FRANCE STRATÉGIE
ÉVALUER ANTICIPER DÉBATTRE PROPOSER

Climate risks, networks and interdependencies: it’s time to act

This work on electricity, road and rail transport and telecommunications networks highlights the vulnerability of their infrastructure at a time of climate change. Rising average temperatures and increasing heatwaves pose many risks, not least for active telecommunications network equipment. Uncertain future changes in high wind and storm patterns will have consequences for overhead network infrastructure (e.g. power lines or telecommunications).

Most importantly, these networks are interlinked – both in everyday operation and in times of crisis – by numerous relationships of dependence, both physically and in consequence of the relationships between stakeholders. For example, electrical or telecommunications cables in close proximity to roads are affected by issues relating to those roads, and telecommunications networks are dependent on the power supplied to them. This tends to increase the vulnerability of networks to climate change. The measures taken in response to these risks remain only partial responses, which means that interdependencies must be fully factored into adaptation strategies.

To address these challenges and contribute to the development of the “Adaptation” component of France’s new Energy-Climate Strategy, France Stratégie has drawn up a series of actions for the State along three lines (see figure below): strengthening and sharing knowledge, establishing a system of national governance, and experimenting with adaptation strategies in volunteer regions that are subject to interdependence issues. All these initiatives could feed into large-scale exercises, such as a national risk assessment.

Three initiatives to facilitate the adaptation of network infrastructures to climate change, taking interdependencies into account

THEME 1
Establish shared references

1. Facilitate the use of the same set of climate projections by all stakeholders
2. Improve knowledge of the current state of network infrastructure and its dependencies

THEME 2
Set up a system of national governance

1. Create a working body to act as a forum for at least network operators and the State
2. Enshrine in law the creation of a joint roadmap for the adaptation of networks to climate change

THEME 3
Base the national vision on regional approaches

1. Recommend that regional bodies experiment with a system for establishing a diagnosis and a shared action plan at local level
2. Test a system to return and leverage feedback at national body level

Source: France Stratégie

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INTRODUCTION

Climate change is not some distant reality in time or space: its first effects are visible all over the world, and these will increase significantly. The current diagnosis produced by Météo France on the basis of the various scenarios of changes in emissions put forward by the Intergovernmental Panel on Climate Change (IPCC) can be summarised as follows[1]:

- as regards the average annual temperature, in the case of the RCP4.5 scenario[2], it is expected to increase by 2.1 °C by 2100 (compared to the period 1976-2005) in France, with a decreasing gradient from the South-East to the North-West and more marked warming in summer and in the mountains;
- heat waves will intensify and lengthen under all scenarios: their duration could double in the most optimistic scenario, and increase tenfold in the most pessimistic;
- in terms of precipitation, the uncertainties are more marked but they are slightly higher (less than a 10% increase), regardless of the emission scenario adopted. However, precipitation will increase by more than 10% in winter, and decrease in summer.

These effects of climate change make network infrastructure – particularly electricity, transport and telecommunications – a central issue in the resilience of our societies.

For example, storm *Alex* in 2020 led to the destruction of roads and disruption to water, electricity and telecommunication networks in some valleys of the Alpes-Maritimes[3], and the damage was estimated by the local authorities at more than one billion euros[4]. An ability to anticipate such impacts would presumably offer the potential to improve the implementation and effectiveness of existing crisis management systems (see inset 1), by improving the robustness and general resilience of infrastructures and limiting residual risks.

Although the current European and national framework emphasises the importance of modifying network infrastructures, it does not emphasise their interdependencies[5]. However, these are increasingly structural and, in conjunction with climate change, can cause cascading reactions and generate unprecedented damage[6].

Based on a diagnosis of the general vulnerability of road and rail transport, electricity distribution and telecommunications infrastructure (wired, wireless, satellite and the equipment associated with their operation, including data centres) in mainland France, this note puts the interdependencies between these networks into perspective and opens up avenues for public action, in connection with discussions relating to the development of the French Energy-Climate Strategy and the revision of the National Plan for Adaptation to Climate Change[7].

Inset 1 — Major crisis management in France

France has an interministerial institution that reports to the Prime Minister, the Secretariat-General for Defence and National Security (SGDSN), which coordinates actions such as advance planning, prevention and response to crises of all kinds[8]. In particular, the SGDSN organises the preparation of crisis response via the mechanism relating to the security of activities of vital importance (AIVs). In this respect, the State involves all vital operators in the identification of points of vital importance (establishments, works or installations providing essential services and goods) and in the implementation of security plans, specific protection plans and business continuity plans.

The implementation of this system involves all State services, including the prefects of defence and security zones and the prefects of departments. In addition, service continuity for networks for electricity transmission and distribution, the transportation of goods and people, and telecommunications is governed in Europe and in France by the national security strategy, and specifically by the policy on the security of activities of vital importance (SAIV).

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1. Météo France (2020), *Les nouvelles projections climatiques de référence Drias 2020 pour la métropole*, report.
2. RCP (Representative Concentration Pathway) scenarios are reference scenarios of change in radiative forcing levels.
3. Météo France states that such types of event, described as "Mediterranean episodes", have become increasingly intense since the 1990s, and that their intensity is likely to increase still further under the effect of global warming. See in particular Météo France (2020), "Tempête Alex: des intempéries exceptionnelles", 3 October.
4. Ville F. (2020), "Tempête Alex: plus de un milliard d'euros pour reconstruire", *La Gazette des communes*, 23 October.
5. The EU Adaptation Strategy makes little consideration of the question of network interdependencies, but the so-called CER Directive (Directive on the resilience of critical entities), which is currently being prepared, should cover these issues. See in particular: European Commission (2021), "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Forging a climate-resilient Europe – the new EU Strategy on Adaptation to Climate Change", February.
6. See in particular IPCC (2022), *Climate Change 2022: Impacts, Adaptation and Vulnerability*, sixth Assessment Report, Intergovernmental Panel on Climate Change, Box 6.2, February; and CGEDD (2013), *Vulnerability of infrastructure networks to natural hazards*, report, Conseil général de l'alimentation, de l'agriculture et des espaces ruraux, September.
7. Water and sanitation networks have not been covered in this work, but are infrastructure networks that should be integrated into an overall climate change adaptation strategy.
8. The SGDSN website can be accessed via the following link: http://www.sgdsn.gouv.fr/

NETWORKS EXPOSED TO CLIMATE CHANGE IN FRANCE AND DISPARATE RISKS OF FAILURE

Physical vulnerabilities to climate change

Climate change poses many physical risks to network infrastructure. Local electricity, road and rail transport and telecommunications infrastructures are already exposed to climate hazards. By way of illustration, some examples of climate change risks are presented below[9]. Firstly, rising average temperatures, the lengthening and intensification of summer heat waves, droughts and the increase in fire outbreaks pose the following risks:

- of overheating (or even fire) in electronic and electrical components for all the networks studied here. In particular, equipment at strategic sites, mobile sites (more than 60,000 for all operators[10]) and local concentration points for fixed networks (more than 14,000 connection nodes for fibre-optic or copper networks for the Orange operator alone[11]) and telecommunications networks, or electrical traction installations on the rail network;
- of increased rail expansion;
- of interruption of electricity or telecommunications transmission, depending on the design temperature of the cables[12] and the heat resistance of the various components;
- of degradation of equipment air-conditioning systems at strategic sites and large sites in telecommunications networks[13], or at local concentration points in fixed networks, which can have a strong impact depending on the number of lines and users served;
- of disruption of electricity and transport networks and destruction of telecommunication network poles, due to the increase in fire-prone areas;
- of slowing down maintenance work during heat waves.

Secondly, flooding of all kinds, submersion (particularly linked to rising sea levels) or landslides can lead to traffic disruption as a result of structural infrastructure damage, or even to the localised destruction of parts of land transport networks or infrastructure (masts and antennas) of telecommunications or electricity networks[14].

Finally, storms and strong winds such as the Mediterranean episodes pose a risk of damage to the overhead infrastructure (cables, lines) of electricity networks or to the engineering structures of road and rail networks. For telecom operators, the risk is the destabilisation of towers, antennas or poles necessary for the operation of the local loop[15]. For example, Orange has a stock of over 16 million poles (in some cases shared with the operator Enedis), which is a point of vulnerability.

Quantifying the socio-economic effects of climate change, particularly on infrastructure, is a complex and still patchy task[16]. Nevertheless, all projections anticipate increases in costs related to the impacts of climate hazards on transport infrastructure at European level[17]. For example, the risk of flooding on the rail network could double or triple in the case of a global warming level of +1.5 °C to +3 °C, and generate additional annual costs of more than €1 billion for public authorities if adaptation measures are not implemented[18].

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[9] In interviews, other weather phenomena (such as sticky snow) or trends due to climate change (such as rising sea levels or increasing fires) were discussed.

[10] According to the Agence nationale des fréquences (ANFR) in May 2022.

[11] Strategic sites and the largest telecommunications network sites have cooling systems. This is not true of smaller sites, especially mobile sites.

[12] Heat expands and lengthens cables; a power line can only operate up to a certain temperature, which depends on the design dimensions.

[13] Strategic sites number around one hundred for the Orange operator alone.

[14] Example: in Thailand in 2011, repairs to road infrastructure following flooding cost $4.5 billion. See Hall J.W., Aerts J.C.J.H., Ayyub B.M. *et al*. (2019), "Adaptation of Infrastructure Systems: Background Paper for the Global Commission on Adaptation", Environmental Change Institute, Oxford University.

[15] Arcep definition: the local loop is the physical circuit linking the network termination point at the subscriber's premises to the main distribution frame.

[16] COACCH (2018), *The Economic Cost of Climate Change in Europe: Synthesis Report on State of Knowledge and Key Research Gaps*edited by Watkiss P., Troeltzsch J. and McGlade K., Policy brief by the COACCH project, May.

[17] *Ibid*.

[18] Bubeck P., Dillenardt L., Alfieri L. *et al*. (2019), "Global warming to increase flood risk on European railways" *Climatic Change*, 155, April, pp. 19-36.

Various initiatives for adaptation to combat physical risks

In general, adaptation of the infrastructure of these networks to cope with climate change is still only partial today: the consideration of current risks and their projected development as a result of climate change is inconsistent from one sector to another. Yet for the road network, for example, such climate-related hazards already represent significant costs, as the Court of Auditors points out[19].

For electricity transmission and distribution networks, which consist of more than 1.5 million kilometres of power lines[20], adaptation strategies are being implemented by managers in response to most current climate hazards, but also taking the future climate into consideration (see Table 1).

These strategies deployed in recent years have paid off, for example during summer heatwaves by reducing the number of incidents[21], or during winter storms by minimising the widespread destruction of pylons.

Similar strategies have been implemented for the telecommunications network, sometimes primarily for economic or operational reasons, and based on knowledge of current risks without anticipating the future climate[22]: the burying of networks where economically possible, the use of lightning arrestors on all equipment, the use of materials resistant to high temperatures, or load-shedding strategies between fixed, mobile and satellite networks or between networks of competing operators. However, such actions are subject to unpredictable risks that make them difficult to implement universally.

Table 1 – Examples of adaptation of electricity network infrastructure in response to climate change

Climate-related hazards		**Electricity transmission network**	**Electricity distribution network**
Climate change trends	Rising temperatures	Upward revision of the minimum cable design temperature (set at 65 °C from 2019; it had previously been between 40 °C and 60 °C)	Replacement of accessories (transition boxes between the different parts of the networks) and the most fragile cables (especially the oldest cables using oil-impregnated paper)
Extremes related to climate regime change	Heat waves		
	Floods and landslides	Ongoing study on flooding by 2050 with a view to improving the location of new electrical substations (10 to 15 per year) and pylons, and possible protection of existing sites	Use of more flood-resistant equipment, provision of rapid resupply facilities and water level sensors
	High winds and storms	Mechanical security programme (2002-2014), management of vegetation around infrastructure	Burying of medium-voltage overhead lines (priority for coastal and wooded areas) and renovation of maintained overhead lines to extend their life span by about twenty-five years(*)

(*) The current rate of burial of distribution network lines is approximately 1% per year (i.e. 3,000 kilometres of high voltage lines, 3,000 kilometres of low voltage lines and 8,000 kilometres of new underground networks).

Summary: The anticipation of rising temperatures and summer heat waves has led the electricity transmission system operator to raise the minimum design temperature of its cables. On the distribution network, a strategy of burying the portions of the network most exposed to the wind is being implemented.

Source: France Stratégie

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[19] Court of Auditors (2022), *L'entretien des routes nationales et départementales*, report, March.

[20] According to RTE, by late 2021 the electricity transmission network consisted of approximately 106,000 kilometres of high-voltage lines, including 7,000 kilometres of underground links. According to Enedis, the electricity distribution network consisted by late 2021 of 659,000 kilometres of high voltage lines (52% of which are underground) and 732,000 kilometres of low voltage lines (48% of which are underground). See RTE (2021), "Bilan électrique 2021. Réseau de transport – Évolution du réseau de transport."

[21] CGEDD and CGAAER (2020), *Retour d'expérience sur l'épisode caniculaire et la sécheresse de 2019*, report, April.

[22] A 2018 report highlighted the limited consideration of climate change in the reference documents (e.g. standards) available to telecom network operators. See EY and ARCADIS (2018), *Adaptation des grands projets d'infrastructure au changement climatique. Rapport pays pour la France*, p. 21.

Given that alternative solutions to fibre (mobile, followed by satellite) have lower performance, it may be difficult to switch from fixed networks to these alternative solutions, even temporarily, particularly when there is a strong need for high speeds (hospitals, industries). Burial strategies, on the other hand, are expensive to install and maintain[23].

In the case of rail transport, research and development work is being carried out to enable the use of more heat-resistant materials (e.g. fibreglass) and traffic management strategies, which may ultimately involve disruptions, are being put in place in summer and given greater emphasis during heat waves.

Climate change vulnerabilities are not just of a physical nature

In addition to the physical risks to network infrastructure, climate change poses various different risks to organisations. For example, periods of heat waves present health risks for workers. For Orange, for example, some 20,000 service technicians (including subcontractors) may be exposed to extreme weather conditions in the course of their duties maintaining or repairing equipment[24]. Consultations are making it clear that insurance and financial issues are also significant and should be taken into account in broader risk assessment approaches, which is in line with the conclusions of an April 2022 position statement issued by the Economic, Social and Environmental Council[25].

In the case of the road network, the proliferation of management bodies, limited and fragmented knowledge of the state of the network and a lack of resources are all structural weaknesses that impede the deployment of adaptation strategies[26]. For this reason, the role of public technical operators – such as Cerema, which is able to assist network managers in assessing vulnerabilities and implementing action plans – is central (see Box 2) and complementary to private engineering. This issue is linked to the proliferation of players, and also concerns telecommunications networks, particularly with regard to fibre roll-out, where three types of operator are involved (infrastructure operator, varying according to the area of intervention, commercial operator and industrial operator), but is also indicative of the heavy preponderance of subcontractors in the technical intervention teams.

Moreover, the habit of adopting a reactive – rather than anticipatory – approach may also increase the difficulties observed among certain infrastructure managers. For example, with regard to the road network, emergency budgets dedicated to repairing damage are increasing without risk anticipation strategies being put in place[27]. Hence the benefits of being able to objectively identify the expenses avoided by the adoption of adaptation strategies in relation to these maintenance and upkeep costs.

Inset 2 – Cerema, a key player in supporting transport infrastructure managers

For the past ten years, Cerema has been involved in developing practical tools and supporting road, rail and port infrastructure managers in their efforts to improve their resilience to climate change. For example, it has developed a vulnerability analysis methodology, which will be published in 2019 in the form of a methodological guide[28]. The methodology is part of a broader climate change adaptation process, which also includes the definition of an adaptation strategy featuring prioritised solutions. The objective of the approach is to help network managers to tailor their technical solutions – among other things – to future climate constraints and to prioritise adaptation solutions, in order to improve management policies and strategies and streamline budgetary expenditure. This method has been applied several times to different networks in various regional contexts.

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[23] The cost of dismantling buried networks amounts to around 100 million euros per year for Orange. These reroutings are carried out at the request of the authorities in cases where Orange's civil engineering infrastructures are affected by works (tramways, roads, etc.).

[24] This risk was identified during an internal audit exercise conducted by the organisation.

[25] CESE (2022), *Climat, cyber, pandémie: le modèle assurantiel français mis au défi des risques systémiques*, by Arav F. and Brunet F.-X., Position statement by the Economic, Social and Environmental Council, April.

[26] The National Road Observatory (ONR) approach is a step in the right direction; but even so, the 2021 report was still emphasising the lack of data for a global vision. See IDRRIM (2021), *Rapport ONR 2021* report, November.

[27] Court of Audits (2022), *L'entretien des routes nationales et départementales*, *op. cit.*

[28] Cerema (2019), *Vulnérabilités et risques. Les infrastructures de transport face au climat*, "Connaissances" collection.

Table 2 – Network infrastructure risk qualification test

		NETWORK					
CLIMATE RELATED HAZARDS		Electricity transmission	Electricity distribution	Rail transport	Road transport	Fixed telecommunications	Mobile telecommunications
Trends	Increase in average temperature	🟩	🟩	🟧	🟧	🟧	🟧
Extremes	Heat waves, fires and drought	🟧	🟧	🟧	🟧	🟥	🟥
	Flooding, submersion, high water and landslides	🟧	🟧	🟥	🟥	🟧	🟧
	High winds and storms	🟩	🟧	🟥	🟩	🟧	🟧

Note: the qualitative assessment is based on interviews conducted for the study (including RTE, Enedis, SNCF Réseau, Cerema and Vinci Autoroutes). The colour represents the intensity of the physical risk (green when vulnerability is limited, red when it is high).

Summary: The physical risk to transport infrastructure from high winds and storms is considered to be limited, and the increase in average temperature has been anticipated for electricity infrastructure (green boxes). Flooding poses risks of structural deformation or even failure of transport network infrastructures (red boxes). Heat waves pose significant risks to the operation of air-conditioning systems for strategic active equipment in telecommunications networks (boxes in red).

Source: France Stratégie

General test to qualify risks to the network infrastructure

Without obscuring the geographical dimension of the vulnerability of networks to climate change, the elements presented above offer a potential qualitative view of the risk (see Table 2). The most marked physical risks concern transport infrastructures, especially in connection with flooding or the phenomenon of shrinking-swelling of clays[29], as well as telecommunications infrastructures, in connection with heat waves and the challenges of air conditioning for active equipment.

For example, the heavy rainfall in July 2021 in Germany, Belgium, Luxembourg and the Netherlands caused around 200 deaths and destroyed roads, electricity networks and homes[30]. 30 billion in reconstruction aid was announced in Germany in August.

INTERDEPENDENCIES: AN OVERLOOKED ASPECT OF CLIMATE CHANGE ADAPTATION

In addition to the risks faced by individual networks, each is increasingly connected to others, creating interdependencies (see inset 3 on next page).

These networks can therefore be negatively impacted by an event – whether climate change related or not – affecting another network on which they depend (see Figure 1). For example, the (non-climate change-related) fire at an electrical substation in Issy-les-Moulineaux in the summer of 2018 cut electrical power to about 6,000 households for one day and impacted the rail network by degrading the operation of the Montparnasse station in Paris. In addition, studies have estimated that flooding of the Seine river could cause 30 billion euros in direct damage and up to 58 billion in total due to the complete or partial shutdown of activities and the spread of impacts[31]. Disruptions related to the effects of climate change on infrastructure are significantly greater in the case of interconnected networks, and can have major social and economic consequences[32].

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[29] See the "Résilience des infrastructures" factsheet series by Cerema.

[30] This extreme event has since been linked to climate change. See Kreienkamp F., Philip S.Y., Tradowksy J.S. *et al.* (2021), "Rapid attribution of heavy rainfall events leading to the severe flooding in Western Europe during July 2021", World Weather Attribution, August.

[31] Bouquentin M., Vuillet M., Lhomme S., Cariolet J.-M. and Diab Y. (2018), "FMEA et REX: Développement d'un premier formalisme pour améliorer l'étude empirique des (inter)dépendances et des défaillances en cascade entre les infrastructures et réseaux techniques urbains", 10es journées Fiabilité des matériaux et des structures, Bordeaux, 27 and 28 March 2018.

[32] See in particular IPCC (2022), *Climate Change 2022: Impacts, Adaptation and Vulnerability*, *op. cit*, Box 6.2 and Jaroszweski D, Wood R and Chapman L (2021), "Chapter 4: Infrastructure", *in* Betts R.A., Haward A.B. and Pearson K.V. (ed.), *The Third UK Climate Change Risk Assessment Technical Report*, London, prepared for the Climate Change Committee, pp. 4-5.

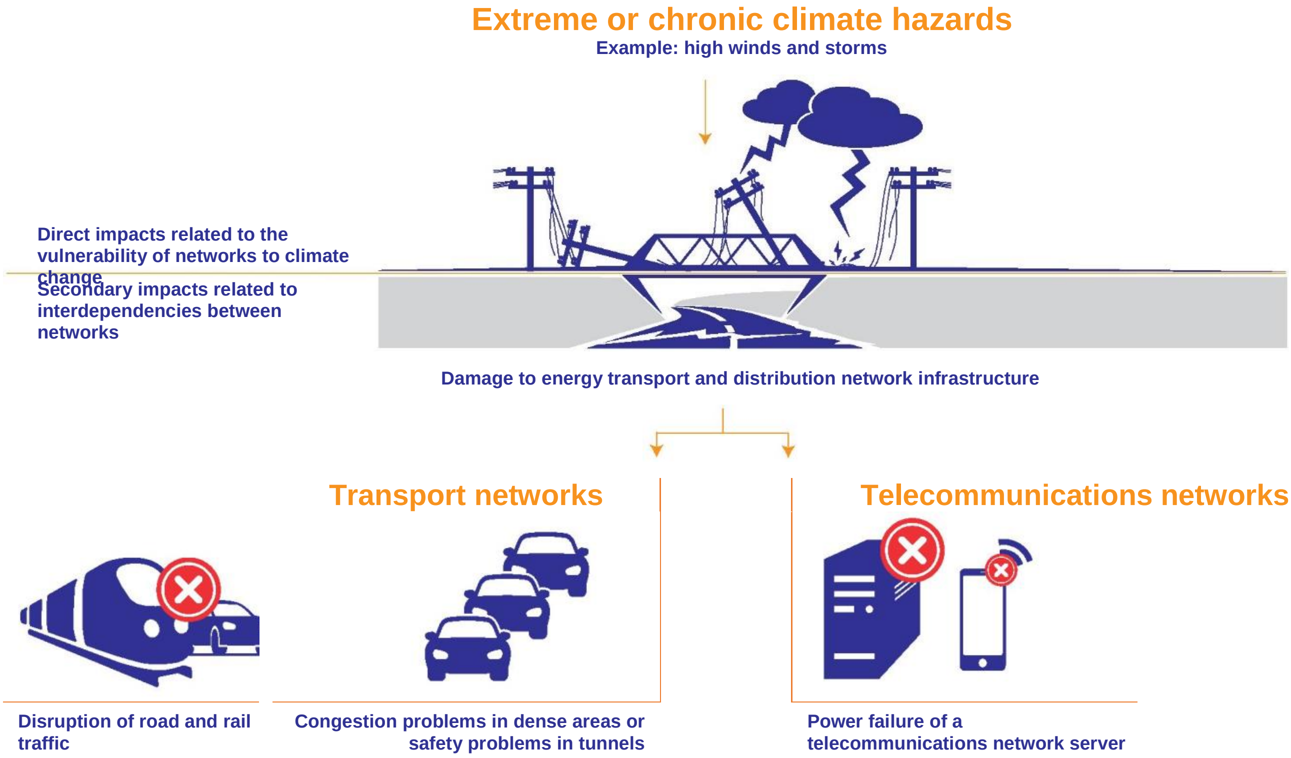
Inset 3 – Nature of interdependencies and interactions with climate change

Four categories of interdependencies are considered[33]: physical interdependencies involving physical and material links between infrastructures; geographical interdependencies based on proximity links between infrastructures; cyber interdependencies based on information transmission; and logical interdependencies including political, structural or social dependencies between stakeholders.

According to the IPCC, the crucial dependencies in the context of climate change are the use of information and communication technologies for the operation of many network infrastructures, including railways; the use of water for power generation or cooling of energy production units; the use of energy for the operation of infrastructure systems; the use of transportation systems for access to resources or emergency response services; and the geographical proximity of infrastructure which results in simultaneous exposure to risks[34].

Various methodologies for assessing vulnerabilities to climate change incorporate issues of interdependence[35]. For example, the Institute for International and Strategic Relations (IRIS) has defined a method for assessing the vulnerability of French military bases to climate change[36]. This method considers issues related to interdependencies and feedback loops that may impact on the military sphere.

Figure 1 – Theoretical example of cascading damage related to interdependencies



Summary: high winds can cause significant damage to electricity transmission and/or distribution infrastructure. In a cascade of impacts, rail traffic may be interrupted and telecommunication network servers may suffer outages. All of this has socio-economic impacts that extend beyond mere physical damage to network infrastructure. In France, the programme to mechanically secure the electricity transmission network has limited the likelihood of the cascading effects described in the diagram in terms of storm hazards.

Source: France Stratégie based on Figure 6.2 of IPCC (2022), *Climate Change 2022: Impacts, Adaptation and Vulnerability*,*op. cit*. p. 1123

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33. Rinaldi S. M., Peerenboom J. P. and Kelly T. K. (2001), “Identifying, understanding, and analyzing critical infrastructure interdependencies”, *IEEE Control Systems Magazine*, 21(6), pp. 11-25.
34. IPCC (2022), *Climate Change 2022: Impacts, Adaptation and Vulnerability**op. cit*, Box 6.2.
35. See, for example: Dawson Richard J. (2015), “Handling Interdependencies in Climate Change Risk Assessment”, *Climate*, 3(4), pp. 1079-1096; or Yang Z., Clemente M.F., Laffréchine K., Heinzlef C., Serre D. and Barroca B. (2022), “Resilience of Social-Infrastructural Systems: Functional Interdependencies Analysis” *Sustainability*, 14(2), 606.
36. Gemenne F., Kabbej S., Taithe A., Tasse J. and Babalone F. (2021), *CEMC: Climate Change Evaluation Methodology for Military Camps*, Study Report No. 16, IRIS and Observatoire géopolitique des enjeux des changements climatiques en termes de sécurité et de défense, May.

In the context of this study, the physical interdependencies encountered are related to the electricity grid, as the networks under consideration are partly dependent on the electricity supply from them[37]. This is true of the rail network, 58% of which is electrified (carrying 80% of traffic) and the rate of electrification has increased by almost 14% in twenty years[38]. Dependency relationships exist between telecommunication and electricity distribution networks: the former depend on a regular power supply, and the latter are facing increasing digitalisation. Geographical interdependencies between infrastructures are, for example, linked to the burial of electrical cables or fibre optics under roads or along railway lines. In the event of damage to the civil engineering of transportation infrastructure, these networks could be interrupted. Intersections between transport networks (e.g. road/rail crossings) are a geographical node of interdependence, where the failure of a single structure can have a series of consequences. Like the consequences of climate change, geographical interdependencies have a regional dimension (see inset 4).

The identification of geographical areas with specific vulnerabilities (isolation, altitude, steep slopes, coastline, etc.) could provide food for thought on the differentiation of adaptation strategies and support methods to be implemented.

Cyber interdependencies directly involve telecommunications networks and the use of information and communication technologies. Telecommunications are essential for both day-to-day management and crisis management, particularly to the extent that they enable the coordination of working teams.

Electricity and telecommunications networks: critical sources of interdependence

The vulnerability and criticality of the networks with regard to their interdependencies takes a variety of forms (see Table 3 on the following page). For example, a failure of the electricity transmission networks would bring electricity distribution, rail transport and a portion of telecommunications networks to a halt[39].

Inset 4 – Illustration of the interdependence issues between networks in the case of storm *Alex* in the Alpes-Maritimes

Storm Alex*, which occurred in October 2020, was an extreme Mediterranean episode that affected five valleys in the Alpes-Maritimes, three of which were particularly affected (Vésubie, Roya and Tinée valleys). The torrential activity, unprecedented in recent times, has brought about a complete change in the topography of the valleys, with retreating banks and slopes and massive sedimentary deposits which have sometimes buried the historical torrent beds. The bed of the river Vésubie, for example, has increased from about ten metres to one hundred metres wide in the Saint-Martin-Vésubie area. An initial assessment at the end of the crisis revealed that nine people had died and nine were missing, and that the damage was over one and a half billion euros.*

Network vulnerability and geographical interdependencies

Many communities in the valleys were left without water and electricity, road and rail links and telephone communications (mobile, copper and fibre-optic sites were affected). During the storm, contact with some communes was lost for more than twenty-four hours and the cross-border Roya valley remained cut off for more than three months.

The torrential floods washed away the roads under which all the cable networks were buried (especially electricity, fibre and copper). The need for functioning transport networks to provide access to other damaged infrastructure in the valleys was also highlighted. In the Roya Valley, traffic on the railway line between Breil-sur-Roya and Saint-Dalmas-de-Tende resumed on 19 October (just 16 days after the storm), although no road access to the valley floor was available. The line was suspended again the following month, following the discovery of storm-generated weaknesses in one of the structures.

Governance and crisis management: logical interdependencies

The prefecture's departmental operational centre, devoted to crisis management, was activated for a month and a half. It acted as a central hub for services provided by the State and local authorities, the emergency services and the operators. In addition, units with specific responsibilities were set up. In particular, a specific infrastructure unit was set up to overcome the difficulties of linking operators, as consultation between the various operators was complicated.

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[37] The road network is only partially dependent on the electricity network as roads can be used without signs or tolls, although this may cause significant congestion problems in dense areas and safety problems in certain areas such as tunnels, level crossings, etc.

[38] Ministry of Ecological Transition (2021), *Chiffres clés du transport - Édition 2021,* May.

[39] For example, approximately 80% of the Orange Group's electricity consumption is related to network infrastructure. While large operator sites may have installed generators, small sites are most often equipped with simple batteries that have a limited life span (between thirty minutes and four hours in the best case).

Table 3 – Qualitative view of interdependencies between networks

AND... / RELATIONSHIP OF DEPENDENCE BETWEEN...	Road network	Railway network	Electricity network: Transport	Electricity network: Distribution	Telecommunications network: Fixed	Telecommunications network: Mobile
Road network		⬜	⬜	🟧	⬜	⬜
Railway network	🟩		🟩	🟩	⬜	⬜
Electricity network: Transport	🟩	🟥		🟥	🟥	🟥
Electricity network: Distribution	⬜	🟥	⬜		🟥	🟥
Telecommunications network: Fixed	⬜	⬜	🟧	🟧		🟧
Telecommunications network: Mobile	⬜	⬜	🟧	🟧	🟩	

Note: the colour indicates the degree of dependency of the network in the column on that in the row: a red box indicates a greater dependency than a green box.

Summary: the railway network, the telecommunications network and the electricity distribution network are highly dependent on the electricity transmission network (red boxes). By contrast, the road network is only marginally dependent on the electricity networks, except for interdependencies related to tolls or traffic elements (grey boxes). Geographical interdependencies exist between many networks and especially with the road network, given the presence of electricity or telecommunications cables under or along roads (first row of the table). Electricity networks are dependent on telecommunications; for example, in the case of distribution control (orange boxes).

Source: France Stratégie

Other infrastructure networks are particularly dependent on telecommunication systems (e.g. for the dynamic control of energy production). In addition, geographical interdependencies also exist; for example, due to the fact that electricity and telecommunication cables can share the same physical poles or lie beneath the same transport arteries. Finally, during crises, other dependencies arise: on the one hand, emergency communication infrastructure is needed in case of disasters, and road infrastructure becomes crucial for access to disaster areas; in addition, there is a vital need for coordination between intervention strategies (as shown in the example in inset 4).

Cross-referencing this matrix with Table 2 clearly demonstrates the critical nature of the electricity and telecommunications networks, given the exposure of these networks to climate risks that are set to worsen in future, and the number of networks and systems that depend on them[40].

In addition, above and beyond the question of the physical impacts of climate change, the dependence on the electricity system of the sectors studied here raises questions over their resilience when confronted with potential situations of load shedding, arising from a production-consumption mismatch, whether linked to the climate or not. The cold snap that left more than 3.5 million homes without electricity in Texas in February 2021, the “Futurs énergétiques 2050” study conducted by RTE and climate change risk assessment work in the United Kingdom show that extreme weather can cause stress on the electricity system[41]. The needs in this area concern the availability of stable and continuous electrical energy at a rate compatible with the economic model of the various operators, the ability of the electricity network to provide a continuous supply – particularly during peaks in network use (6 pm to 10 pm) – and the ability to anticipate load shedding operations (which are likely due to the diversification of supply sources).

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[40] This is in line with similar findings from studies in the UK. See in particular Jaroszweski D., Wood R. and Chapman L. (2021), “Chapter 4: Infrastructure”, *op. cit*. pp. 4-5.

[41] See in particular: RTE (2021), *Futurs énergétiques 2050. Principaux résultats*, October, p. 44; Jaroszweski D., Wood R. et Chapman L. (2021), “Chapter 4: Infrastructure”, *op. cit.* pp. 4-5 and “Une vague de froid historique aux États-Unis: plus de 3,5 millions de foyers privés d’électricité au Texas” *Le Monde*, 17 February 2021.

The difficulties inherent in taking interdependencies into account

Interdependencies are of critical importance, but the issue of how to adapt network infrastructure to climate change is still mainly being considered on a sector-by-sector basis by the various stakeholders. Yet even an operator that has scrupulously adapted its infrastructure to the future climate will remain vulnerable if the networks on which it depends have not adopted their own appropriate adaptation strategies.

Several difficulties can explain the fact that interdependencies are currently poorly integrated into adaptation strategies, pointing in particular to one of the challenges identified by the High Council for the Climate; the transition "from a reactive, sector-based and case-by-case response to a systemic, proactive, preventive and forward-thinking approach[42]":

- The identification of risks and interdependencies is complex: it requires a proper assessment of the risks to each infrastructure and a projection of the impacts on other networks based on dependencies;
- the habit of reactive stances remains entrenched: the complexity and coordination costs associated with the challenges of interdependence can have the effect of encouraging stakeholders to favour a reactive stance;
- lastly, an overall lack of cooperation was highlighted by the IPCC[43]: in France, for example, there is no forum for structured exchanges between stakeholders to provide links between different spatial scales[44].

Avenues for action exist: crisis exercises and redundancy

To overcome these difficulties, it can be useful to plan exercises, and lessons learned from crisis management experiences can be leveraged. For example, the Ministry of Ecological Transition is currently organising climate-related crisis management exercises (drought, flooding, extreme cold, storms, etc.) with electricity or fuel supply/distribution and transportation operators (e.g. the Labo-crise initiative). The Paris police prefecture organised a crisis management exercise – Sequana 15/18 – which enabled numerous operators and public authorities to interact in response to a simulated flood of the Seine. Another example is the Zita cyclone preparedness exercise in Guadeloupe in 2021, involving all relevant stakeholders[45]. Such exercises enable the various stakeholders to cooperate in real time and identify existing difficulties (organisation of the sharing of confidential data, different working habits, etc.) and the ways in which they can be overcome. Extending this type of exercise beyond crisis management should facilitate the emergence of a shared culture of adaptation.

In several cases, including in the case of dependence on electricity or telecommunications networks (especially for crisis management), there is a preference for adaptation strategies based on redundancy[46]. This makes it possible to redirect road traffic to another part of the network, and this is also the case for electricity or telecommunications networks. At sensitive points in the motorway network such as tunnels, back-up equipment such as power generators or 4G keys can be deployed to temporarily mitigate failures in the power or communication networks[47]. However, this strategy implies efforts to maintain redundant systems, which may appear less essential under everyday circumstances. In addition, the back-up devices provided to supply power to a telecommunication antenna have a standalone life of about thirty minutes, and are therefore not sufficient in the event of a prolonged failure.

LESSONS FOR PUBLIC AUTHORITIES

The State, by virtue of its role as a co-ordinator of all the stakeholders concerned (at both national and local levels), would seem able to play a decisive role in encouraging greater consideration of the challenges of adapting networks to climate change and their interdependence. Several approaches could be taken; these are presented below.

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[42] Haut Conseil pour le climat (2021), *Renforcer l'atténuation, engager l'adaptation*, Annual report, Chapter 4, June.
[43] IPCC (2022), *Climate Change 2022: Impacts, Adaptation and Vulnerability op. cit*, Box 6.2.
[44] Individual situations obviously vary considerably, as shown by the examples of discussions between two operators cited during the hearings (for example, there are regular meetings between RTE and Enedis, and between RTE and Orange).
[45] See in particular: Prefect of the Guadeloupe region (2021), "ZITA cyclone exercise: red alert, share the alert messages and safety instructions", 7 May.
[46] Zimmerman R. (2002), "Enjeux et gestion des interactions entre les différents réseaux d'infrastructure", *Flux*, 47, p. 54-68.
[47] This is a measure implemented by Vinci Autoroutes, for example.

Increase knowledge

The work carried out highlights the importance of increasing:

- the ability to envisage a future climate different from today's, on a granular geographical scale, based on shared scenarios: the managers of the various networks will probably need to draw upon the same set of climate projections and expected impacts;
- knowledge of the current state of network infrastructures and interdependencies, by organising knowledge sharing;
- tools to capitalise on this knowledge[48], by initiating the development of a mapping tool able to identify the interdependencies (particularly of a geographical nature) between the various infrastructures[49].

In addition to these prerequisites, it is also necessary to have methodologies that make it possible to transition from the assessment of the physical impacts of climate change to an analysis of socio-economic impacts, so as to quantify both the costs of climate change and the costs of adaptation[50].

Develop a national perspective on the issues

The revision of the National Climate Change Adaptation Plan provides an opportunity to involve all network managers (not only transportation, electricity and telecommunications, but also water and sanitation, for example) in a national discussion on climate change adaptation and interdependence. The State could support the establishment of a body to promote dialogue in this area. The following themes would thus be addressed within an interministerial body capable of taking a cross-cutting approach:

- feedback and concatenation of operators' vulnerability assessments;
- identification of particularly vulnerable and/or strategically interdependent geographical areas;
- sharing of experience and best practice on sector-by-sector adaptation strategies;
- identification of interdependencies between networks, both at national and international level[51]. The importance of interational cooperation is underlined by (a) European networks' consideration of these themes, and (b) exposure to climatic events that may have a geographical scope that extends beyond France's national territory;
- construction of a shared system for diagnosing interdependencies and proposing measures to limit their effects;
- assessment of the amounts needed and discussion of potential funding mechanisms.

At national level, these discussions could take shape through the creation of a joint roadmap for the adaptation of network infrastructures to climate change, including a review clause to ensure that such measures are implemented and are relevant. In line with the provisions of the so-called "climate and resilience law" on the definition of decarbonation roadmaps for the highest-emitting sectors[52], this could be included in the energy and climate planning law (scheduled for adoption in 2023).

Encourage the emergence of local approaches

Several points underline the benefit of dealing locally with these issues linked to interdependencies, thus making them easier to consider and manage. At local level, the subject would appear easier to delimit than at national level, and managers of regional networks are likely to have detailed knowledge of vulnerabilities[53]. Moreover, the issue of adaptation to climate change has many local aspects, which makes conducting diagnoses at a granular geographical scale a logical choice.

By leveraging the knowledge already accumulated from the implementation of the ORSEC plan by the prefects of departments and zones[54], it could be possible to implement an initiative involving all the stakeholders in the territory and at least the network managers, State services and local authorities to identify the impacts of climate change on these infrastructures and on existing interdependencies.

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48. This issue of knowledge of the state of networks is one of the recommendations of the Court of Auditors: "to organise compulsory national data reporting for all road networks, and add this data into a shared information system."
49. The IPCC points out that these crucial nodes between different infrastructures are often located on the periphery of urban areas. See IPCC (2022), *Climate Change2022: Impacts, Adaptation and Vulnerability*, *op. cit*, Box 6.2.
50. In terms of assessing the impacts of climate change, the European COACCH and PESETA projects are helping to build an aggregated perspective. The Quanti-Adapt project, led by the Institute for Climate Economics, will also provide information on the costs of adaptation under different scenarios and for crucial sectors.
51. After all, French infrastructure networks also form part of an interdependent relationship with international infrastructure networks, which should not be ignored.
52. See article 301 of Law No. 2021-1104 of 22 August 2021 on combating climate change and strengthening resilience against its effects.
53. For example, within the SNCF, vulnerability studies on railway lines are carried out by regional offices.
54. See in particular: Directorate General for Civil Security and Crisis Management (2009), *Guide ORSEC départemental et zonal. Mode d'action, rétablissement et approvisionnement d'urgence des réseaux électricité, communication électronique, eau, gaz, hydrocarbures*, part 2.1.6.

Regional climate expertise groups could also be involved in the process[55]. The aim would be to generate diagnoses and action plans concerning the most critical interdependencies.

An experiment could first be conducted in a limited number of volunteer regions, presenting exposure to both hazards and critical interdependencies[56]. These pilot territories could be identified when the dialogue forum is set up (see *above*), and the feedback could serve as a basis for extending the system and consolidating a global vision.

CONCLUSION

In addition to the vulnerability of the studied networks to the effects of climate change, both now and increasingly in the future, the study highlights the great disparity in the abilities of all stakeholders to take these risks into account. In particular, the interdependencies between these networks remain poorly addressed. This is an area requiring work by the public authorities, both at national level (for example, in the context of the revision of the French Energy-Climate Strategy), and at regional level to encourage, structure and maintain interaction between stakeholders, chief among whom are the network operators. The courses of action presented appear to be capable of effecting a global change in network maintenance strategies. Moreover, the approach proposed here in relation to the adaptation of infrastructures to climate change could be used to support advance planning and preparation exercises for major risks. For example, a national risk assessment, extended to cover risks other than those of climatic origin and along the same lines as the Council of State proposal[57], could be based on similar procedures, favouring cross-sectoral approaches and making it possible to incorporate the issues of interdependence.

Keywords: adaptation, interdependencies, climate change, networks, risks, electricity, rail, road, telecommunications.

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[55] See the websites of these regional groups, acting as a forum for scientists who are experts in the field, such as: http://www.grec-sud.fr/, https://grec-idf.eu/ and https://www.acclimaterra.fr/.

[56] It is difficult to set the ideal scope for such an experiment in advance. It will need to be thought out in consultation between representatives of the State and the local authorities. Departmental level, at a minimum, seems to be an appropriate scale for considering interdependencies with regard to the communities concerned and the stakeholders on the ground.

[57] In a 2018 study, the Council of State refers in particular to the National Risk Assessment approaches promoted by the Organisation for Economic Cooperation and Development (OECD). See Council of State (2018), *La prise en compte du risque dans la décision publique. Pour une action publique audacieuse*, June, Part 2.1, pp. 83-85.

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