Energy Infrastructures in France: Climate Change Vulnerabilities and Adaptation Possibilities.

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Abstract

As indicated by the Intergovernmental Panel on Climate Change (IPCC) in its 4th report, certain short and medium-term effects of climate change will be unavoidable. While some action has been taken at the international level to reduce the negative effects of climate change, related to the adaptation aspect, much work has still to be done concerning both the protection to the negative effects and the development of actions to take advantage of its positive consequences. The interest of this paper is to focus on the development of adaptive actions for the French energy infrastructures. The energy infrastructures considered concern the energy production, storage, and the energy grid. The vulnerabilities to climate change are analyzed taking into account both the seasonal and the extreme events. Two models of the IPCC (A2 and B2) are considered to explain the expected temperatures increases and rainfall patterns in France. The conclusions show that the major difficulty in adapting to climate change is the uncertainty regarding climate change impacts at the local and regional level and thus one should be sure to build in some flexibility that will prevent losses in the case that a climate event does not occur as predicted. However, a panorama of adaptation possibilities for the energy infrastructures in France is proposed as well as some comments on financing adaptation actions.

Keywords: adaptation – energy system – energy demand – infrastructures – climate change

JEL codes: Q54 – Q40 – O18

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Introduction

As indicated by the Intergovernmental Panel on Climate Change (IPCC) in its 4^{th} report, certain short and medium-term effects of climate change will be unavoidable, and thus it is interesting to develop adaptive actions in order to both alleviate its negative effects and take advantage of its positive consequences. While increasing attention has been dedicated to the mitigation of climate change through emission reduction policies, much has still to be done in adaptation issues. In this paper, we would like to help fill the gap in the literature, and with this purpose we will analyze the vulnerabilities of French energy infrastructures in order to determine how best to adapt them to climate change impacts.

The interest of focusing on energy infrastructure (electricity, gas and heat production, transmission and distribution facilities), is mainly the fact that it is at the heart of economic and social development. Consequently, it is essential to answer two fundamental questions: (i) what influence will climate change have on the viability of these installations, and (ii) what measures should be taken today to deal more effectively with tomorrow's conditions.

These questions have already been approached in some European countries but not yet in France. Met Office (2006) and Scotland and Northern Ireland Forum For Environmental Research (2007) analyzed the potential impacts of climate change on the electricity system in the United Kingdom and Ireland. Their main conclusions concern energy production, energy transmission and supply, and energy requirements. The authors assert that the energy production system could be directly damaged by frost, subsidence, flooding and high winds. Additionally, there could be a lack of river water for cooling power stations, water temperatures could be too high to properly cool the stations, coastal nuclear power plants could face flooding risks due to rising waters and tides, and the efficiency of combined cycle gas turbine (CCGT) power stations could be reduced due to increased air temperatures and a resulting reduction in air density. However, climatic changes could also make possible the development of solar energy sources due to reduced rainfall and cloud cover. Regarding energy transmission and supply, the authors conclude that it may be necessary to reduce the use of underground cables due to higher temperatures and drier soil, and, as in the case of energy production, there could be direct damage to energy transmission and supply facilities as a result of frost, subsidence, flooding and high winds. Finally, the authors anticipate changes in energy requirement patterns that could provoke power shortages or blackouts if the countries do not invest additional resources in power production capacity. Specifically, they expect an increase in summer energy demand due to greater use of air conditioning and a decrease in winter energy demand due to milder winters.

While Met Office's and Scotland and Northern Ireland Forum For Environmental Research's studies are interesting, the expected impacts of climate change on the English and Irish energy systems cannot be directly applied to France. This is due principally to two reasons (i) the structure of the energy industry in France is considerably different and (ii) the potential impact of climate change has to be considered at a regional scale.[4]

The paper is organized as follows. In the first section, we describe the French energy system, taking into account energy production, energy storage and the electricity distribution grid. In section two, we analyze the vulnerabilities of the French energy system to anticipated climate impacts. We consider results generated from two French regional climate models: Météo France's Centre National de Recherches Météorologiques (CNRM) model and the Institut Pierre-Simon Laplace (IPSL) model presented in Greenpeace-Climpact (2005). Both of these models base their regionalization on two scenarios considered by the IPCC: the widely-used IPCC A2 and B2 emissions scenarios[5]. In section three, we study how the French energy system might adapt to these vulnerabilities. The paper concludes with a summary of our main findings.

[4] Note that even if the inherent uncertainties of climate change increase with the reduction of the geographic area being studied, the regional climatic models have the advantage that they describe smaller scale phenomena (due to their enhanced spatial resolution of the area being studied - currently 50 to 100km as against 200 to 300km for large scale climatic models). This reduction in scale makes it easier to pinpoint the expected climate changes and thus allows for a better adaptation.

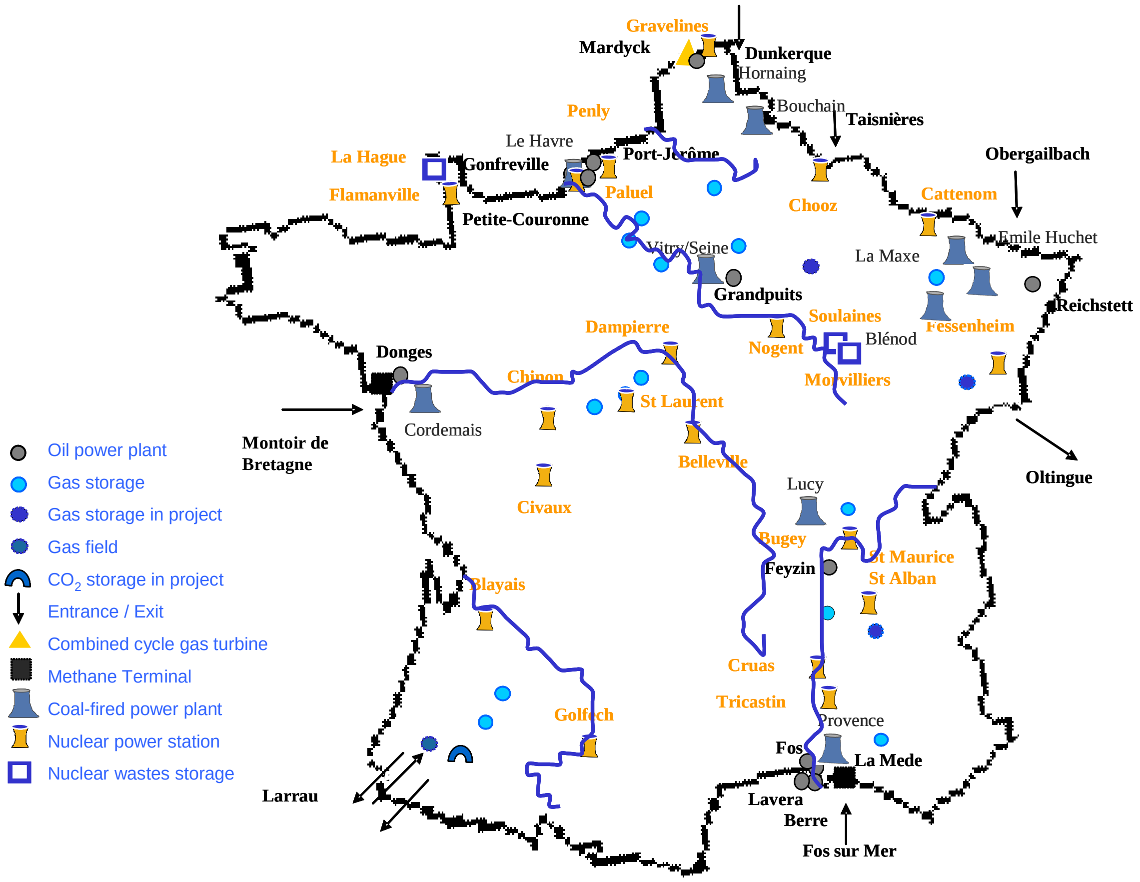
[5] For further details on the scenarios specifications, please refer to IPCC (2007).

2. The French Energy System

2.1. Energy Production

Primary energy production in France is comprised of 19 nuclear power stations, 10 coal-fired thermal power stations, one combined cycle gas turbine (CCGT) facility and 12 refineries. Figure 1 shows the location of these installations.

Figure 1: Energy Production and Storage



Source: Mission Climat of the Caisse des Dépôts based on Observatoire de l'énergie

Among all those energy production systems, nuclear energy is the main primary energy produced in France.[6] Nuclear power stations produce 84% of France's primary energy. Their capacity ranges between 900 and 1,500 MW per reactor. With the exception of the Gravelines station in the north of the country, which has 6 reactors, all of France's nuclear power stations are comprised of 2 or 4 reactors.

[6] Primary energy: raw energy, i.e. not converted after extraction (coal, brown coal, crude oil, natural gas, primary electricity). For a detailed picture of the domestic production of primary energy for the year 2007, please see Annex 1.

France's coal-fired thermal power stations are concentrated mainly in the north and northeast of the country. The primary energy produced by these installations represents only 0.15% of total primary energy output. The main CCGT power station in France is at Dunkerque, in the very North of France. Lastly, the refineries are located at the oil pipeline terminals, generally in coastal regions.

2.2. Energy Storage

While electricity cannot be stored, energy sources can. Gas is the primary fossil fuel stored in France. Gas storage depots are primarily located in Ile-de France and the surrounding area.

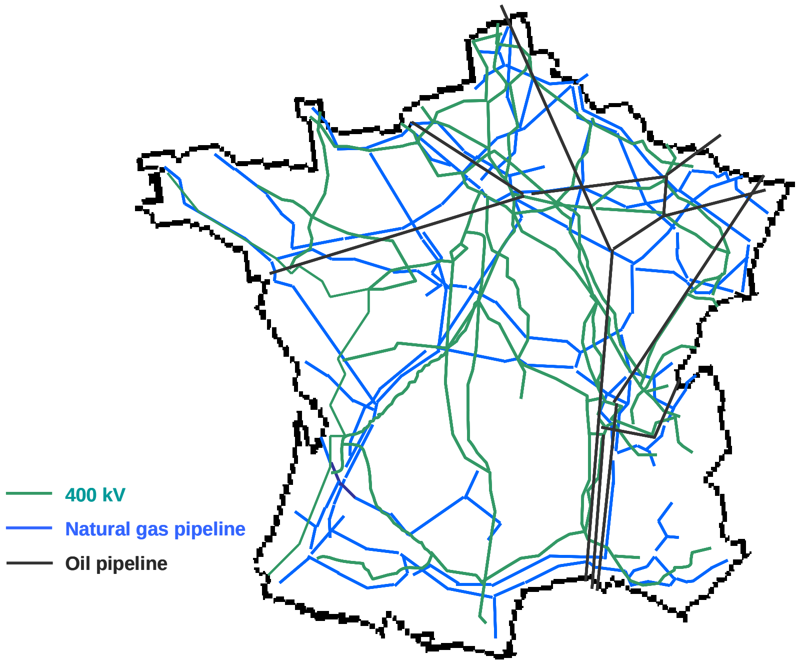
In what concerns the nuclear waste and CO_2 storage sites in France, there are currently three main nuclear waste storage sites: two in the Aube (at Soulaines and Morvilliers) plus one in La Manche at La Hague. Please see Figure 1 for a detailed situation in a map. France is currently constructing its first CO_2 storage site, at the Lacq underground gas reservoir in the Pyrénées-Atlantiques.

2.3. Energy Transmission

Energy is transmitted through natural gas pipelines, oil pipelines and the electricity grid. The transportation of refined products (fuel for road vehicles, heavy fuel oil) in France is effected primarily by pipeline (45.1% of supplies) but also by truck (29.4%), by tanker (7.2%) and by boat (9.5%).[7] In Figure 2 we can see that there are relatively few oil pipelines and that these are concentrated in Northern and Eastern France, with the Paris-Nantes pipeline (in the west of the country) being the exception. Gas pipelines and high-tension electricity cables provide a consistent electricity supply to the whole of France.[8]

[7] Source: French Industry Ministry website. Please see http://www.industrie.gouv.fr/energie/comprendre/q-r.htm for further information (in French).
[8] Note for the facility of reading, we only show the 400kV network and not the medium or low tension networks.

Figure 2: Energy Transport



Source: Observatoire de l'énergie

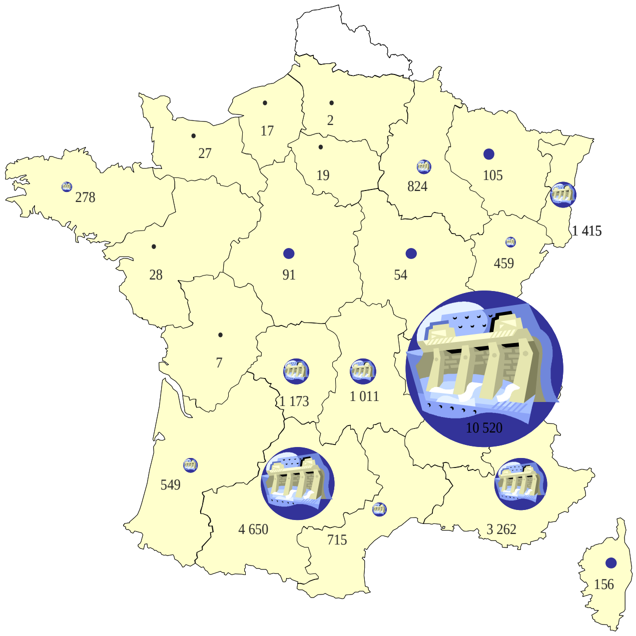
2.4. Renewable Energy

Four percent of the primary energy output produced in France comes from renewable sources. However, they represented in 2005, 10% of the electricity production.[9] Hydropower is the main renewable energy source, accounting for four percent of the country's primary electricity generation. As of 1 January 2007, installed hydro capacity amounted to 25,607 MW.

As shown in Figure 3, the Rhône-Alpes region produces the most hydro power, with a hydro capacity of 10,520 MW as of 1 January 2007. This region is followed by the Midi-Pyrénées (4,650 MW) and Provence-Alpes-Côte d'Azur (3,262 MW).

[9] Source : Eurostat.

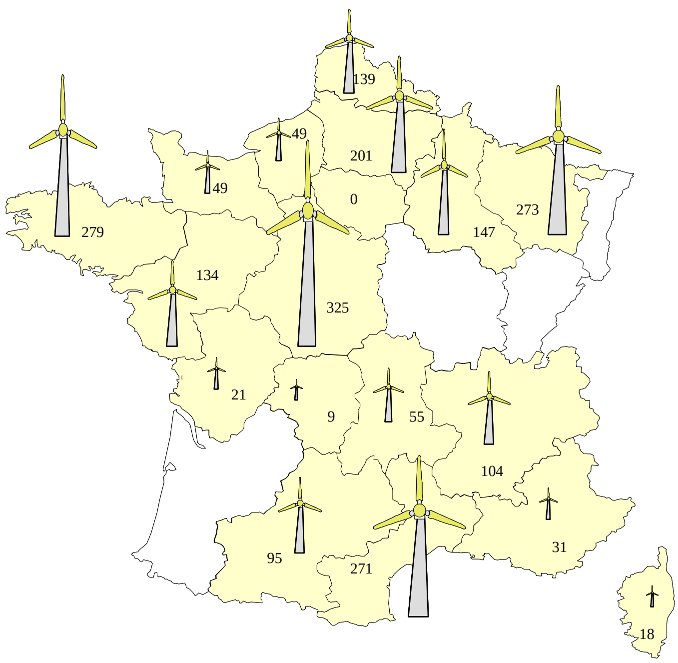
Figure 3: Hydro power capacity in MW (2007)



Source: Observatoire de l'énergie

Wind power represents a substantially smaller share in terms of total generating capacity. In 2007, wind accounted for only 2,200 MW of total capacity, as opposed to 25,363 MW total hydro capacity in 2005 (more than 11 times less). Figure 4 shows installed wind power capacity per region as of 1st January 2008. The primary wind power regions are the Centre (325 MW), Brittany (279 MW), Lorraine (273 MW) and Languedoc-Roussillon (271 MW). However, none of the units in these regions generates more than 350 MW.

Figure 4: Wind power capacity in MW (2008)



Source: Observatoire de l'énergie

3. Vulnerabilities of the French energy system to changing climate conditions

According to the 4th Assessment report of the IPCC, vulnerability is "*the degree to which a system is susceptible to, and unable to cope with the adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and the rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity*".

We will now analyze the vulnerabilities of the French energy system to anticipated climate change impacts, drawing on Greenpeace-Climpact's 2005 Report "*Changements Climatiques : Quels Impacts en France?*". We will focus only on those climate changes that may affect the French energy system, taking into account both the anticipated changes in climate trends and the potential impacts of extreme events. Like Greenpeace-Climpact (2005), we will take into consideration the predictions from scenarios A2 and B2 in the IPCC's Fourth Assessment Report. Regional modeling performed by Météo France and IPSL show what these different scenarios might mean for France.

3.1. Vulnerabilities to Changes in Climate Change Trends

Both IPCC scenarios, A2 and B2, predict an increase in average temperatures in France. Using these scenarios, the Météo France and IPSL models predict that, by 2070-2099, average annual temperatures in France could increase by 2ºC to 3.5ºC from 1960-1989 levels. As shown in Table 1, Scenario B2 modeling shows a potential increase of 2ºC by 2070-2099. Scenario A2 modeling shows an even greater increase in annual average temperature, from 3ºC to 3.5ºC.

Table 1: Expected average increasing in temperatures for the period 2070-2099 with respect to 1960-1989

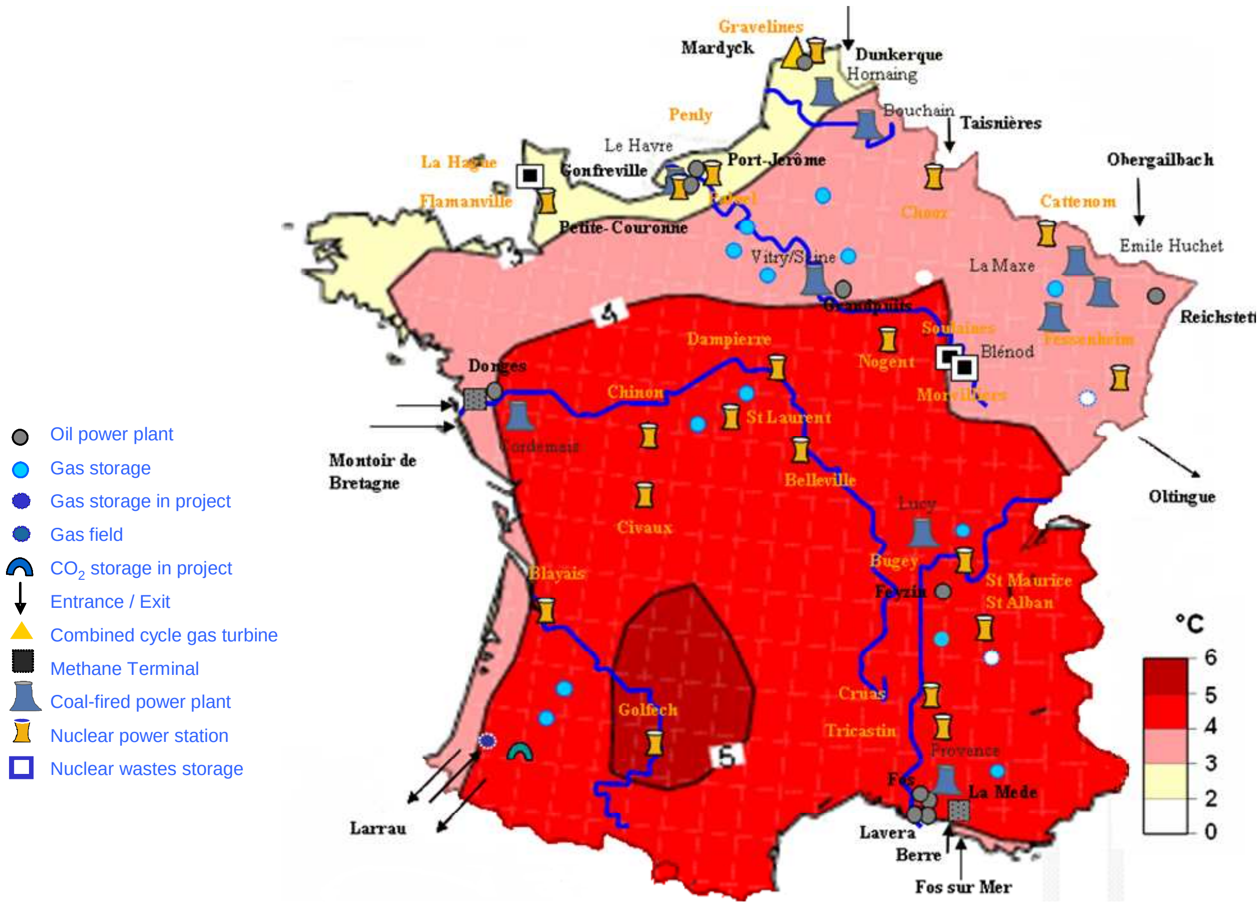
	Temperatures		
	Year average	Winter	Summer
Scenario B2	2ºC to 2.5ºC	1.5ºC to 2ºC	2.5ºC to 3.5ºC
Scenario A2	3ºC to 3.5ºC	2.5ºC to 3ºC	4ºC to 5ºC

Source: Greenpeace-Climpact (2005)

In both scenarios, warming would be greater in summer than in winter. As pointed out by Greenpeace-Climpact (2005), even if the increases in average temperature may seem moderate, they should be compared to the existing average temperature variations in France. If we imagine that the relief is the same throughout all the French territory, today, a change in latitude of 200km means a 1°C change in temperature.

Modeling shows that variations in warming in France may exceed 3°C from one region to another. The greatest increases (up to 5°C) will occur in the Central-West area. Thus, the management of energy production in the face of climate changes will not be the same in all regions of France. Figure 5 presents the summer temperature increases that may occur by 2070-2099, taking the A2 scenario into account.[10]

Figure 5: Summer temperatures predictions for the period 2070-2099 considering the scenario A2 and the energy production and storage in France - Source: Observatoire de l'énergie and Greenpeace-Climpact (2005)



[10] For sake of brevity, we have only considered here the case of the scenario A2. We have chosen this scenario because it shows a wider range of climate manifestations among French regions. Note that due to the projections uncertainties, the precise borders of the map's areas are difficult to delineate.

An increase in average temperature throughout France could impact the energy system in several ways. First, a rise in average temperatures will lead to a progressive increase in summer energy consumption as more air conditioning is used, and a progressive decrease in winter energy consumption as less heat is used due to milder temperatures.

Valor et al. (2001) dwell on the impact of temperatures in energy demand in Spain. The authors obtain that there is a progressive "U-shaped" curve of electricity consumption patterns over the course of time (1983 then 1991 and 1998). The parallelism between France and Spain is evident as we could consider that the French consumers are nowadays as equipped in air-conditioning as Spanish ones 20 years ago.

According to Hallegatte (2007), if the Ile-de-France region acquired an amount of air-conditioning equipment comparable to that in the USA (i.e. 64% of households), the demand for electricity would rise by 10 TWh per year, with 10 GW demand spikes in summer. Responding to this demand for electricity would require an investment of 7 billion euros (1.2% of Ile-de-France GDP) and additional operational costs of 400 million euros per year.

Electricité de France's (EDF) estimates of the additional energy that would be needed to meet changing electricity demands in summer and winter pinpoints that:

- For a decrease of 1ºC in winter temperature, an additional 1.5 GW capacity is required and
- For an increase of 1ºC in winter temperature, an additional 1GW to 1.2 GW capacity is required.

Second, the increase in the average temperatures may cause snow and permafrost to melt, therefore increasing the risk of natural phenomena such as floods, avalanches and landslides. These events will not only directly threaten energy systems but may also have serious economic consequences for nearby towns which will impact their demand for energy.

In addition, the melting of the snow and permafrost may also have a significant impact on hydroelectric output. First, the inability of the dams to retain all the increase of water may cause the under-use of water resources. Second, a disappearing snow and permafrost will reduce the amount of water that may be stored in reservoirs during the driest periods of the year, thus leaving less water available for electricity production during these periods. Additionally, restrictions in availability of water would cause usage conflicts between agriculture, domestic consumption and electricity production.

A third climate change trend that may impact the French energy system is a rise in water temperatures. This may create problems for French energy production, as water is used for cooling reactors at nuclear power stations for instance. In addition, increased temperatures cause water molecules to expand, thus contributing to sea-level rise. Currently, most of the French coastline is threatened by erosion and/or flooding, including Northern France (Normandy), Western France (Pays de la Loire, Poitou-Charentes and Aquitaine) and the Mediterranean regions (Languedoc-Roussillon and Provence-Alpes-Côte d'Azur). As one can see in Figure 1 presented earlier, most French energy production and storage sites are located on the coast or near rivers and waterways. Energy installations located in these areas will therefore face the risk of flooding.

Finally, a change in the rainfall pattern will also affect the French energy system. Table 2 presents the expected average changes in rainfall for the period 2070-2099 with respect to 1960-1989 for the B2 and A2 scenarios as simulated by Météo France and IPSL and presented in Greenpeace-Climpact (2005).

Table 2: Expected average rainfall changes for the period 2070-2099 with respect to 1960-1989

	Rainfall		
	Year Average	Winter	Summer
Scenario B2	-5% to 0	0 to +10%	-25% to -5%
Scenario A2	-10% to 0	+5% to +20%	-35% to -20%

Source: Greenpeace-Climpact (2005)

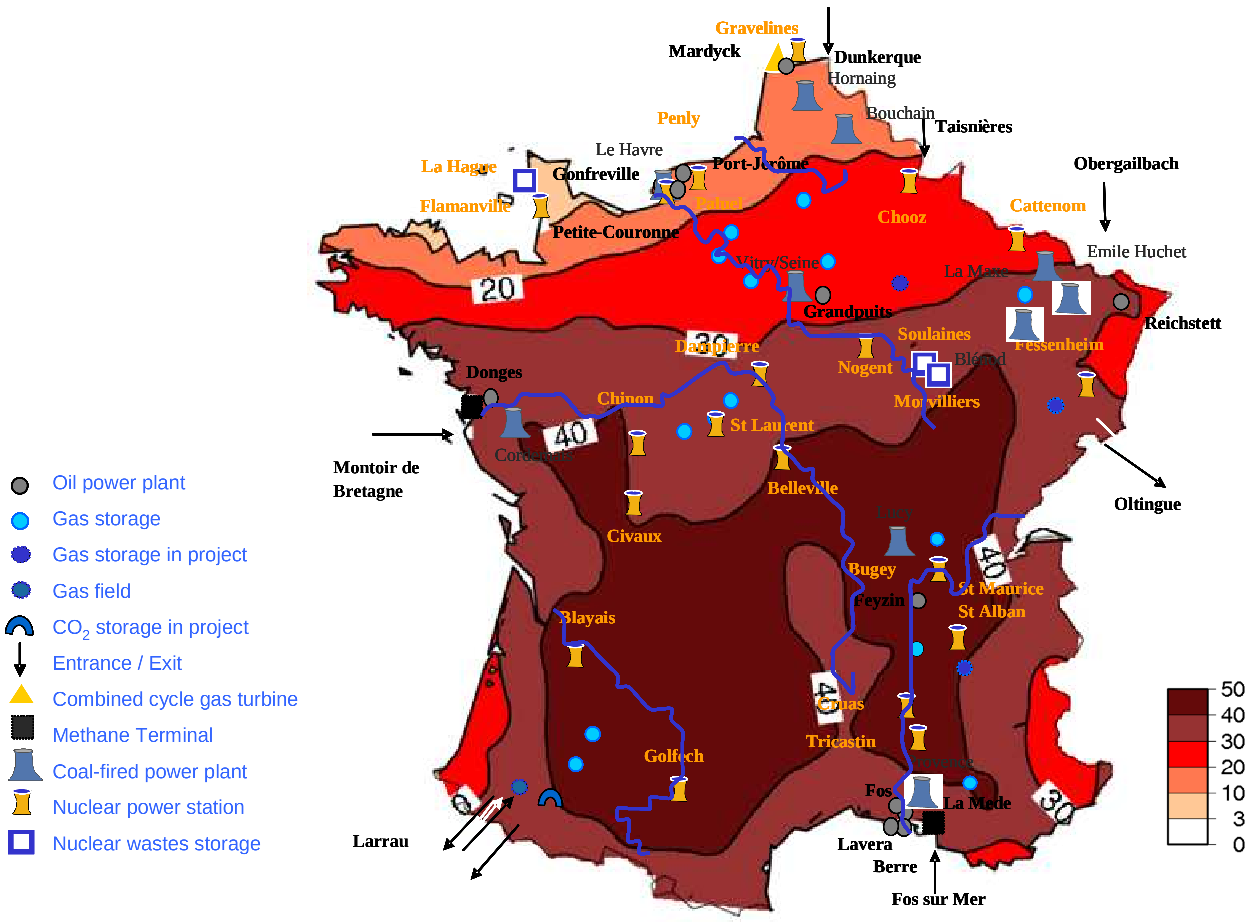
According to the model, rainfall would be slightly higher in winter and markedly reduced in summer. Rainfall over the year as a whole would also diminish, but only by a small percentage. These results are more pronounced if we consider IPCC scenario A2. As discussed in Greenpeace-Climpact (2005), rainfall changes will vary across the different regions of France. New rainfall patterns will change water availability and thus hydroelectric production capacity.

3.2. Vulnerabilities to Extreme Climate Changes.

In addition to analyzing the gradual changes in climate trends that France may experience, it is also necessary to examine the potential for extreme climate events. These types of events can have serious impacts on socioeconomic infrastructures, and thus must be taken into account in order to construct a complete picture of the vulnerability of the French energy system.

While energy demand will continuously increase due to the progressive increase in the temperatures, the energy sector will also have to face an increase in the number of consumption peaks. These peaks will likely be driven by more frequent, longer and more intense heat waves in France. According to Greenpeace-Climpact (2005), one way to characterize heat waves is to count the number of days when the summer temperature exceeds 35°C. During 1960-1989, the average did not exceed 1 day per summer across France, even though locally it reached around 4 days in the South-East of France. However, the Méteo France and IPSL regional models predict a considerable increase in the number of 35°C+ days during the 2070-2099 period. According to the A2 scenario, the average of the number of days that exceed 35ºC in summer will go roughly from 1 to 14. Scenario B2 predicts an increase from 1 to approximately 7 days. In Figure 6, we show the expected number of heat wave days in 2080 according to scenario A2, along with France’s energy production and storage facilities.

Figure 6: Expected number of heat wave days in 2080 following the scenario A2 and the energy production and storage in France

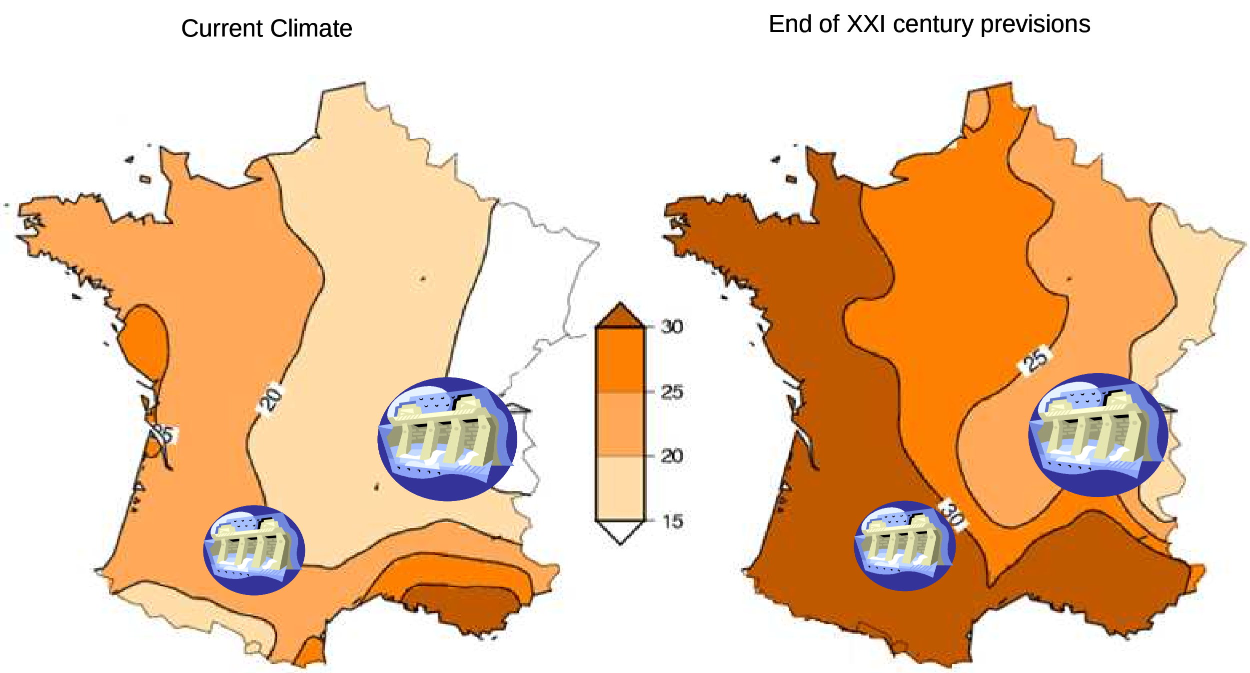


Source: Observatoire de l'énergie and Météo France

Regarding power production, the most important extreme event that the French energy sector could face is an increase in droughts in the south of the country. Decreases in rainfall may have serious impacts on this region, which is where most of the hydroelectric dams are located. Figure 7 shows the current number of consecutive dry days in summer, along with the projections for the end of the 21st century provided by the project IMFREX[11]. We can see that, in the Rhône-Alpes region, the number of consecutive dry days could increase from less than 15 days today to 20 to 25 days by the end of the century. As hydroelectric dams depend on sufficient reservoir levels to provide power, significant decreases in rainfall can reduce electricity production by these facilities.

[11]IMpact des changements anthropiques sur la FRéquence des phénomènes EXtremes de vent, de température et de précipitations. Please see http://imfrex.mediasfrance.org/web/index. to have more information on the IMFREX project.

Figure 7: Maximum number of consecutive dry days in summer (IMFREX, Rapport Final) following the ARPEGE model



Source: Observatoire de l'énergie and IMFREX, Final Report.

Regarding the risk of storms, the Greenpeace-Climpact (2005) simulations do not reveal any significant variation in their number or intensity. Thus, storms are unlikely to have a changing impact on the electricity grid.

4. Adaptation Solutions to energy infrastructures

Now that we have analyzed the vulnerabilities of the French energy system, we will study the adaptation options open to players in the energy sector and policy makers as well. According to the 4th Assessment Report of the IPCC, adaptive capacity is "*the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences*".

While the main objective of adaptation solutions is to ensure the security of people and assets, in the case of the energy system, the primary objective is to guarantee the supply of electricity by maintaining a permanent equilibrium between production and consumption throughout time and space. Furthermore, increasing socioeconomic dependence on electricity obligates electricity suppliers to reduce the frequency and the duration of the interruptions of electricity provision.

However, before focusing on the variety of adaptation possibilities available to energy infrastructures in France, we would like to remind the reader that one of the biggest difficulties in adapting to climate change is the uncertainty regarding climate change impacts at the local and regional level. This uncertainty complicates the standardization of adaptation measures and makes choosing between them difficult. When deciding between adaptation projects, especially those that require investments in protective infrastructure investments projects, one should be sure to build in some flexibility that will prevent pure losses in the case that a climate event does not occur as predicted.

4.1. Panorama of adaptation possibilities for the energy infrastructures in France

A number of typologies have been developed to classify adaptation strategies. According to OCDE (2008) and Tol (2005), one can differentiate between *anticipatory* versus *reactive* adaptation, *local* versus *regional* adaptation, *short term* versus *long term* adaptation, and *autonomous* versus *planned* adaptation, among others.

However, for the purposes of this paper, we will focus on two different adaptation approaches as they particularly relate to energy infrastructures: (1) adaptation by means of protective infrastructures designed to mitigate the potential harm to energy installations and (2) adaptation by means of modifications to the energy infrastructures themselves. In this section we will consider the advantages and disadvantages of both types of adaptation approaches.

The goal of a protective adaptation strategy is to physically protect the energy infrastructure of the damages that may be caused by climate change extreme events. These types of adaptation measures, known as *hard adaptation* measures, are often extremely costly, and include the construction of dykes and dams. While a protective strategy may be used to protect the electricity production centers, it is of little use in protecting the power grid.

The second type of adaptation strategy involves adapting existing energy infrastructures themselves to cope with climate changes. This type of strategy is known as *soft adaptation:* its objective is to directly manage the risk and the specific impacts of climate change developing without any additional infrastructure. Those types of adaptation measures are less expensive in terms of fixed costs and are often more flexible than hard adaptation strategies. A good example of this sort of adaptation is the elaboration of a climate action plan which might predict the necessary changes that should be made, anticipate the climate hazard, and inform players on how to manage a crisis.

As we have seen the French power supply is mostly assured by the production of nuclear electricity. Consequently, it would be increasingly important to make the production installations less sensitive to increases of air and water temperature (throughout, for example, the installation of mobile ventilation and refrigeration systems), make the power grid less sensitive to climate aggressions (throughout burying or cable re-rating for example) or promoting the management of the energetic demand. Those are some of the aspects that have to be taken into account during the first phase of the plan. The second phase consists in anticipating the arrival of a climate hazard. This may be done through the development of meteorological prevision tools inside the energy company or improving the relationship with the national meteorological centre. Then the information about the energy demand management and about the risks of power outages has to be sent to the clients, the national and local authorities, among others, which are the most concerned. Finally, when the climate hazard takes place, we should be ready in advance to manage the crisis.

An interesting concept is the *no-regret adaptation* measures. Following Hallegatte (2008), *no-regret adaptation* measures are characterized by the fact that the decision will not be regretted even in the case where the risk does not materialize. The reason is that this type of measures produces other benefits that do not depend on the underlying risk. Due principally to the uncertainty concerning the prediction of future climate conditions commented before, in order to face climate change it will be extremely interesting to find this type of adaptation options.

Concerning the energy sectors the *no-regret* measures *par excellence* are the set of actions that promote the energy efficiency. On the one hand, with this actions we will contribute to manage the electricity demand, which, as we have seen, is an adaptation measure, and on the other hand, we are contributing to mitigate the CO_2 emissions and thus, to reduce the greenhouse effect. With *no-regret* measures, even if there is no climate hazard that requires a reduction of the energy demand, the environment will benefit of the emission reduction already undertaken.

Additionally, the energy efficiency measures can even be financially rewarded using the European Union Emissions Trading Scheme (EU ETS). The EU ETS is the main European carbon mitigation policy. It is a cap-and-trade mechanism where some 11,000 intensive carbon emitting installations have the possibility to trade their allowances (emissions rights that correspond to a ton of CO_2). In case a participant in the scheme is able to reduce its carbon emissions beyond required, he is entitled to sell carbon allowances in excess hence generating revenues. These emission reductions can be achieved notably by means of energy efficiency, which is one of most cost-effective mitigation options.

4.2. Financing Adaptation Actions

We have explored a broad range of adaptation measures that the French energy sector can undertake in order to adapt to climate change. We will now discuss some possibilities for financing these efforts.

Adaptation financing may be provided by both the private and the public sector (Mendelsohn, 2006). Some of the adaptation possibilities present the characteristics of a public good and thus should be financed by the public sector. For other measures, the private sector will be the most suitable actor, as it is better adapted to act independently in response to economic stimuli. In addition, Public Private Partnerships (PPPs) may be necessary to address the extremely high cost of some of the adaptation measures and to reach objectives that are in the common interest. In the specific case of the energy sector, the financing of the adaptation measures is in general mostly assured by the private sector, at least in regard to *soft adaptation* measures.

It is important to emphasize that public investment in adaptation measures acts as a guarantee and proof of credibility which in turn stimulates private investment. Public action should lead to the production and dissemination of credible, independent information that enables private actors to make better decisions. It should also allow risks and costs of climate change to be shared at a national level, so that the affected regions do not carry the burden alone.

When deciding on the timeline for undertaking adaptation measures, one must take into account the problem of uncertainty related to the real impacts of climate change. According to the OECD (2008), we should take three factors into account in determining which adaptation measures should be undertaken and financed first:

- The difference between the adaptation costs over time (the effects of discounting),
- The short term profits of adaptation (which are called the win-win measures),
- The long term profits of adaptation.

All these factors depend on the projections of climate change impacts and the real impacts that will occur in the future. Thus, a misperception of the risk associated with different climate scenarios may lead to inefficient ordering of the adaptation measures.

Lastly, in funding adaptation measures it is necessary to use financial tools that take into account the uncertainty of climate impacts. The mobilization of real options analytic tools can help, as these techniques take into account the uncertainty of future impacts through the potential distribution of a risk rather than a single expected future value. They also enable the timing of the investment decision to be optimized according to the information available. This is especially important in the adaptation of infrastructures that have (i) long life cycles, (ii) operational rigidity, (iii) very high initial investment costs for relatively uncertain returns that are distant in time, and (iv) major effects on human activities. This is the case of the energy infrastructures, which may find these types of tools useful in adapting to climate change.

5. Summary and Concluding Remarks

Studies carried out in the United Kingdom and Ireland regarding the impact of climate change on the energy sector identify three types of important changes (i) there will be additional constraints on classic production facilities (cooling systems, physical resistance of systems to climatic events) but also new opportunities for renewable energies, (ii) we will find additional constraints on transmission systems, and (iii) there will be some important modifications of the seasonal demand on electricity with a tendency to smooth out demand in winter but accentuate the demand spikes in summer. Even if the regional climate change expected in France is not the same as the one expected in the United Kingdom or in Ireland, the results of those studies offer an idea may be the expected impacts of different climate conditions.

In France, the map of these various facilities shows three important parameters: (i) the proximity to waterways of the energy system, with a high density of production and transmission facilities in the Rhône corridor and in the valley of the Seine, (ii) the proximity to large ports with four clusters around Marseille, Le Havre, Dunkerque and Nantes, (iii) special density of hydroelectric installations in the country's two large mountain ranges.

Overlaying the energy installations map on those of the anticipated climate change impacts presented in Greenpeace-Climpact (2005) we realize that there are very different expected effects on the major energy-producing concentrations. There is a high exposure of the Fos industrial centers and the Rhône corridor to temperatures higher than the average expected level of warming and to serious water deficiency, while the industrial centers in the Seine valley and of Dunkerque are exposed to higher rainfall levels. The management of the energy infrastructures situated in those two different regions should be adapted to the expected regional climate change.

A major consequence of higher temperatures will be the change in energy consumption patterns. An increase in energy consumption in summer is expected due principally to the increased demand for air-conditioning and industrial refrigeration but there will be a decrease of energy consumption in winter (reduced demand for heating). Thus, energy producers should be able to handle heavy peak loads and produce more electricity in summer, in line with the development of air-conditioning.

In what concerns the adaptation measures, we have seen that there are two main strategies to face the negative climate change impacts on energy infrastructures. On the one hand, it is possible to protect them using hard infrastructures and on the other hand, we may afford the adaptation of the energy infrastructures themselves. However the most important idea to underline is that the uncertainty related to the local effects of climate change is a factor not to be overlooked that makes difficult the decision on the adaptation actions. Thus, the maximum flexibility to the adaptation actions should be favored.

Finally, it should be borne in mind that, in general, the money allocated to adaptation measures cannot be available for financing greenhouse gas emissions reduction measures and thus there is a high opportunity cost (Tol, 2005). Consequently, it is essential to fight climate change on the two fronts simultaneously: emissions reduction (the greater the emissions reduction, the less radical the adaptation measures called for) and adaptation measures (that demand less by way of emissions reduction).

6. References

Greenpeace and Climpact, 2005. “Changements climatiques : quels impacts en France?”. http://www.greenpeace.org/france/presse/dossiers-documents/impactsclimatiquesenfrance

Hallegatte S., 2007. “Using climate analogues for assessing climate change economic impacts in urban areas”. Climatic Change Volume 82, Number 1-2 (May 2007).

Hallegatte S., 2008. “Adaptation to climate change: Do not count on climate scientists to do your work”. Reg-Markets center, Related Publication 08-01 (Feb. 2008).

IPCC, 2007, Climate Change 2007. Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp.

Mendelsohn R., 2006. "The Role of Markets and Governments in Helping Society Adapt to a Changing Climate", Climatic Change Volume 78, Number 1 (Sept. 2006).

Met Office, 2006. "Climate Change and Energy Management: A scoping study on the impacts of climate change on the UK energy industry". Research report.

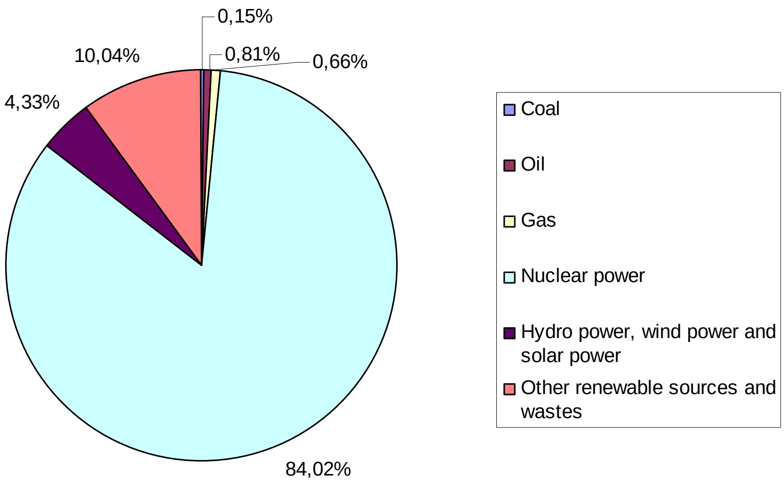
OECD 2008, "Economic Aspects of Adaptation to Climate Change. Costs, Benefits and Policy Instruments". Research Report.

Scotland and Northern Ireland Forum For Environmental Research, 2007. "Preparing for a Changing Climate in Northern Ireland". Research report (Jan. 2007).

Tol R.S.J., 2005. "Adaptation and mitigation: trade-offs in substance and methods", Environmental Science & Policy, Volume 8, Issue 6 (Dec. 2005), Pages 572-578.

Valor, E., Meneu, V. and Caselles, V., 2001. "Daily Air Temperature and Electricity Load in Spain." Journal of Applied Meteorology (Aug. 2001), Pages 1413-1421.

ANNEX 1: Main Primary Energy Produced in France (2007)



Source: Observatoire de l'énergie