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CLIMATE CHANGE VULNERABILITIES AND ADAPTATION POSSIBILITIES FOR TRANSPORT INFRASTRUCTURES IN FRANCE

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The impacts of climate change, while widespread, are inherently confined to specific locations and thus demand that adaptation to changes in climatic conditions occur locally and/or regionally. This paper identifies the risks posed by climate change to transport infrastructures in France, the concerned actors and potential adaptive measures. Ground (round and rail), aviation and internal navigation are taken into consideration. Vulnerabilities to changes in both seasonal and extreme climatic events are assessed using the outputs of two IPCC global climate models (A2 and B2) downscaled to the French territory by MeteoFrance/IPSL to assess potential changes in temperature and precipitation in France. The graphical analysis of the potential impacts of over the French territory serves to elucidate the possible location and extent of impacts.

Paired with an analysis and description of physical and operational impacts for each mode, the paper indicates that a number of infrastructures are potentially at risk and further, more detailed analysis is necessary concerning vintage, construction norms and geographical context. Changes in climatic averages may also lead to changes in transport infrastructure demand stemming from modified tourism flows and from agricultural production. Adaptive measures focus primarily on changes in planning procedures and technical criteria to better adjust new infrastructure to a changing climate as well as the retrofitting and, in certain cases, the protection of existing infrastructures. Equally, it may be necessary to rethink concession-granting and the contracting of transport services and infrastructure maintenance to incentivize adaptive measures. Success in these efforts will depend on the ability of the large number of actors involved in the planning, construction, maintenance and operation of transport infrastructures to develop and implement coherent approaches.

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I. Introduction

Reported in the Fourth report of the Intergovernmental Panel on Climate Change (2007), existing and expected levels of greenhouse gas emissions will result in unavoidable short- to medium-term changes in the climate. As such, while reducing overall greenhouse gas emissions is necessary to limit further changes, it is equally important to develop adaptive measures to reduce negative impacts and, whenever possible, take advantage of positive consequences. Much attention, especially in the transportation field, has been given to the subject of reducing greenhouse gas emissions. Limited analysis has been conducted on how changes in the climate, including increased temperatures, precipitation and variability in extreme weather events, will affect the infrastructures necessary to fill current mobility needs. The purpose of this paper is to fill a perceived gap in the literature by analyzing the risks[1] posed by climate change to passengers and goods transportation infrastructures in France[2]. Due to the difficulties in modeling climate change and the current lack of detailed, high-resolution climate scenarios, this paper attempts to indicate areas for concern and demonstrate the main aspects on which further research is necessary.

The impacts of climate change are directly linked to location: an understanding of impacts to specific infrastructures requires an analysis of a wide range of factors including geographical location, topographical elevation, vintage and specific use and construction characteristics of the infrastructures being studied. Due to data and information constraints, the detailed analysis of specific infrastructures is beyond the scope of this paper. Nevertheless, it is possible to generalize about the potential impacts of changes in climatic averages and extremes through an identification of hazards, vulnerability and adaptive capacity in France.

Climate change impacts will take the form of physical effects on the infrastructures themselves as well as influence their use, operation and management. As, particularly in the transportation sector, a wide range of institutions, companies and individuals are involved in the construction, maintenance and operation of the infrastructures, not to mention the wide range of users and beneficiaries of the services provided, it is equally important to understand how different actors will be, firstly, impacted, and secondly, required to adapt.

Table 1 - Estimated Transport Infrastructure Lifetime in the United States

Mode	*Infrastructure*	*Lifetime*
Surface Transportation	Pavement Bridges Culverts Tunnels Railroad tracks	10-20 years 50-100 years 30-45 years 50-100 years 50 years
Aviation	Runway Pavements Terminals	10 years 40-50 years
Marine	Docks and port terminals Pipelines	40-50 years 100 years

Source: Kahrl et al. (2008).

Passengers and goods transportation infrastructures (including roads, railways, airports, tunnels, bridges, ports and canals) are vital to economic and social development. Constructed through extensive public and private investment, transport networks are not only important to foster trade and the delivery of goods, but also to provide access to basic needs and service (work, medical, education, etc.).

[1] While changes in climatic trends may potentially induce a number of social and economic benefits (longer growing season, etc.), the author focuses on the potential negative risks as proactive action will be necessary to addresses them in a timely fashion.

[2] Energy and communication transportation systems are not addressed in this paper.

Furthermore, the capital-intensive nature and relatively long-life of individual installations means that decisions shaping infrastructure development today will have ramifications from 30 to 50, even as many as 100, years in the future. Table 1 presents the example of the estimated average lifespan of different modes of transportation in the United States: transportation infrastructures tend to represent extremely long-term investments (upwards of 100 years).

Additionally, the emplacement of roads, rail lines, airports and waterways heavily influences urban and regional development pathways. Any interruption of service or redevelopment is costly in terms of both direct and indirect costs stemming from the disruption of normal circulation. These development patterns, once locked into place, make individual components (rail and roadbeds, etc.) difficult to modify or retrofit and can become lynchpins ensuring the efficient operation of an entire network.

Given their relative importance to human society and the timescales over which infrastructure choices operate, it is essential to answer three fundamental questions for their continued well functioning: (i) what influence will climate change have on the short- and long-term viability, (ii) what measures should be taken today to deal more effectively with tomorrow's conditions both in operations and investment choices, (iii) how will climate change influence long term mobility flows and trends?

While a number of studies have been conducted in North America and Oceania, few European countries have conducted evaluations of national and sub-national transport infrastructures, with no comprehensive study yet conducted in France (see Annex 1 for a detailed review of the existing literature). Responding to the evident lack of analysis of climate change impacts on transportation infrastructures in France, the paper is organized as follows. In section one, the primary French transportation infrastructure networks will be analyzed to better understand the vulnerability stemming from the configuration of actors and the scope of each sector. This will include an analysis of ground (rail and road), maritime (ports and canals) and aviation. In section two, the vulnerabilities of these networks to climatic changes will be assessed using a mapping method developed in-house (Mansanet *et al* 2008). As the potential impacts of climate change must be considered at a regional scale,[3] the results from two French regional climate models will be used to make this assessment. The Météo France's Centre National de Recherches Météorologiques (CNRM) model and the Institut Pierre-Simon Laplace (IPSL)[4] model have downscaled the widely used IPCC A2 and B2 emissions scenarios to the scale of the French territory.[5] Section three will briefly discuss the potential adaptive measures with an emphasis on the concerned actors. The paper concludes with a summary of our main findings.

II. French Transportation Networks

Taken as a whole in 2007, transport networks in France were used for the transportation of over 881.1 billion passenger-kilometers and over 366 billion ton-kilometers.[6] (MEEDDAT, 2007:7-8). With a combined estimate of 18.3 billion euros in investment alone in 2007, these networks represent an important long-term capital investment (MEEDDAT, 2007:98).

For the purposes of this paper, the transportation infrastructures considered are divided into three primary categories: ground (road and rail), water (inland and maritime) and air (aviation). Transportation can further be divided within each mode between the transportation of passengers and goods with in many cases shared material infrastructures.

[3] 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).

[4] Presented in Climpact (2005).

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

[6] A passenger-kilometre (pkm) is the product of the distance a vehicle travels times the number of occupants. A tonne-kilometre is a similar measure used for freight and is the product of the distance a vehicle travels times the tonnage.

Table 2 - Transport Infrastructures in France: Length, Domestic Use & Actors in 2007

Mode	Length/Scope*	Usage: Passenger billion pass.-km	Usage: Passenger %	Usage: Freight billion ton-km	Usage: Freight %	Administrative Actors
Road Network	1 027 000 km	762.6	87%	323.3	87%	Direction Générale des Routes, DSCR, Departmental and local actors
Rail Network	29 213 km	105.3	12%	42.7	11%	Réseau Ferré de France, SNCF, RATP, Local Organizing Authorities (Autorité Organisatrice de transports - AO)
Inland Navigation	5 444 km	*NA*	*NA*	7.5	2%	Voies navigables de France (VNF), Compagnie Nationale du Rhône, local actors
Aviation	155 registered airfields	13.2***	1%	*NA*	*NA*	MEEDDAT – Aviation Directorate; Aéroports de Paris (mixed capital); Locally-controlled public companies
Total Excluding Ports†		**881.1**		**373.5**		
Grand Maritime Ports	*7 Grand Ports Maritimes*	NA**		304.4		MEEDDAT – Maritime Directorate

** Only the segments currently in operation are included in these statistics.*

***11.5 million passengers entered internationally through the port of Calais in 2007*

**** 125 million passengers, including domestic and international, passed through French continental airports in 2007*

†Ports have been excluded as complete data was not available.

Source: Mission Climat of Caisse des Dépôts after MEEDDAT/SESP 2008 ; Réseau Ferré de France 2009.

In the following section, each category of transportation infrastructure is described, detailing the length/scope, passenger and freight use and the actors involved in its construction, maintenance and operation.[7] The administrative responsibility for the different transport infrastructures is often fragmented between a large number of actors. As such, coordinating comprehensive and coherent adaptation efforts may prove difficult. Table 2 summarizes the information presented in this section.

A. Ground Transportation

The Road Network

The road network is the largest and fastest-growing transport infrastructure, totaling over 1 million kilometers in 2007. The road system is administratively divided into three categories: national roads, including highways, (20,638 km), departmental roads (377,300 km) and local roads (628,987 km). The network also requires extensive complementary infrastructure systems, including but not limited to, signalization and security equipment, signage, roadway landscaping, and drainage systems.

[7] The data below is from MEEDDAT (2008) unless stated otherwise.

The road network is the most heavily used transport infrastructure fostering in 2007 762.6 billion passenger-km, 87% of national totals, of which 727.8 billion km (83%) stemmed from private vehicles and 34.8 from road-based public transport (4%). The network facilitated the movement of 323.3 billion ton-kilometers of goods, equally representing 87% of national totals.

Administrative responsibility for road infrastructure is distributed across a number of both public and private actors. The national road system is managed primarily by the public sector through the *Direction Générale des Routes* (DGR) and the *Direction de la Sécurité et de la Circulation Routières* (DSCR). Nevertheless, management of a portion of the larger controlled-access highways has been delegated to private companies (approximately 8 000 km of the total 11 000 km). Departmental and local roads are managed publicly by the respective departmental- or municipal-level administrative unit. A number of the major tunnels (Mont Blanc highway and tunnel, Fréjus tunnel) are administered by mixed public-private companies.

The Rail Network

The rail network in France extends for a total of 53,452 km of principal rail lines in operation of which 29,213 km is open to commercial circulation. Of the operating commercial lines, 1,875 km are high-speed (LGV - *Lignes à Grande Vitesse*) with an additional 15,164 km of electrified lines (Réseau Ferré de France, 2009). In addition to the required signalization and security equipment, the high level of electrification of the network requires a system of power lines, electrified rails and power stations to maintain the necessary input of electricity for operation.

In 2007 the rail network was used for over 105.3 billion voyager-kilometers, (12% of national totals), of which 36.1 billion from urban rail systems and 69.2 billion on the principal national network. The network facilitated the movement of 42.7 billion ton-kilometers of goods (11% of national totals) during the same time period.

Institutionally, the national rail network continues to be managed primarily by the French State. In 1997, responsibility for the construction and maintenance of the rail network was separated from the SNCF, the national public rail operator, with the creation of the public company Réseau Ferré de France (RFF). Urban rail systems, with exception of the one in Paris - Ile de France, are managed and operated by local organizing authorities (*Autorité Organisatrice de transports* - AO). In the Paris metropolitan area, the network is managed by the RATP, a public company controlled by the State. Responsibility for rail lines located on autonomous ports has been devolved from the RFF to the ports themselves since 2007.

B. *Water Transportation*

Inland Navigation

The inland navigation system in France, including rivers and canal systems, is composed of 8,501 km of waterways, of which 5,444 km are in consistent use. While the size of the inland navigation network has remained relatively stable since 1980, losing only about 60 km of total length, the length of waterways in operation has been reduced by 1,100 km (from 6,586 km in 1980). This reflects the reduction in use of water transportation in general. The inland navigation network is made up not only of the river and canals, but also the systems of locks, reservoirs, dams and water collection systems that allow to control both the water flow and elevation change across the territory.

In 2007, inland navigation was used only for the transport of 7.5 billion ton-kilometers (2% of national totals), a reduction of 5.1% from the previous year. The portion of freight transported by barge has consistently lost ground over the last decades to road transport. No information is available concerning passenger transport.

The inland navigation network is managed publicly at different levels of government. Voies navigables de France (VNF) is the primary national public entity changed with the maintenance of the national canal and river network open to freight transportation.

The mixed-capital Compagnie Nationale du Rhône (CNR) is responsible for management on the Rhône River, with the remaining canals in the Paris region and those not open to freight transportation maintained by local authorities. The principal 32 river ports are managed by the respective local chambers of commerce and industry. The exceptions are Paris, Strasbourg (as autonomous ports, managed by the central government) and Lyon (managed by CNR).

Maritime Ports

The system of maritime ports in France is divided into a number of categories depending on their size, relative importance and administrative structure. Reclassified in October 2008 as *Grands Ports Maritimes* (previously *ports autonomes*), the seven principal French maritime ports are in decreasing order of commercial flows: Marseille, Le Havre, Dunkerque, Nantes-Saint-Nazaire, Rouen, Bordeaux, and La Rochelle. There are additionally 12 other important ports of varying size, the most important of which is the Port of Calais. A number of ports of national interest (3 principal) are located in the French overseas territories (DOM-TOMs, for *Départements d'Outre-Mer* and *Territoires d'Outre-Mer*). Port infrastructure includes, but is not limited to, the unloading and loading infrastructure (docks, piers, cranes, container equipment) as well as protective structures (jetties, etc.). An equally important part of the shipping infrastructure is the interchange hubs between maritime and ground transport networks.

The seven *Grands Ports Maritimes* alone handled over 80% of water-based commerce traffic in and out of the mainland territory, or 304.4 million tons in 2007. The 12 smaller principal ports were the site of the import and export of over 72.5 million tons. In terms of passenger traffic, in 2007 the Port of Calais alone saw 11.5 million entries and departures from the French territory (Port de Calais, 2009) and the Port of Marseille reporting 2.04 million passengers in 2007 (Port de Marseille, 2007).

The seven *Grands Ports Maritimes* are currently under the direct control of the central government, although their change in status in 2008 is part of a movement towards their concession for operation to private companies. The 12 smaller ports are under the administrative control of the corresponding local authority. The three principal ports of national interest in the DOM-TOMs[8] are under the control of the central government, but administered locally by the respective chamber of commerce and industry.

C. Air Transportation

Air transportation is a continually growing sector in France, increasing in the total number of passengers by 6.2% in 2007. With over 450 airfields, 155 of which are registered with the Union of French Airports (*Union des Aéroports Français*), France has an extensive international and domestic flight network. Airport infrastructure consists of fueling and maintenance facilities, passenger terminals, tarmacs and runways as well as navigation equipment (lights, radar towers, etc.).

The ten principal airports in order of passenger flows in 2007 are Paris-Charles de Gaulle, Paris-Orly, Nice-Côte d'Azur, Lyon Saint-Exupéry, Marseille-Provence, Toulouse Blagnac, Bâle-Mulhouse, Bordeaux Mérignac, Nantes-Atlantique and Beauvais Tillé. In 2007, over 125 million passengers used the airport transportation network throughout the territory (including the DOM-TOMs). The majority of air traffic occurs in Ile de France: in 2007 Paris-Charles de Gaulle and Paris-Orly airports accounted for just under 60% of total air passenger traffic (not including transit) on continental territory. No data is available concerning airfreight transport.

Until 2005, the French airport infrastructure was entirely managed by the public sector. In that year, the company Aéroports de Paris (ADP), charged with the management of both Paris-Charles de Gaulle and Paris-Orly, was opened to private capital and listed in the stock exchange. Nevertheless, the central government is legally required to remain the controlling shareholder.

[8] The DOM-TOMs are the French overseas departments and territories, including Guadeloupe, Réunion, French Guiana, French Polynesia, Martinique, Mayotte, New Caledonia, Saint Barthélemy, Saint Martin, Saint Pierre and Miquelon, and Wallis and Futuna.

Since 2007, through the process of decentralization, local administrations have the right to create locally-controlled public companies to oversee the management of other principal airports, as has occurred most notably in Lyon, Bordeaux and Toulouse. The remaining airports are under the administrative control of the local chamber of commerce and industry.

III. VULNERABILITIES OF THE FRENCH TRANSPORT SYSTEM TO CHANGING CLIMATE CONDITIONS

Framing climate change as a risk management problem allows an approach that breaks the issue down into three principle elements: hazards, vulnerability and adaptive capacity (Mehrotra *et al*., 2009:8-9).

Hazards are the climate-induced forcing, such as heat waves and storms, which will lead to physical and operational impacts on infrastructures. Their configuration, strength and frequency depend on changes in climatic averages.

The *vulnerability* of a given system, in this case transportation infrastructures, is the physical attributes and socio-economic conditions that determine susceptibility to changes in climate.[9]

Adaptive capacity is a function of the ability and willingness of those involved in infrastructure and service provision to adapt.

Figure 1 presents the configuration of these different elements.

Figure 1 - General Framework for Climate Risk Assessment

Source: Mehrotra et al., 2009.

This section of the study will assess the vulnerabilities of the French transportation infrastructure network (as described above) to the potential climate change impacts, drawing on Climpact's 2005 report, "Changements Climatiques: Quels Impacts en France?" and the IMFREX[10] (2007) project modeling work. As discussed earlier, increased greenhouse gas concentrations will affect both average climatic trends as well as the frequency and intensity of extreme weather events.

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[9] The 4th assessment report of the IPCC (2007), defines vulnerability as "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 systems is exposed, its sensitivity, and its adaptive capacity"

[10] IMFREX (IMpact des changements anthropiques sur la FRéquence des phénomènes EXtrêmes de vent, de température et de précipitations) is a joint project between Meteo-France, IPSL among others.

The analysis will take into consideration both aspects, differentiating the effects on physical infrastructures and operations. Like Climpact (2005), the analysis will be based on predictions stemming from the A2 and B2 scenarios[11] laid out in the IPCC's Fourth Assessment Report. Regional modeling performed by Météo France and IPSL have downscaled these scenarios to the French metropolitan territory.[12]

A. Increased Vulnerability to Average and Extreme Climatic Conditions

A number of global, national, and regional studies[13] have begun to outline the physical impacts expected to transport infrastructures as a result of changes in climatic averages (sea level rise, temperature, precipitation, humidity, freeze-thaw cycles etc.). As to be expected, the range and relative intensity of changes to climatic averages depends greatly on location and contextual characteristics as well as the type of infrastructure in question (road, rail, maritime, etc.). Transportation infrastructures appear to be more susceptible to changes in climate extremes rather than averages. As noted by Peterson for the US context, "…sensitivity is less to the mean weather conditions than to extremes… Therefore, climate variability and changes mainly impact transportation through changes in extreme conditions" (2006:1). Increases in the frequency and intensity of extreme weather events will have a wide range of negative impacts on transport infrastructures. It is nevertheless important to identify those regions and infrastructures that will potentially be at high risk from changes in average temperature and precipitation. This section explores the potential impacts of changes in temperature trends and extremes.

Mean Temperature 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 2°C to 3.5°C from 1960-1989 levels. As shown in Table 3, Scenario B2 modeling shows a potential increase of 2°C by 2070-2099. Scenario A2 modeling shows an even greater increase in annual average temperature, from 3°C to 3.5°C.

Table 3 - Expected average increase in temperatures in France 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: Climpact (2005).

In both scenarios, warming would be greater in summer than in winter. As pointed out by Climpact (2005), even if the increases in average temperature may seem moderate, they should be compared to the existing average temperature variations in France: all things being equal, a change in latitude of 200 km results in a 1°C change in temperature today (Mansanet *et al.,* 2008). The A2 model[14] for example shows that variations in warming in France may exceed 3°C from one region to another.

[11] The A2 scenario is based on a heterogeneous world with regionally-concentrated economic development, continued population growth and comparatively slow low-emission technology development. The B2 scenario is based on a world with an accent on local economic, social and environmental solutions, population growth is slower than in the A2 scenario, with moderate, but diverse, low-emission technology development.

[12] While Port vulnerability to sea level rise is not evaluated here due to a lack of data, it is included in the table in Annex 2 summarizing the potential physical and operational impacts due to climate change.

[13] See Koetse & Rietveld, 2009; TRB, 2008; USCCSP, 2008; Natural Resources Canada, 2008; Government of Victoria, 2007.

[14] For sake of brevity, we have only considered here the case of the scenario A2. This scenario shows a wider range of climate events among French regions.

The greatest increases (up to 5°C) should occur in the Central-West area. Thus, the management of transportation infrastructures will not be the same in all regions of France.

As observed in the literature, changes in temperature averages and extremes will lead primarily to increases in temperature-related wear-and-tear of infrastructures. Equally, increased temperatures can potentially lead to operational impacts, ranging from the well-functioning of the rail network due to thermal expansion to the ability of airplanes to function properly in high temperatures. A range of indirect impacts are also possible, from changes in driver behavior (heat stress) due to high temperatures to decreased visibility for all modes due to increased forest fire activity (Koetse & Rietveld, 2008).

Figures 2 to 5 present the localization of current transportation infrastructures[15] and their exposure to changes in temperature averages and extremes between 2070 and 2099. Impacts will vary across regions and different transport networks will be impacted in different ways. Tables 4 to 8 summarize the potential impact of changes in temperature averages as described in the literature[16]. The analysis presented below should be taken only as indicative as there is still significant uncertainty concerning the changes in temperature trends. Equally, technical specifications of infrastructures already vary greatly across the territory making predictions difficult without further information. For example, while similar methods are used in terms of road-bed construction throughout France, the type of pavement used varies between regions.

Rail Infrastructures

As seen in Figure 2, a relatively large portion of the French rail infrastructure, including both high-speed and conventional rail lines, will be in zones affected by changes in temperature averages and extremes.

As outlined in Table 4, changes in temperatures can cause rails to expand and buckle, leading to rail track movement.

Beyond the cost of repairing these physical damages, this can have a number of operational impacts including, but not limited to, slower operating speeds, decreased payload capacity and the potential for complete interruption of service. The heat wave in 2003 provided a good example of what may happen in such cases. It led to a number of disruptions in the normal operations of the SNCF. In addition to extreme discomfort due to overheated passenger cars, the expansion and buckling of rail lines led to frequent and significant delays. During this period the SNCF recorded a reduction in the regularity of trains by 10 points to 77% from 85-87% recorded during the same period in 2001 and 2002. Beyond the uncounted indirect economic impacts, this led to losses between 1 to 3 million euros in relation to its commitment to refundable, guaranteed on time arrival. (Létard, 2004). While it has been suggested that the rail technology used in the construction of *Lignes à Grande Vitesse* (LGVs) is less prone to heat-induced buckling, it is unknown to what extreme temperatures this remains true. Further, beyond direct impacts, in certain areas, the climatic changes described above can increase the probability of wild fires and trees falls, leading to both physical damages as well as a number of operational disruptions.

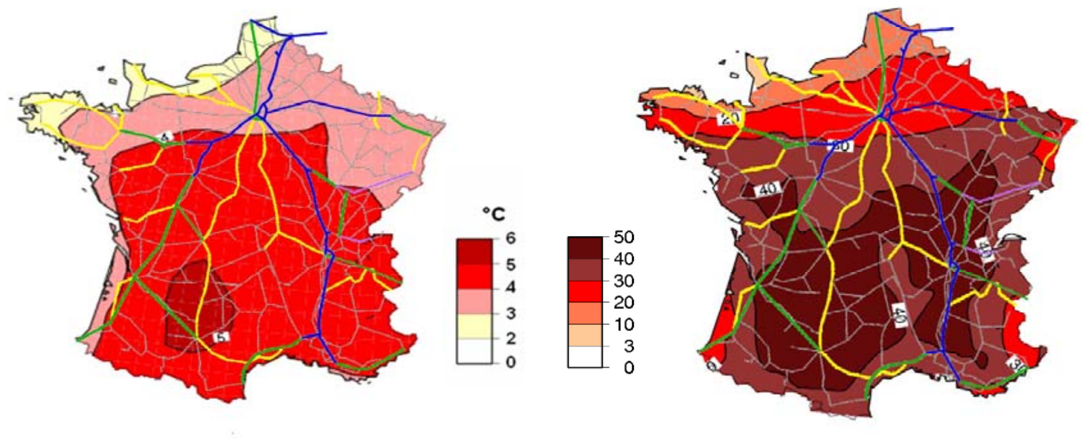
As can be seen, rail infrastructure is concentrated in a small number of corridors, with connections or nodes concentrated in a number of urban areas (Paris, Bordeaux, Toulouse, Lyon, and Avignon). As indicated by our analysis, two of the principal corridors (Rhone valley and the Italy-Spain linkages passing along the southern coast) appear to lie in arrears that will potentially experience significant changes in temperature.

[15] Maritime ports have not been analysed here due to insufficient data on their elevation and exposure to sea level rise.

[16] Assessing the impacts in France from changes in average temperature and upper temperature extremes depend on the climatic norms to which the infrastructures have been constructed, information that was not available for this study.

Figure 2 – Current Rail infrastructures and summer climate predictions for the period 2070-2099 considering the A2 scenario

Increase in average summer temperature	Increase in mean heat wave duration (days) from 1960-1989 average*



Conventional Line	*Operational LGV*	*LGV In Construction*	*Potential LGV Lines*

**Change in mean heat wave duration (number of days per period where, in an interval of at least six consecutive days, the temperature passes beyond the 1960-1989 mean of a five day window centred on the same calendar day by more than 5°C) between the decadal periods of 2100 and the 1960-1989 period.*

Source: Mission Climat of Caisse des Dépôts after Climpact (2005); RFF (2009).

Table 4 - Potential Impacts of Changes in Temperature on Rail Infrastructures

Physical Risks	Climatic Variable	Operations Impacts
Rail track movement	Increased temperature and heatwaves Decrease in available moisture	Slower operating speeds Decreased payload capacity Increased monitoring of rail temperatures Increased maintenance
Fire damage to rail infrastructure	Decrease in variation in wet/dry spells Decrease in available moisture	Decreased visibility

Source: Mission Climat of Caisse des Dépots, after CSIRO 2007, Natural Resources Canada 2008, USCCS 2008, TSB 2008.

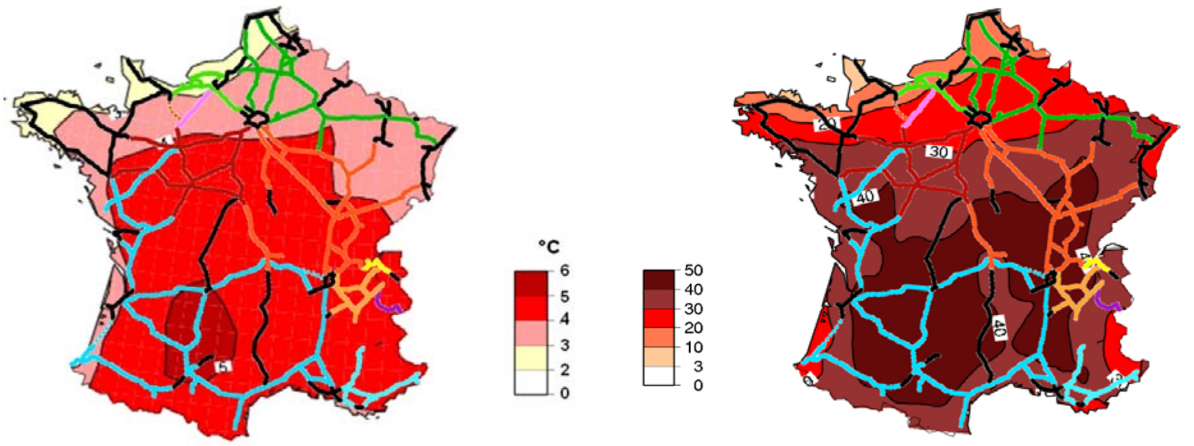
Road Infrastructures

As seen in Figure 3, a significant portion of the road infrastructure is located in zones where increases in average temperature and extreme temperature event frequency are probable. Changes in average temperature can lead to the physical effects of asphalt degradation, road foundation degradation (due to decrease soil moisture content) as well as increased damage from wild fires.

This can lead to a wide variety of operational impacts, including slower speeds, limitation on construction periods, negative impacts of vehicles as well as decreased visibility in the case of wild fires. Equally, research concerning the impacts of temperature on driver behavior indicates an increase in the risk of an accident related to increased heat-stress conditions (Stern & Zehavi, 1990 *as citied in* Koetse & Rietveld, 2009:213).

Figure 3 – Current Primary Controlled-Access Highways and Summer Climate Predictions for the period 2070-2099 considering the A2 scenario*

Increase in average summer temperature	Increase in mean heat wave duration (days) from 1960-1989 average**



** Different colors represent different concession companies operating the infrastructures with non-concessioned sections in black.*

*** Change in mean heat wave duration (number of days per period where, in an interval of at least six consecutive days, the temperature passes beyond the 1960-1989 mean of a five day window centred on the same calendar day by more than 5°C) between the decadal periods of 2100 and the 1960-1989 period.*

Source: Mission Climat based on Climpact (2005); MEEDDAT (2009).

Table 5 - Potential Impacts of Changes in Temperature on Road Infrastructures

Physical Risks	Climatic Variable	Operations Impacts
Asphalt degradation (rutting, buckling)	Increased solar radiation Increased temperature and heat waves Increased freeze-thaw cycles (mild winters)	Slower operating speeds Increased maintenance Limitations on periods of construction
Road foundation degradation	Increased variation in wet/dry spells Decrease in available moisture Sea level rise	Vehicle overheating and tire deterioration
Fire damage to road infrastructure	Decrease in variation in wet/dry spells Decrease in available moisture	Decreased visibility
Changes in landscaping and road-side vegetation	Changes in precipitation Changes in temperature	

Source: Mission Climat of Caisse des Dépots, after CSIRO 2007, Natural Resources Canada 2008, USCCS 2008, TSB 2008.

Inland Navigation

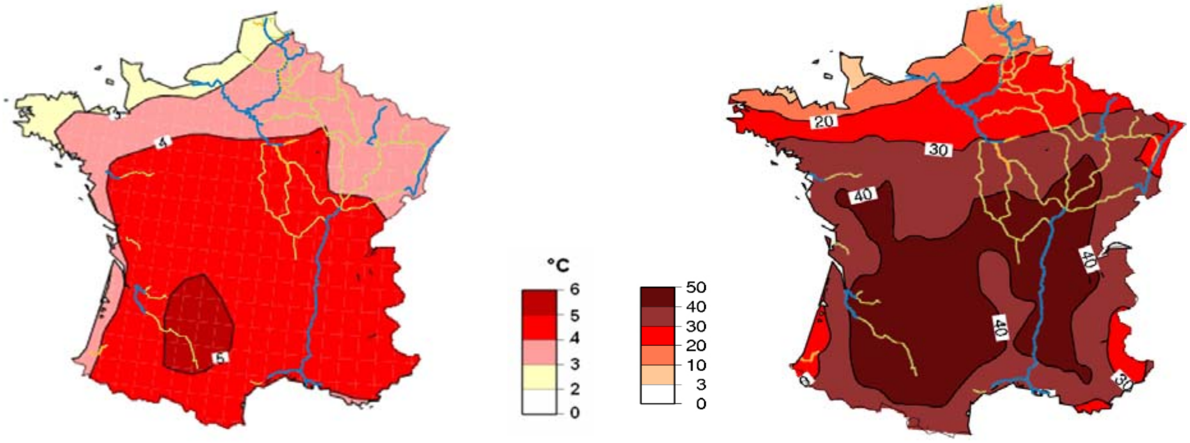
Increases in average temperatures and in the frequency and strength of extreme temperature events hold the potential to reduce the availability of sufficient water supplies for efficient operation of inland waterways. Rivers, such as the Seine and the Rhône, are less likely to experience major reductions in water levels due to evaporation and an increase in the speed of seasonal hydraulic cycles.[17] Canals and other inland navigation channels, however, may be subject to decreasing supplies and increased water-sharing and allocation conflicts from both agricultural and urban demands.

[17] For further information, see the work of J. Boe (2007) on potential changes in river flows, Y. Caballero (2003) for the Garonne, A. Ducharne (2008) for the Seine and B. Manoha (2007) concerning La Loire and Le Rhone.

Increased average temperatures could also lead to increased growth of invasive aquatic vegetation, leading to the clogging of water supply lines and drains as well as increased demand for cleaning, maintenance and dredging.

Figure 4 – Current inland navigation infrastructures and summer climate predictions for the period 2070-2099 considering the A2 scenario

Increase in average summer temperature	Increase in mean heat wave duration (days) from 1960-1989 average*



High capacity (1000-3000 tons)	Medium capacity (400-1000 tons)	Low capacity (250-400 tons)

**Change in mean heat wave duration (number of days per period where, in an interval of at least six consecutive days, the temperature passes beyond the 1960-1989 mean of a five day window centred on the same calendar day by more than 5°C) between the decadal periods of 2100 and the 1960-1989 period.*

Source: Mission Climat based on Climpact (2005); Voies Navigables de France (2009).

Table 6 - Potential Impacts of Changes in Temperature on Inland Navigation Infrastructures

Physical Risks	Climatic Variable	Operations Impacts
Reduced water levels	Decreased rainfall Increased temperatures and heat waves	Decreased payload Water-sharing and allocation conflicts
Increased aquatic vegetation growth	Increase in temperatures	Increased dredging required Clogging of drains, supply lines

Source: Mission Climat of Caisse des Dépots, after CSIRO 2007, Natural Resources Canada 2008, USCCS 2008, TSB 2008.

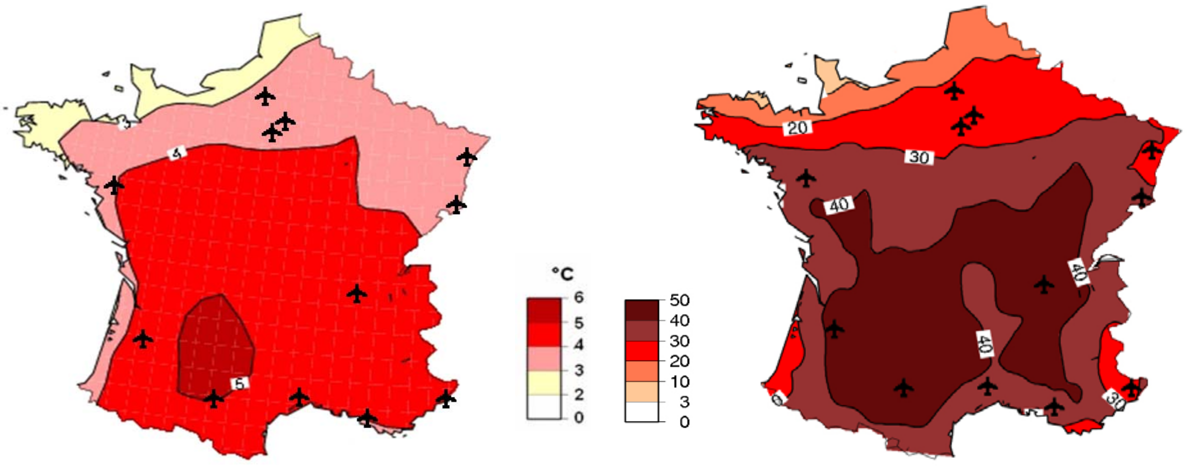
Aviation

While it is expected that aviation technology will evolve to compensate for a reduction of lift and efficiency due to increased temperatures (TRB 2009), a number of impacts are expected on the other components of aviation infrastructures. Similar to the situation of roads, tarmacs and runways may suffer asphalt degradation as well as a degradation of runway foundations due to changes in soil moisture content.[18]

[18] Further, even with improvements in aviation technology, an increase in the strength and frequency of extreme temperature events may result in a loss of engine efficiency.

Figure 5 – Current airport locations and summer climate predictions for the period 2070-2099 considering the A2 scenario

Increase in average summer temperature	Increase in mean heat wave duration (days) from 1960-1989 average*



**Change in mean heat wave duration (number of days per period where, in an interval of at least six consecutive days, the temperature passes beyond the 1960-1989 mean of a five day window centred on the same calendar day by more than 5°C) between the decadal periods of 2100 and the 1960-1989 period.*

Source: Mission Climat based on Climpact (2005).

Table 7 - Potential Impacts of Changes in Temperature on Aviation Infrastructures

Physical Risks	Climatic Variable	Operations Impacts
Asphalt degradation	Increased solar radiation Increased temperature and heat waves	Decreased payload capacity Increased monitoring of runway condition Increased maintenance
Degradation of runway foundations	Increased variation in wet/dry spells Decrease in available moisture	
Loss of engine efficiency	Increased temperature and heat waves	

Source: Mission Climat of Caisse des Dépots, after CSIRO 2007, Natural Resources Canada 2008, USCCS 2008, TSB 2008.

Precipitation Trends

A change in the rainfall pattern will also affect the French transport networks. Table 8 presents the expected average changes in rainfall for the period 2070-2099 with respect to 1960-1989 averages for the B2 and A2 scenarios as simulated by Météo France and IPSL and presented in Climpact (2005).

Table 8 - 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%

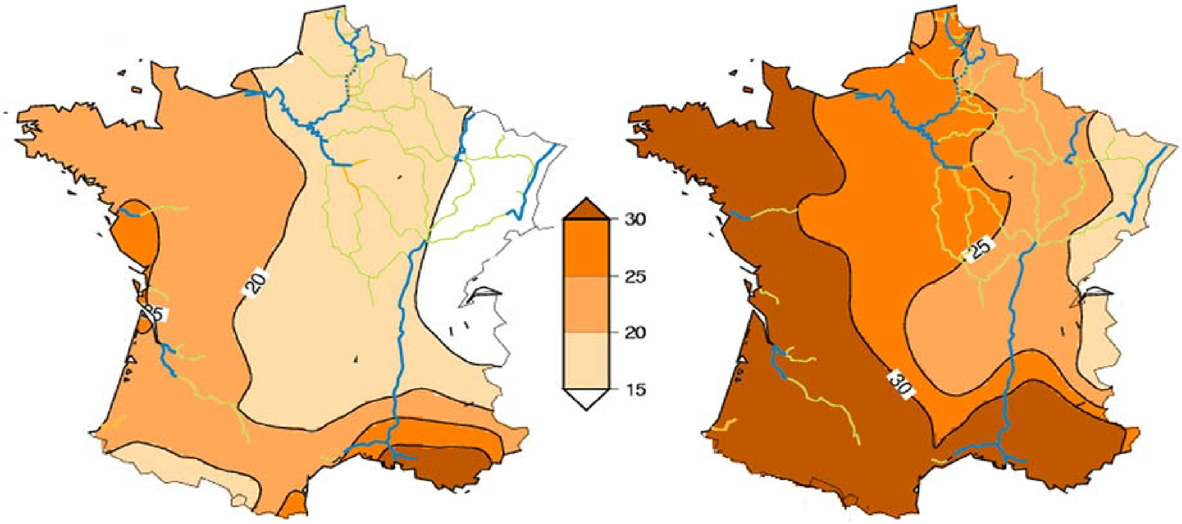
Source: Climpact (2005).

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 Climpact (2005), rainfall changes will vary across the different regions of France. Figures 6-7 present the potential changes in summer and winter precipitation patterns projected at the end of the 21st century using the ARPEGE model.

Figure 6 - Inland navigation waterways and the maximum number of consecutive dry days in summer following the ARPEGE model

Current Climate	End of 21-Century Previsions



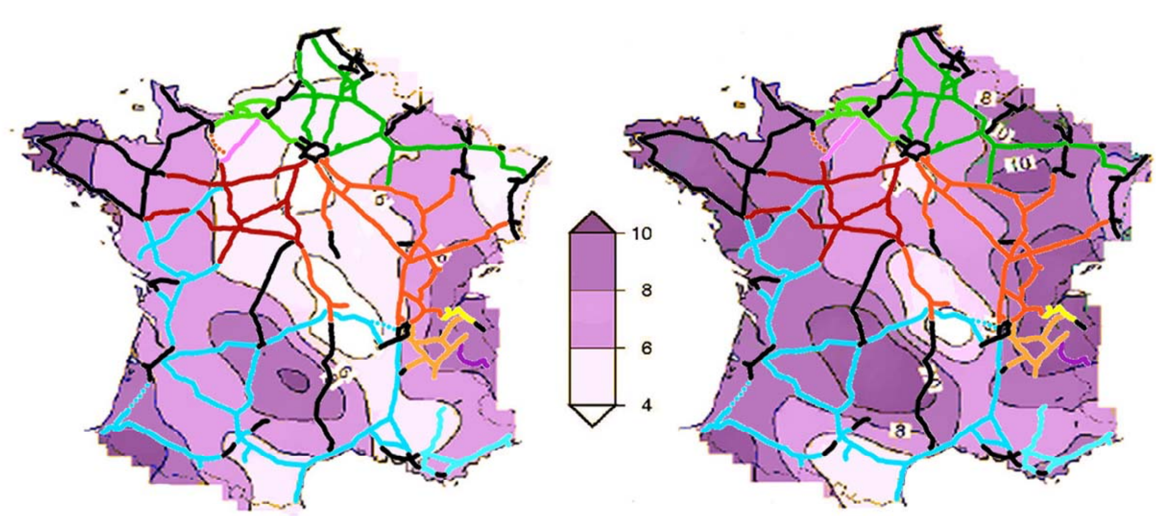
High capacity (1000-3000 tons)	Medium capacity (400-1000 tons)	Low capacity (250-400 tons)

Source: Mission Climat based on IMFREX (2007) ; Voies navigables de France (2009).

As seen in Figure 6, it is expected that there will be an increase in the maximum number of consecutive dry days during the summer months. Decreased summer precipitation could potentially reduce the water available for the well-functioning of inland navigation waterways, leading to reductions in barge capacity and/or disruptions in functioning. A significant portion of the inland navigation network is located within potentially affected regions, mainly located in Southern France.

Figure 7 - Primary controlled access highways and the number of winter days experiencing more than 10mm of precipitation with the ARPEGE model*

Current Climate	End of 21-Century Previsions



**Different colors represent different concession companies operating the infrastructures (non-concessioned sections in black).*

Source: Observatoire de l'énergie and IMFREX (2007) ; MEEDDAT (2009).

As presented in Figure 7, there is an expectation for increased precipitation in winter months in many regions, potentially leading to increased flooding in some areas. Table 9 presents the potential physical and operational risks from increased precipitation. In many regions, flooding already poses a number of difficulties for the efficient operation of transport infrastructures, leading to a number of road closures and costly repairs. Similar impacts could potentially occur to rail and aviation infrastructures. Increases in winter precipitation trends hold the potential to lead to increased maintenance costs and reduced lifespan for infrastructures as well as operational disruptions. Further, unseasonable melting of snow pack holds the potential of increased flood risk.

A study of flooding in the Artois-Picardie basin within which the cities of Amiens and Lille are located (Northern France) indicates the relative extent of damages to transport infrastructures in relation to totals. Total damages from the extensive 2001 flooding of the Somme basin have been estimated at between 140 and 160 million euros. Of this, 55 million stems from damages and operational losses from road infrastructures with 2.3 million in losses from rail infrastructures. This combined transport portion of approximately 60 million euros represented around 40% of all costs (Ecodecision, 2006).

While net annual precipitation may not change substantially, it is not expected that increases in winter precipitation will be able to balance out increases in summer dry periods as winter moisture will come primarily in the form of rain as average yearly temperatures increase and potential decreases in snow pack (IMFREX, 2007).

Table 9 - Potential Impacts of Changes in Precipitation on Road Infrastructures

Physical Risks	Climatic Variable	Operations Impacts
Flood damage to roads (pavements, embankments)	Increase in extreme daily rainfall Increase in frequency and intensity of storms	Slower operating speeds Increased maintenance Limitations on periods of construction Decreased operating times due to flooding
Changes in landscaping and road-side vegetation	Changes in precipitation	Decreased visibility
	Changes in temperature	

Source: Mission Climat of Caisse des Dépots, after: CSIRO 2007, Natural Resources Canada 2008, USCCS 2008, TSB 2008.

B. Vulnerabilities to Changes in Extreme Wind Events Trends

As indicated earlier, changes in greenhouse gas concentrations in the atmosphere will also lead to increases in both the frequency and severity of extreme wind events. Nevertheless, while climate modeling practices have improved greatly, it still remains difficult to predict with any accuracy the localization, strength and frequency of future extreme wind events. Some indicative results are, however, available from the IMFREX modeling work using the ARPEGE and LMDz models. Slight increases are expected in higher wind speeds over the northern half of the country with a slight decrease or no change over the lower half of the country (Planton, 2008:573).

Nevertheless, as seen with the Klaus storm, which struck the southwest of France in January 2009, extreme winds can have major consequences for transport networks. In this case, train service was severely reduced between Bordeaux - Toulouse and in the surrounding area for a number of days due to fallen trees and power losses to signaling and operating equipment (Le Figaro, 2009). While information on the cost to the SNCF and RFF from the storm is not available, 1,500 km of rails were affected, requiring the mobilization of over 1,000 SNCF staff with train service being returned to normal only after one to two weeks (LCI.fr, 2009).

The literature indicates that the costs of infrastructure damages related to sea level rise, flooding and wind-induced storm surge will be substantial, especially when compounded by extreme weather events such as seen in the damages stemming from hurricanes Rita and Katrina (Koetse & Rietveld, 2009:209).

Furthermore, an increase in the number and frequency of storms and extreme winds will have a particularly negative impact on the operation of aviation infrastructures, for which increased wind speeds and/or decreased visibility can cause substantial delays.

C. Implications for the Operation and Use of Transport Infrastructures

In addition to physical degradation, changes in climatic averages may require reduced or altered use as routine operating conditions exceed the range of norms to which systems were constructed. Changes in climate averages and extremes will have a wide range of impacts on the day-to-day operation, the reliability of different transport infrastructures and their capacity to remain in operation during increasingly frequent and intense extreme weather events. Again, extreme events may pose the greatest challenge as increased major events (extreme precipitation, heat, cold or wind) can reduced both the safety and operational capacity of a system, leading to service reductions, reduced operating speeds or complete system failures. Changes in both averages and extremes will likely increase both the frequency and the cost of maintenance.

In addition to the infrastructures related to the operation of specific modes, a number of structures such as bridges and tunnels are susceptible to impacts from changes in temperature and precipitation patterns, presented in Table 10. Work conducted in New Zealand (Kinsella & McGuire, 2006) indicated that bridges and culverts with design lives of over 25 years were not completely protected from the potential impacts of climate change by current policy practice. Their analysis of a policy scenario where no action was taken indicated that up to 711 million NZ$ (320 million euros) in emergency costs up to 2080, not including economic and social losses due to decreased transport service, etc.

Table 10 - Potential Impacts of Changes in Temperature on Other Transport-Related Infrastructures

	Physical Risks	Climatic Variable	Operations Impacts
Bridges	Bridge structural material degradation	Increased temperature and heat waves Increased solar radiation	Increased structural monitoring Increased maintenance
	Storm damage to bridges	Increase in extreme daily rainfall Increase in frequency and intensity of storms Increase in intensity of extreme wind	Decreased operating times due to flooding
Tunnels	Tunnel flooding	Increase in extreme daily rainfall Increase in frequency and intensity of storms Sea level rise	Increased structural monitoring Increased maintenance Decreased operating times due to flooding

Source: Mission Climat of Caisse des Dépots, after CSIRO 2007, Natural Resources Canada 2008, USCCS 2008, TSB 2008.

The table in Annex 2 summarizes the variety of different impacts on the operation of transport infrastructures by type of transport described above. Overall, it is important to note that changes in climatic averages and extremes will potentially reduce system efficiency and performance with important consequences for dependent economic and social activities. Transportation systems are highly susceptible to the network effects of climatic related disruptions, for which an incident affecting a single part can cause widespread disruption, leading to a number of indirect costs stemming from delays, detours and trip cancellations (Koetse & Rietveld, 2009:209).

D. Implications for Transport Infrastructure Demand

The above sections has focused primarily on the supply of transport infrastructure. However, overall mobility demand may also be impacted by climate change and may represent an important factor in the localization and operation of future infrastructure. Changes over time in climatic averages can also influence long-term operational- and user-behavior patterns as major passenger and freight flows change. As reported in the literature, changes in climatic averages will impact a number of economic sectors, including tourism and agriculture, influencing the demand for mobility between regions (Koetse & Rietveld, 2009).

Studies conducted concerning tourist flows in European countries indicate a potential increase in tourist flows towards northern Europe in the summer with part of southern Europe loosing their relative attractiveness. This process is reversed, however, during the spring and winter months, indicating a transfer in seasonal flows (from summer to winter months) for these regions (Nicholls and Amelung, 2008; Amelung and Viner, 2006 as cited in Koetse & Rietveld, 2009). Similar studies have also been conducted concerning changes in travel demand related to winter skiing holidays (*for a summary see* Koetse & Rietveld, 2009). As suggested by the above Figures, changes in summer and winter temperatures could provoke an increase in tourism flows to the Normandy and Bretagne coasts in summer months with increases for the Côte-d'Azur in spring and winter periods.

Koetse & Rietveld also describe the potential changes in freight transport linked to shifts in agricultural production. While the impacts of climate change on different agricultural sections are, for the moment, more uncertain than the impacts on for example the skiing industry, it is expected that at a global scale, countries in the northern longitudes will be better suited for production (Easterling et al., 2007 *as cited in* Koetse & Rietveld, 2009). While the French agricultural production may be modified, changes will occur primarily in the global South where the increase of the temperature (more than 3°C) is supposed to decrease yields (IPCC, 2007) and could yield changes in transportation patterns of these products. These trends, however, can only be estimated at the global level and thus it is difficult to extrapolate specific impacts.

IV. Adaptation of Transport Infrastructures to Climate Change

As seen above, climate change impacts will vary over the French territory and across transport modes. Nevertheless, the purpose of adaptive action is the same: to guarantee the ability of the transport network to meet the demand for accessibility to passenger and freight transportation and to maintain key corridors necessary to ensure basic needs and evacuation in times of crisis. As noted by the Transportation Research Board (TRB) in reference to USA context "The impacts will vary by mode of transportation and region of the country, but they will be widespread and costly in both human and economic terms and will require significant changes in the planning, design, construction, operation, and maintenance of transportation systems" (2008:4). These lessons will most likely hold true for the French example as well.

One of the biggest difficulties in adapting to climate change revolves around the uncertainty regarding climate change impacts at the local and regional level. Equally, even when estimated, there is much difficult in quantifying the economic effects of changes in climatic conditions. This uncertainty complicates the standardization of adaptation measures and demands a certain level of flexibility to adapt to future conditions that are not predictable today. However this uncertainty should not paralyze adaptive action. In concrete terms, this means that both protective measures as well as new systems should be designed and constructed in a way allowing for future modifications if so needed.

A. *Adaptive measures*

As summarized by Mansanet *et* al. (2009), a number of typologies have been developed to classify adaptation strategies. According to the OECD (2008) and Tol (2005), it is possible to differentiate between *anticipatory* versus *reactive* adaptation, *local* versus *regional* adaptation, *short-term* versus *long-term* adaptation, and *autonomous* versus *planned* adaptation, among others. Within all of these frameworks, adaptive measures will need to take two broad forms: actions related to the planning and construction of new infrastructures and, second, the retrofitting and 'climate proofing' of existing systems. These two approaches should be complemented with demand-management policies to result overall network stress. While responses will need to be tailored to specific local contexts, the broad lines of the types of measures and changes in planning procedures that will likely be necessary are outlined below. These approaches are not exclusive to transport infrastructures and can be applied to other sectors.

Changes in planning procedures and technical criteria

One of the most critical steps in adapting infrastructures is the integration of adaptation and mitigation considerations into standards and decision-making. In concrete terms, this will require a review of the cost-benefit decision-making exercises used in infrastructure choice as well as a modification of technical standards and criteria to better match estimates of future climatic conditions. The re-evaluation and modification of planning and technical criteria will potentially influence the scope and placement of future projects, the favoring of more climate-suited modes, as well as adjustments in construction techniques and materials employed to better reflect the demands of a potentially more variable and extreme climatic conditions. More research, however, is necessary to better understand how these criteria and standards are currently established and enforced in order to identify the relevant actors and institutions.

Retrofitting and protecting existing infrastructures

Given the long lifespan of the majority of transport infrastructures, it will be critically important to identify and implement cost-effective means of retrofitting existing network components to more extreme climatic conditions. Retrofitting may also require the construction of protective elements against flooding, etc, and can extend into the reorganization of current operational practices and approaches. While few examples of the retrofitting of transport infrastructures to a changing climate exist, it is likely that this will be an expensive process. The recent retrofitting of the bridges in California to accordance with seismic norms required over 8 billion USD (Karhl & Roland-Holst, 2008:64). While this represents a different type of intervention, it demonstrates the high economic costs of adapting existing structures.

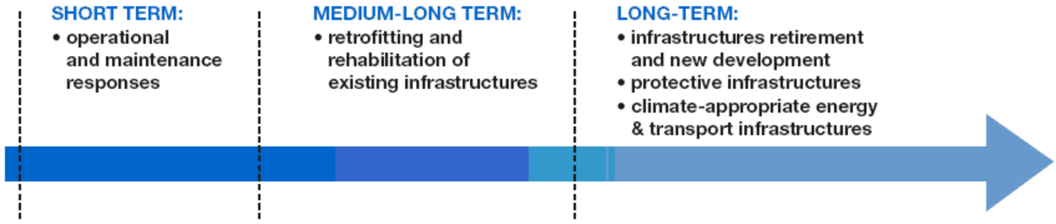
Part of this process will require the identification and prioritization of critical network “nodes” for immediate attention and reinforcement. In many cases, ensuring the robustness of these nodes may require the construction of redundant systems for use in the case of point failures. Thus, the retrofitting of existing and design and construction of new infrastructures will overlap with the need to develop protective redundancies at critical points in the transport networks. This may prove difficult, as new infrastructure development often requires substantial investment that, when channeled into the creation of necessary redundancies may be criticized as unnecessary in a time of budget streamlining and cuts.

Incorporating demand management

While demand-management policies are often associated with mitigation strategies primarily designed to reduce greenhouse gas emissions, it is important to consider them in a coherent adaptation strategy. Firstly, it is important to take into consideration the coherence between adaptation and mitigation strategies. Secondly, reducing the overall strain on infrastructures can help limit the effects of potential disruptions, reducing overall network stress.

Figure 8 presents a general timeline to frame the order within which adaptive measures could be understood.

Figure 8 - Time Horizons for Action



Source: Mission Climat of Caisse des Dépôts.

In the short term, operational and maintenance responses will be necessary to ensure that existing infrastructures are functioning properly within changing climatic conditions. In the medium to long term, a process of retrofitting and the rehabilitation of existing infrastructures is projected, setting the basis for long-term action involving the retirement and development of new infrastructures, either protective or climate-appropriate in nature.

It may also be necessary to adapt and/or create crisis management plans, including replacement modes, secondary itineraries ("itinéraires bis" in France) and temporary network shutdowns, in preparation for the potential increase in frequency and intensity of extreme weather events. The development of "crisis scenarios" for a number of principal transport corridors (Paris area and the Rhone Valley) could serve as a useful exercise to prepare energy responses and evaluate the ability of infrastructure robustness.

B. The Importance of Actors and the Limits on Cohesive Action

In the framework outlined by Mehrotra et al. (2009) for understanding climate risk, assessing the ability and willingness of institutions and involved actors in a sector is an important component in evaluating the adaptive capacity of a system. Table 11 presents the general mix of actors involved in transport infrastructure development and operations. The specific configuration of actors can change significantly from country to country depending particularly on the equilibrium between public and private actors involved. Nevertheless, it is vital to take (i) the range of actors into consideration, (ii) their relative access to resources (technical and financial), (iii) the distribution of impacts and the costs of adaptation, and (iv) the communication between actor groups to better understand the potential and incentives for adaptation.

In France, the transportation sector involves a wide range of actors not only in the construction, financing and operation of infrastructures, but as well in their daily use. Equally, within each category of actor, market share or responsibility can range between a numerous competing firms to a single large national or international actor responsible for the various functions.[19] As such, coordinating action across functions and between actors can prove challenging.

Table 11 - Actors involved in the construction, operation and maintenance of transport infrastructures

Function	Actors*
Financing	Finance institutions; government agencies; financial funds;
Construction	Public authorities; construction firms; consultancy firms; planning firms; regulatory agencies
Maintenance	Operators; subcontractors
Operations	Port authorities; operators of public transport; specialized transport service companies (airlines / train-lines);

** Actors are not designated here as private or public entities as there is usually a mix of each involved*

Source: Mission Climat of Caisse des Dépôts.

In addition to the actors presented in Table 11, an equally important group of actors are the users of the different transport infrastructures, a group that cuts across all economic and social divisions within a given country (although access to different modes is far from homogeneous). Given their necessity to the well-being and functioning of both the economy and society in general, transportation infrastructures often take on the character of a public good. Reiken *et al.* note that "since transport infrastructure often has the character of a public good, incentives for those actors that have the means to prepare transport systems for future climate change are likely to be insufficient to account costs for actors that are directly or indirectly affected by impacts that disrupt transport" (2009:2). For Reiken *et al.*, this suggests a crucial role for the government or civil society in assuring the ability of transport infrastructures to meet accessibility needs under climate change.

[19] It should be noted, however, that infrastructure provision and operation often show tendencies to monopoly or oligopoly conditions given the required high level of capital and economies of scale.

Limitations

As Reiken et al. have explored in their 2009 article, the relationships between actors can often impose a number of limitations on the ability to adapt. A number of barriers exist due to the complexity of the actor networks involved. Firstly, it is often difficult to disentangle hazards, impacts, and responsibilities in a way that fosters a clear framing of the issue and adaptive action. Second, the complex dependencies, assignment of responsibilities and the externalities involved often make non-action a rational behavior even when convincing expert knowledge is available. Further, even in light of convincing evidence, long-established routines and habits can block the inclusion of changing environmental conditions and previsions into technical and decision-making processes. (Reiken *et al.*, 2009:16)

The necessity for concerted action across a wide range of actors to proactively adapt to climate change poses a number of difficulties as in many cases the costs and benefits are not evenly distributed. As at times in the case of mitigation actions, adaptive measures can imply real costs to individual or groups of actors with benefits for the public good. As such, it may be difficult in many cases for *proactive*, *autonomous* adaptive measures to be put in place by individual actors without some form of incentive (positive or negative) from local or national authorities. As described below for the controlled-access highway system, this can especially be true in the transport sector where concession granting, even when long-term, may not induce proactive action by operators. The involvement of both public and private actors in many of the potential adaptive actions may pose difficulties in terms of the introduction of moral hazards (compensation payments, insurers of last resort). As such, it is important that a focus is placed on identifying *no-regret adaptation* measures as described by Hallegatte (2008) and other approaches that attempt to develop co-benefits in order to foster action from all actors involved.

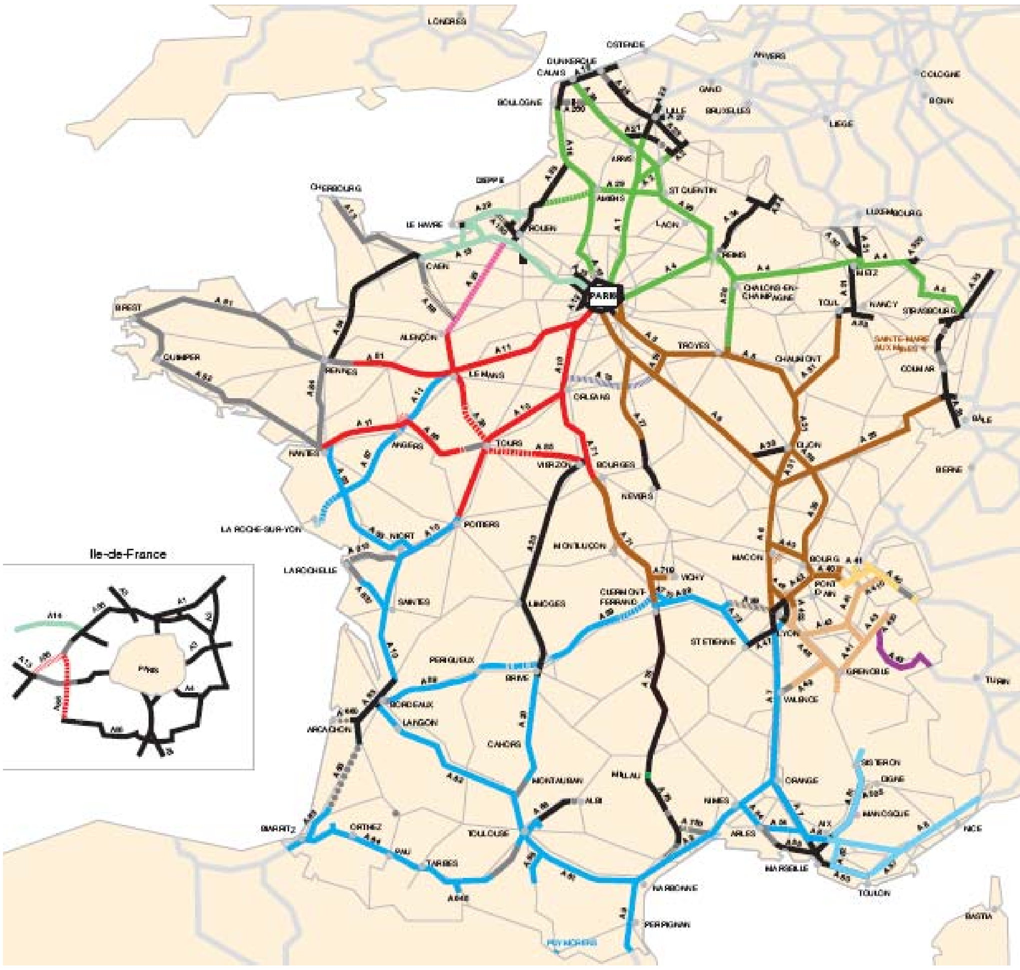
C. *Impacts of Concession-Granting and Private Investment Strategies*

In France, recent trends in the concession-granting of national transportation infrastructures to private companies over the last few decades demonstrate the increasingly complex regulatory and managerial context within which networks operate. The case of the granting of construction, maintenance and operation concessions for the French controlled-access highway system to a number of private and semi-private companies presents a relevant illustration of this situation. The granting of concessions for the construction, maintenance and operation of a number of routes has a long history, involving principally mixed-capital companies. However, revisions to the concession-granting systems at the end of the 1990s in accordance with EU directives have increased the participation of fully private companies and transferred full responsibility for the highway infrastructure and operation to the private company during the concession period. As part of this process, the State no longer serves as the guarantor of last resort and will not assume the debt held by operators at the end of contract. Further, the French State begun in 2006 to sell its shares in a number of mixed companies. Currently, close to 15 different entities are involved in the administration of the controlled-access highway system, the majority of which are privately held.

These different companies are responsible for the operation, maintenance and investment in the highways, with contract duration between 50-70 years (for those established after 2001). Due to both the length and structure of the contractual agreements, under the current agreements these companies would be responsible for bearing the costs of investment necessary for climate change adaptation efforts. While changes in technical standards set by central regulatory bodies can influence the resilience of newly-constructed roadways, private companies may lack the necessary incentives to retro-fit existing structures as many of the impacts (and thus costs) are expected to occur after their contacts have come to term. While concession contracts are long-term, short-term obligations between the State and the company are re-negotiated every 5 years through a “contrat de plan”. This document establishes obligations for investment, user-tariffs, commercial, quality of service and different environmental aspects, and could be potentially used to require adaptive actions by operators. The increasing number of actors involved may require the formation of new institutional and contractual relationships if adaptation is to be addressed in a coherent fashion.

Nevertheless, as Figure 3 and Figure 7 showed, it is likely that impacts of climate change on the controlled-access highway system will vary by region, and thus by concessionaire. As such, companies operating in different localities will need to establish different levels of responsive actions, often at increased costs, which may go against a shareholder-based private business model. A given company would be at a comparative disadvantage to its competitors when the level of investment required for the adaptation of infrastructures is superior to that of other companies operating in geographic areas with potentially lower climate-related costs. Further, as it is expected that revenues generated by the toll road system may be reduced in the coming years due changes in user modal distribution (transfer to rail and air),[20] research is needed to understand how these variations and needs for adaptive planning could be included in short- and long-term contracts when paired with decreasing operating budgets

Figure 9 - Network of highway concession companies in France*



Each color represents a different public or private operator. Roadways managed by the State are in black.

Source: MEEDDAT (2005).

CONCLUSIONS

This paper has attempted to fill what we identified as a gap in the literature concerning the potential impacts of climate change on transport infrastructures in France. Transport infrastructures play an

[20] While road transport remains dominant, the modal share of rail transport of passengers has increased since the 1990s. Parellely, the modal share of road transport has flattened out. Further, in 2008 in France, the modal share of road passenger transport decreased by 1.5%, while the share of rail transport increased by 6,0%. MEEDDAT (2009)

important role in the social and economic development in France, represent important capital investments, and are administered by a wide range of actors functioning at different scales of government.

The graphical analysis of the potential impacts of climate change in terms of changes in temperature and precipitation averages and extremes on the continental French territory serves to elucidate the possible location and extent of impacts.

Paired with an analysis and description of physical and operational impacts for each mode, the section demonstrates that a number of infrastructures are potentially at risk and further, more detailed analysis is necessary concerning vintage, construction norms and geographical context. It also indicates that while changes in extreme event trends are currently uncertain, an increase in the frequency and strength of storm, flooding and extreme-heat events will prove both costly and disruptive. Finally, changes in climatic averages may also lead to changes in transport infrastructure demand stemming from changes in tourism flows, localization of inhabitants and from agricultural production.

Adaptive measures presented focus primarily on changes in planning procedures and technical criteria to better adjust new infrastructure to a changing climate as well as the retrofitting and, in certain cases, the protection of existing infrastructures. Success in these efforts will depend on the ability of the large number of actors involved in the planning, construction, maintenance and operation of transport infrastructures to develop and implement coherent approaches. The effects of concession-granting and the privatization of infrastructures in the case of the French controlled-access highway system are not seen as negative. Nevertheless further research is needed to better understand whether if the shareholder-based private business model will accept the added costs adaptation measures will demand to operate transport infrastructures in certain regions.

Due to data constraints, the paper was unable to fully analyze the different variables related to hazards and vulnerability of specific infrastructures and the adaptive capacity of different actors. Nevertheless, a potential research agenda can be fleshed out focusing on improved modeling and the increased participation of public and private actors in the field:

- Hazards – More detailed modelling is necessary to better understand the micro-level impacts, and related costs, to specific types of infrastructures, particularly in urban areas with increased vulnerability.
- Vulnerability - There is a need to analyze for specific infrastructures the flood-proneness (proximity to coast or river), land area, elevation, population density, socio-economic values, and the quality of infrastructure, including date and method of construction, lifespan, and current condition.
- Adaptive capacity – Working with the actors directly involved in the planning, construction, operation and maintenance of infrastructures, it is important to assess their preparedness and evaluate the resources and information available for coordinated action.
- Contracting – Given the increasing frequency and importance of the concession of infrastructure construction, maintenance and operation to private and semi-private companies, more research is necessary on the types of contracts used and the potential to integrate adaptation planning and actions.
- Financing – Further research is necessary on the economic instruments available to assist and provide adequate incentives to the various actors involved in financing adaptation projects.

Further, as recognized in a large part of the literature, potential changes in sea level will present a significant number of risks to all forms of infrastructures located in coastal areas. While this study was unable to address this subject due to the need for highly detailed elevation data, further research will be essential for necessary adaptive action.

This paper serves as a first step, identifying the need for further research and action from experts, officials and the full range of actors involved. While the graphics presented in this paper cannot accurately predict to any level of certainty the potential impacts of climate change on transport infrastructures, they can serve to identify key concerns and draw attention the essential actions that must be taken to reduce negative social, environmental and economic impacts.

ANNEX 1: STATE OF THE INTERNATIONAL LITERATURE

The largest body of research has been conducted in the United States, including the Transport Research Board of the US National Research Council of the National Academies' special report on the potential impacts of climate change on U.S. Transportation (2008) and the U.S. Climate Change Sciences Program's (USCCSP) assessment of the impacts on transportation infrastructure in the Gulf Coast region (2008). Both reports recognized the potentially costly and widespread impacts of climatic changes on transportation infrastructures within the United States. The Transportation Research Board has identified the flooding of coastal roads, railways, transit systems and runways due to global rising sea levels as the having the greatest potential impact on North American transportation systems (2008). Additionally, both reports point to increases in weather and climate extremes, including very hot days, intense precipitation events, intense hurricanes, drought and rising sea level coupled with storm surges and land subsidence, as posing varying levels of significant risk across regions and modes of transit (TRB, 2008, USCCSP, 2008). The Government of Canada's preliminary study of climate change impacts across sectors agrees with the other reports, however identifying both potential harms (terrain instability due to the melting of permafrost) as well as benefits (decreased winter road maintenance costs) for the nation due to milder winter weather (Natural Resources Canada, 2008).

In terms of studies addressing the impacts in specific regions, the USCCSP's preliminary study of the Gulf Coast region identifies a number of potential impacts, pointing to changes in precipitation patterns increasing short-term flooding, sea level rise inundating existing infrastructure, and increased storm intensity leading to greater service disruption and infrastructure damage (2008:ES7-8). The Government of Victoria's (Australia) assessment of potential impacts presented similar conclusions, focusing on the increased flood risks posed by an increase in extreme event frequency as well as pointing to a potential acceleration in degradation of materials and structures (2007). With a road infrastructure network valued alone at 32 billion AU$, the Government of Victoria has recognized that climate change impacts could place a heavy financial burden on operators and owners, including city councils, state government as well as private actors. The primary message of much of the literature reiterates the idea that climate change has the potential to significantly reduce the lifespan of many transport infrastructures, increasing maintenance and replacement costs in a given period.

The literature indicates that the impacts on transport infrastructures in urban areas will be similar as reported in global-impacts studies. However, transport infrastructures in urban areas are more concentrated and point-based impacts within cities have the probability to cause greater total damages due to the higher density of infrastructures overall. The literature also notes that temperature impacts in cities can be exacerbated by the urban heat island effects, increasing average temperatures above regional norms (Atkins, 2006). In an analysis of the impacts of climate change on transport networks in the city of London (LCCP, 2005; Atkins, 2006), climate scenarios indicated that the urban area can expect warmer, wetter winters; more intense downpours of rain; hotter, drier summers, with more frequent and extreme high temperatures; and sea level to rise further, with an increased risk of tidal surges. As such, the city has predicted increased flooding of underground (subway), rail and road infrastructure, including potential extended station closings, damage to national rail and road infrastructure serving the urban area and impacts on voyager health within the public transit systems (LCCP, 2005).

Similar studies conducted for the Boston Metro Area (Suarez et al., 2005), the New York Area (Zimmerman, 1999; TRB, 2008:92-96) and the Seattle / Puget Sound Area (TRB, 2008:98-100) in the United States present similar findings, including increased vulnerability on bridge and road infrastructures often in poor condition (close to 30% of the present 105 bridges in Seattle). It must be noted that in many cases, the costs of responding to potential climate change impacts falls to infrastructure owners, often the municipal governments themselves and also increasingly private actors, who in many cases are under financial pressure to meet current backlog of necessary infrastructure repairs (TRB, 2008; Karhl & Roland-Holst, 2008; Government of Victoria, 2007). Climate change impacts, if not taken into consideration in future, will only serve to exacerbate financial burdens on municipalities.

The impacts of climate change on transportation infrastructures have received less attention in Europe, although a few examples are worth noting. The UK Climate Impact Programme has integrated transport as a theme area and transport has been included in the regional analysis conducted throughout the United Kingdom (UK Climate Impacts Programme, 2009). However, no comprehensive study and/or costing of potential impacts have been released. The Netherlands has included a portion of this analysis in their UNFCCC National Communication, however a comprehensive study was not located by the author (Ministry of Housing, Spatial Planning, and the Environment, 2001). To date, little literature exists concerning the impacts of climate change on transport infrastructure in France. Except for brief mention in a number of articles focusing primarily on mitigation within the transport sector (Bureau, 2008; Gastaud, 2006), only a draft 2008 interim inter-ministerial report roughly characterizes potential impacts in France (ONERC, D4E & EcoFys, 2008). While the initial report provides general information concerning potential impacts, neither systematic analysis nor quantitative evidence is presented. The final version is scheduled for release in mid-2009.

ANNEX 2: TABLE OF PHYSICAL AND OPERATIONAL IMPACTS OF CLIMATE CHANGE ON TRANSPORT INFRASTRUCTURES

Transport Type		Physical Risks	Climatic Variable	Operations Impacts
Ground	**Roads**	• Asphalt degradation (rutting, buckling)	• Increased solar radiation • Increased temperature and heat waves • Increased freeze-thaw cycles (mild winters)	• Slower operating speeds • Increased maintenance • Limitations on periods of construction • Vehicle overheating and tire deterioration • Decreased operating times due to flooding
		• Road foundation degradation	• Increased variation in Wet/dry spells • Decrease in available moisture • Sea level rise	
		• Flood damage to roads	• Increase in extreme daily rainfall • Increase in frequency and intensity of storms • Sea level rise	
		• Fire damage to road infrastructure	• Decrease in variation in wet/dry spells • Decrease in available moisture	• Decreased visibility
		• Changes in landscaping and road-side vegetation	• Changes in precipitation • Changes in temperature	
		• Overloading of drainage systems	• Increase in extreme daily rainfall • Increase in frequency and intensity of storms	
	Rail	• Rail track movement	• Increased temperature and heat waves • Decrease in available moisture	• Slower operating speeds • Decreased payload capacity • Increased monitoring of rail temperatures • Increased maintenance
		• Storm damage to rail (including power lines)	• Increase in extreme daily rainfall • Increase in frequency and intensity of storms • Increase electrical storm activity	• Decreased operating times due to flooding
		• Fire damage to rail infrastructure	• Decrease in variation in wet/dry spells • Decrease in available moisture	
	Bridges	• Bridge structural material degradation	• Increased temperature and heat waves Increased solar radiation	• Increased structural monitoring • Increased maintenance
		• Storm damage to bridges	• Increase in extreme daily rainfall Increase in frequency and intensity of storms Increase in intensity of extreme wind	• Decreased operating times due to flooding

Transport Type		Physical Risks	Climatic Variable	Operations Impacts
	Tunnels	• Tunnel flooding	• Increase in extreme daily rainfall • Increase in frequency and intensity of storms • Sea level rise	• Increased structural monitoring • Increased maintenance • Decreased operating times due to flooding
Maritime	**Ports**	• Storm impacts on ports and coastal infrastructure	• Increase in intensity of extreme wind • Sea level rise • Increase in frequency and intensity of storms • Increase in extreme daily rainfall	• Increased structural monitoring • Increased maintenance
		• Flooding impacts on port infrastructure	• Sea level rise	• Decreased operating times due to flooding
	Canals	• Reduced water levels	• Decreased rainfall • Increased temperatures and heat waves	• Decreased payload • Water-sharing and allocation conflicts
		• Increase in silt deposits	• Changes in precipitation patterns	• Increased dredging required
		• Increased aquatic vegetation growth	• Increase in temperatures	• Clogging of drains, supply lines
Aviation	**Airports**	• Asphalt degradation	• Increased solar radiation • Increased temperature and heat waves	• Decreased payload capcity • Increased monitoring of runway condition • Increased maintenance
		• Degradation of runway foundations	• Increased variation in Wet/dry spells • Decrease in available moisture	
		• Flood damage	• Sea level rise • Increase in extreme daily rainfall • Increase in frequency of storms	• Decreased operating times due to flooding • Increased ground operations energy
		• Loss of engine efficiency	• Increased temperature and heat waves	

Source: Mission Climat of Caisse des Dépots, after: CSIRO 2007, Natural Resources Canada 2008, USCCS 2008, TSB 2008.

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Climate Report

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