). In the building sector - housing or service industries - there are heating and hot water energy costs that can be handled by something other than electricity, and in particular, the solar water heater, which is a very simple technique, and widespread in some countries.

It is really quite surprising that there are ten times as many solar water heaters in Germany than in France, while our solar potential is much greater than that of Germany." [6]

[6] Le Monde 5/04/2011: interview of Bernard Laponche, nuclear physicist, an expert in energy policy, former director of the Agency for Environment and Energy Management (ADEME)

II/ Technical potential for renewable energy in France

1/ Expected energy growth – Environment "Grenelle" for 2020

One objective of the "Grenelle of energy" is, by 2020, to produce 23% of the electricity consumed in France from a mix of green energies. This would effectively cover replacement of fossil fuel plants, which represent 11% of the energy produced in France (59.4 TWh in 2010).

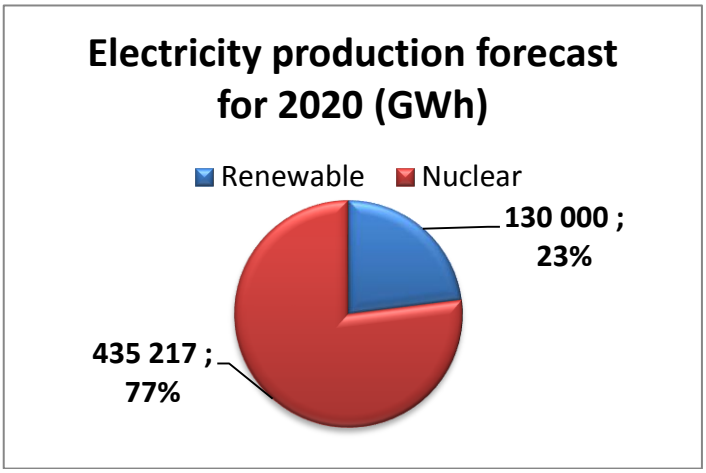


Figure 19: Electricity production forecast for 2020

This blossoming of sustainable energy will consist of power plants using fuel from biomass (wood, agricultural waste ...), wind turbines, hydroelectric dams and solar power plants to a lesser extent.

Renewable energies production in France (Mtoe)	2009	2020
Heat	**10,08**	**19,7**
Biomass	9	15
Geothermal	0,4	2,3
Solar	0	0,9
Wastes	0,4	0,9
Biogas	0,28	0,6
Electricity	**6,29**	**12,8**
Hydraulic	5,6	5,8
Wind	0,49	5
Biomass	0,2	1,4
Solar	0	0,5
Other (ocean, geotherm)	0	0,1

Figure 20: Estimation of required power in France in 2020

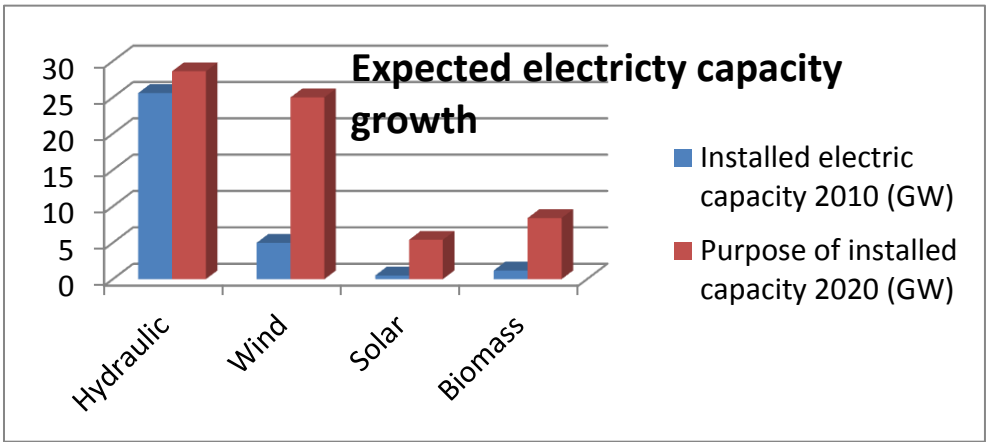


Figure 21: Expected electricity capacity growth

To obtain this "green mix" that will eventually produce 23% of domestic consumption (about 130 TW.h), the following objectives must be achieved:

Hydraulic: 29 GW (+3 GW by 2020)
"There will be little new hydroelectric dams, as with 25 GW in use today, it is estimated that river systems are already developed. There will only be a further 3GW by 2020. The dams with a capacity of 25GW, are already providing 62 TWh per year. The Water Act, which imposes minimum flow to be maintained in the river downstream of hydraulic structures should lead to lower production by 2 TWh per year." [7]

Wind: 25GW (Onshore wind: 19 GW, Offshore wind: 6 GW), against 5GW in 2010.
On average, wind power provides maximum power the equivalent of 23% of the time. We can count on wind energy to provide 25GW for 2100 hours, or about 53TWh per year.

Solar: 5,4 GW in 2020 (growth of 4 GW)

Biomass: 8,4 GW in 2020 (1,4Mtoe), against 1,2GW installed in 2010.
Most of the biomass resource is used directly for heat and is not transformed into electricity. In the total absence of wind and sun, what still remains are biomass and hydro, which will provide the power as energy reserves for each other.

[7] According to Pierre Gadonneix, CEO of EDF, in *La Tribune* newspaper

"The objectives of the "Grenelle" (providing 23% of the total electricity consumption of France (130 TWh) over a year with this green energy mix) for 2020 are perfectly feasible. In addition to eliminating CO_2 emissions from the French electricity sector, the project will create many jobs and contribute to the country's energy independence.

The high price of renewable energy should not be a crippling handicap. Because the industry is young, and the effects of manufacturing scale drive down prices. "A solar module manufactured in China now costs 1 euro watt, against 3 or 4 euros a few years ago," says Jean-Louis Busquet, editor of the journal "Plein Soleil." For example in Italy, where the price of electricity is high and sunshine plentiful, the PV industry has already reached "grid parity": the purchased cost of producing solar kilowatt hour is now the same as the cost of purchased electricity at retail. On the other side of the Alps (from France), photovoltaics can live without subsidies." [8]

[8] *Challenges* magazine No. 252

2/ Linked jobs and turnover

Kind of energy	wind	solar	hydraulic	biomass
turnover (billion €)	2,8	1,4	3,12	0,68
linked jobs (2009)	9600	8600	10 400	3000

Figure 22: Linked jobs and turnover in principal renewable energy sectors (EDF source - 2009)

Jobs promised in offshore wind :

The activity related to the installation of wind farm on land is more important than an offshore wind farm, since there are already many installed units. This multiplier effect justifies the creation of a number of jobs.

"Of the 154,000 jobs reported in 2007 in Europe by EWEA (European Wind Energy Association), 2,800 are within the offshore sector, only 2%. This percentage should increase in coming years, in line with the expected growth of the offshore market. EWEA estimates that by 2025, the number of jobs generated by the offshore wind industry is expected to exceed that of the onshore wind industry and will reach from 215,000 to 375,000 new positions in 2030."[9]

"About France, we are expecting 60,000 jobs in the wind sector for 2020 (11,000 today) according to specialists." [10]

In fact there are essentially two very different phases:

- One is the constitution phase of the projects and the EMR farms' construction. The jobs created are quite numerous, evaluated according to different sources (EWEA, OAS) to 11 jobs per MW installed, but their duration is relatively short, about 2 years for setting up the project and two to three years for the construction of the farm.

- The other phase is the operational maintenance. Jobs are created immediately after the end of the construction phase of the farm, of the order of one job for 4MW installed but for a much longer duration (several decades).

The Germans, who have always been reluctant about nuclear power, reacted to the Fukushima disaster by deciding to stop nuclear power in the next twenty years and to move towards 100% renewable energy, already responsible for 400,000 jobs in Germany.

[9] *« Énergies Marines Renouvelables »* repport, M. Henri Boyé, EIGSI teacher and researcher in renewable energies in France

[10] *France Inter* radio 08/26/2011, "solar, wind, who wins, who loses?"

III/ 100% renewable energy scenario

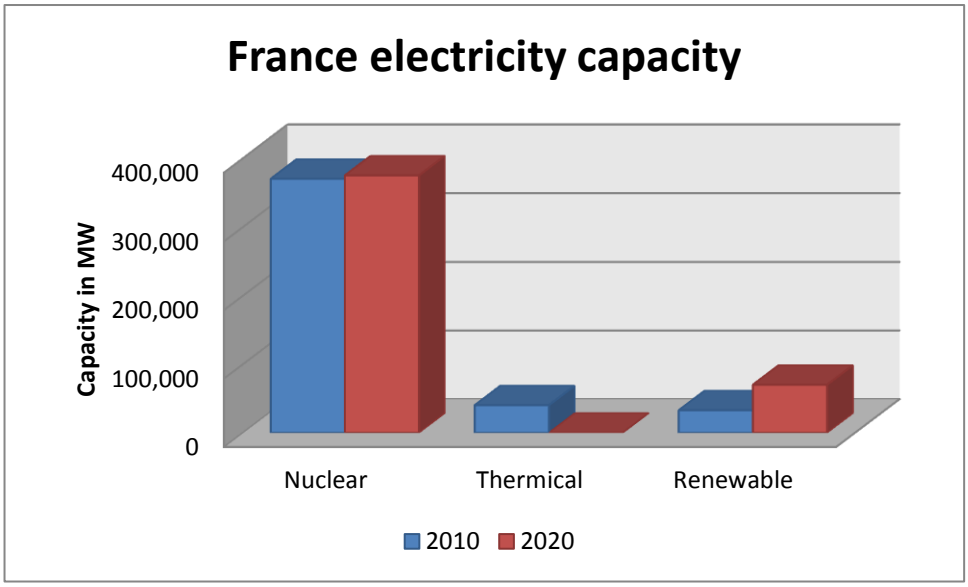


Figure 23: Difference between 2010 and 2020 electricity capacity in France

The graph above shows the official expected trend for 2020 in France. These figures do not seem to represent the efforts being made to develop renewable energy in France. We see very clearly that nuclear decommissioning is not be actively planned. The good thing is the complete removal of thermal power plants (using fuel oil, gas and coal), replaced by the growing capacity of renewable energy.

So we are still very far from the objective of being at 100% renewable energy in France by 2020.

Based on estimates of future consumption from the French "Grenelle" for 2020, France will produce 565,000 GWh of electricity :

- 130,000 GWh from renewable
- 435,000 GWh from nuclear

To be reminded here the proposed alternatives for 2020, as already mentioned in §I,I:

- Tendancial DGEMP 2004: 635 000 GWh
- **Grenelle:** **565 000 GWh**
- DGEMP "facteur 4" 2005: 520 000 GWh
- Negawatt 2006: 435 000 GWh

When looking at these figures, and keeping in mind that France's population will continue to grow slightly along the next decades, we will keep "Grenelle" as a reference, but also having in mind the possibility of remaining stable around 500,000 GWh, allowing for -65,000 GWh potential "prediction cuts" over the period.

"I want to find an energy mix to replace the 435,000 GWh nuclear delivered! "

1 / *"Remove the electric heaters from our homes"*

Electric heating accounted for 10% of the national electricity consumption in 2002 and 36% of household consumption. It supplies 30% of housing in France. The French fleet of electric heaters is half the European fleet. With the continuation of current trends, Greenpeace estimates that France will use 50,000 GWh of electric heaters in 2020. [11]

It is an aberration: We produce electricity from nuclear for electric heating. Heat energy should be provided directly by biomass, geothermal energy and use of solar water heaters.

"Solar water heaters use the heat energy from the sun. We talk a little bit about that but this resource looks very promising with an installation of 4m2 in the south or 6m2 in the north of France, you can produce 50% to 70% of your hot water. And France has a fairly developed industry in this area (3 major industrials in metropol and two or three others in French islands : DOMTOM). There was not a good policy to promote the heat, but we have absolutely to energize and revitalize it. Moreover, there are tax credits rates of 45%.

Consider that the first advantage of renewables is their local character. Regarding the example of solar water heaters, there must be some units in the city of Marseille, where the sun is strong. So we could, by equipping the roofs of a city like Marseille, having a considerable production for heating and hot water, without spoiling anything nor occupy the land. It's a bit like for photovoltaics: it is obvious that we should not put large photovoltaic installations on agricultural land. However, we can equip barren land, but also equip the roofs.

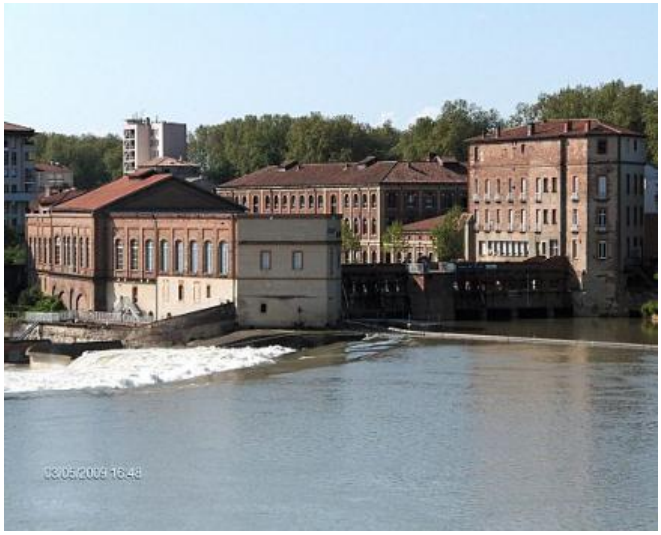
Similarly, in France we have a considerable potential of biomass, and we know that a well maintained forest provides an important annual potential to produce heat and electricity. Also maintenance of the forest is more conducive to respect the heritage than the reverse. So we may develop renewable energy more without wasting or destroying forest land. It is less destructive than making holes for shale gas." [12]

[11] *Greenpeace* summary of the study "electric heating in France"

[12] Newspaper *Le Monde* 04/05/2011: Interview with Bernard Laponche, nuclear physicist, an expert in energy policy, former director of the Agency for Environment and Energy Management (ADEME)

2 / *"Finding axes of development for renewables'*

Some resources are already saturated, such as mountain hydropower. Of course, there are small water facilities, but they can only provide a nominal amount of electricity. A hydraulic unit such as the "Bazacle" in Toulouse was enough to feed the entire city with electricity for its street lighting (now electricity is directly sold to EDF). This hydroelectric plant, equipped with a fishway, has now worked for a century with an installed capacity of about 3,000 kilowatts. It can power a neighborhood of 3,000 inhabitants. Such facilities could be made along the major French rivers (Seine, Loire, Garonne, Rhône) and provide enough electricity to power the lighting of towns and cities on the banks of these rivers.



Hydraulic central "Bazacle" in Toulouse

Other renewables are more challenging to use but have great potential: offshore wind. We can estimate the energy supplied by new wind farms (at the expense of working conditions of seafarers and the associations of anti-wind): "*To replace the 58 French nuclear reactors, just install 40,000 wind turbines in three rows, all along the French coasts.* "[Challenges # 246 p10 Nuclear Wind]

Marine energy has a future along the French coasts. The problem: the price of offshore cables and the difficulty of storing electricity. According to the report for the French Ministry by Mr. Henry Boye, Professor of Energy and Environment in EIGSI, wave power represents a considerable potential (theoretically 400 TWh in France, compared to the French electrical consumption current of about 500 TWh), but less obvious to operate technologically and less mature than wind and tidal turbines. EDF estimates that the exploitable potential in France is, in fact, on the order of 40,000 GWh, therefore, only 1/10th of the theoretical gross potential. It is mainly located on the Atlantic coast due to larger waves on average. The price of such a facility is unknown.

So, it is on these budding energies that French industrials must put the priority of their efforts: it is very important for the jobs of the tomorrow. These are mainly linked to the onshore and offshore wind industry.

One of the limiting factors of these offcoast resources is the cost of underwater electric cables for connection to the network (about 0.5 M€/km for the considered powers). If a technological breakthrough greatly reduces the cost, or if the problem of storing electricity is solved (hydrogen, batteries, compressed air ...) the number of technically exploitable sites do not restrict the near-shore projects (approximately 20 km from the coastline) as it does today.

Solar energy seems to be the most promising sector. We can install photovoltaic panels on the roofs of warehouses. A study done in France by an associated GENI researcher shows that French warehouse roofs can accommodate enough panels to produce 120,000 GWh/year.

Warehouse studies:

Warehouse roofs are a huge unexploited area for photovoltaic installation. Often warehouses are built in the suburbs, far from the city, buildings, and any other construction. So, large warehouse roofs are not shaded and are perfect for installation of solar photovoltaic panels.

In these areas, 48 large warehouses are available. The Region of Paris is a significant location, more than the North or the South in terms of number of warehouses. The available warehouses in the 3 regions are listed below.

Region	Warehouse available
North of France	9
Region of Paris	23
South of France	16
Total	48

Figure 24: Warehouses available in France

This study is based on these 48 warehouses, with an average surface area of 28,900 m^2, with the exception of 5 warehouses with more than 100,000 m^2. The total surface of these warehouses exceeds 3,500,000 m^2 without shade or encumbrances (air conditioning, chimney, etc).

In the end, we have a study showing these 48 warehouses would generate an installed peak around 275,000 MWp (Mega Watt peak), and an electricity production slightly above 120,000 GWh per year.

In addition, the photovoltaic sector in France is trying to better organize, to produce locally, generate green jobs, and avoid an excessive carbon footprint of panels made from other nations acroos the planet (and their associated deliver fules and costs).

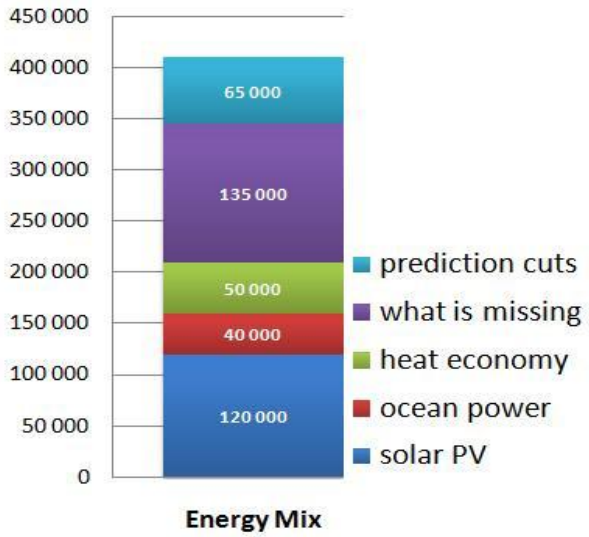


Figure 25: Energy production needed (GWh/year) to get 100% RE in 2020

So if we think we can save 50,000GWh of heating, produce 40,000GWh by wave energy, cover the warehouses of Photovoltaic for 120,000GWh, and 65,000GWh of prediction cuts, we still lack about 135,000GWh to completely replace nuclear power in France.

To complete this target is surely possible from the French residences (over 100m^2 on the ground) can be equipped with photovoltaic panels (with a maximum of 1/10th of a sunny roof area, flat and without kinks). In France, there are about 30 million households. If we estimate that 5 -10% of these households have a house roof area over 100m^2; if fitted with photovoltaic panels, it would reach 1,650 to 3,300GWh/year (1m^2 provides about 110KWh/year, on an installation of 10m^2).

3/ *"Save electricity; Change behavior."*

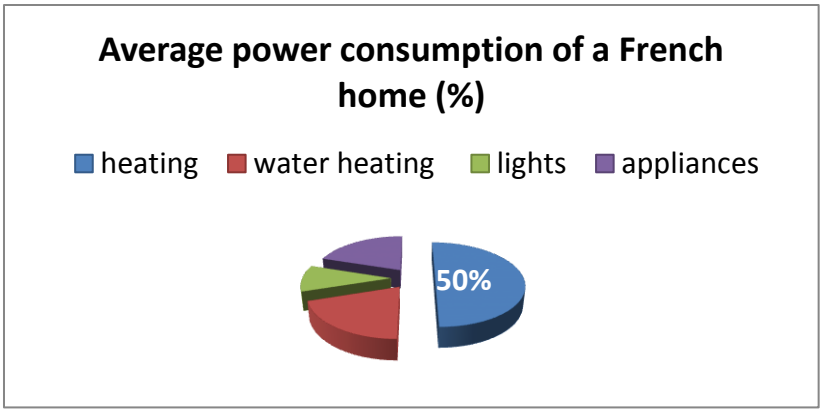


Figure 26: Average power consumption of a French home

Last but not least : to save energy!

The above graph shows the breakdown by usage of French household consumption.

It is clear that for the French household, heating is a majority use of electricity. To effectively reduce this figure, we must act directly on home insulation and replace the staggering power consumption of "toaster" heatings: we could easily save 50% at this level.

In addition, appliances are constantly evolving and producers are moving in the right direction by producing more energy efficient appliances. Also, many appliances are on standby mode (called vampire energy or phantom load) and constantly consume electricity: Reducing these standby times would save several kWh per year – a 20% potential reduction.

Cities are lit at night. Stretlamps and stores lights consume a lot by night, and much of this lighting is wasted into the night sky by by not capping these lamps There is work to do in these areas. Some studies predict a savings of 50% of lighting electricity.

If people cooperate, we could easily save 20% of current electricity consumption (good citizenship). In addition, the French electric bill may increase each year as the price of renewable energy (which is more expensive than nuclear electricity). By hitting the wallet of the French, the State could accelerate this “good citizenship.” That's how Germany (where the price of electricity is more expensive per capita) hopes offset the shutdown of its nuclear plants.

New electric meters called "smart meters" are currently developing in France. By 2020, 80% of 35 million meters will be equipped. They will view household consumption in real time and can be monitered through using screen. It will allow, among other things, remote control of the electrical installation.

So, we no longer seek to generate ever more energy; we must save what is available; that curve should be reversed!

4/ *Possible new heavy consumers*

We also have to mention the challenges of important new electricity consumers, the 100% electrically powered cars, mistakenly called “green cars” as they are taking their energy from the electrical network, from energy that may not be “green.” This new field of activity may move a significant amount of “transportation fuel” toward “electric fuel,” while the current economy of this “electric fuel” is mainly based on low cost nuclear electricity.

Conclusion

Replacing the nuclear power plants in France would not be possible by 2020, but further on the horizon by 2040-50.

Having said that, France has enough renewable resources to be self-sufficient in electricity. The current situation is promising and many projects are underway to move towards a renewable France. Such a change would create thousands of jobs and additional costs. That price factor would make renewable electricity less attractive in the near trem to the vast majority of French citizens who enjoy one of the lowest prices on the continent..

Technically, 100% renewable energy in France is quite possible. This is without covering the countryside with photovoltaic panels or wind turbines. There is no renewable energy miracle. As mentioned throughout this report, each renewable has its advantages but also its drawbacks.

We must diversify our energy sources and take the best of the positives: an energy mix. But the road is still long, and nuclear power will necessarily be there in France during the coming decades.

For now "It's possible to supply France with 100% renewable, but not probable in the near term." Peter Meisen, Director, GENI

Bibliography

Challenges n°246, n°250, n°251, n°252

Challenges n°262 : *Areva EDF*, n°264 : Offshore costs

Dauphiné April 2011 : hydraulic energies

Express n°3116 : special Japan earthquake

Express n°3121 : wind power

Télérama n°3193 : nuclear energy

Télérama n°3195 : the green revolution

Télérama n°3205 : What kind of green energy?; Nuclear & innovation

www.lesechos.fr : Offshore, *GDF Suez*, *Areva* & *Vinci* partnership

www.lemonde.fr April 5, 2011 : Bernard Laponche interview

www.lexpress.fr : Overview of alternatives to nuclear

Baroelec Integral 2010 (Repport by EDF)

Baromètre ER Europe 2007 (Repport by EDF)

Perspectives énergétiques de la France à l'horizon 2020 – 2050 (Centre d'analyse stratégique, 2008)

Vers une entreprise éco-responsable (Livre blanc by *Schneider Electric*, April 2009)

Ocean Renewable Energies, employment, competencies repport, by Mr. Henry Boyé, Teacher/Researcher at *EIGSI*, 2010, delivered to French Prime Minister François Fillion