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# ADAPTATION

I4CE INSTITUTE FOR CLIMATE ECONOMICS
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# Anticipating the impacts of a 4°C warming:
## what is the cost of adaptation?

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Our 40 experts engage with national and local governments, the European Union, international financial institutions, civil society organizations and the media.

Our work covers three key transitions – energy, agriculture, forest – and addresses six economic challenges: investment, public financing, development finance, financial regulation, carbon pricing and carbon certification..

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## ACKNOWLEDGEMENTS

This publication provides an abstract of the information gathered as part of an analysis of the economic implications of adaptation pathways carried out by I4CE and its partners between February 2023 and March 2024. It is based on all the information on adaptation costs that is already available or possible to estimate for three sectors particularly affected by climate change in mainland France: land transport infrastructure, buildings and agricultural crop production.

Several technical partners were directly involved in producing the analyses: The Observatoire de l'Immobilier Durable *(OID)* for the "buildings" section; SETEC and Callendar for the "transport" section; and FINRES for the "agriculture" section.

A wider panel of stakeholders was involved in the discussions in the form of sectoral technical committee meetings. The authors would like to thank all participants involved in these discussions for their comments and contributions.

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This final report represents the views of I4CE only. The partners and contributors cannot be held responsible for the use of the information it contains.

# ABSTRACT

**Assessing the economic implications of climate policies is essential for steering public action.** Significant progress has been achieved in assessing the costs of mitigation, particularly with the publication in 2023 of the report on the economic implications of climate action. However, as the Cour des Comptes noted in its 2024 annual public report, numerous issues surrounding adaptation continue to emerge. Our recent work has nevertheless enabled us to draw five initial conclusions on the subject:

1. **Initial estimates but no single adaptation cost in France.** We have been able to calculate some initial estimates for three major sectors: buildings, land transport infrastructure and agricultural crop production. These are presented in detail in the thematic sections of this document. This patchwork of different elements, of varying degrees of maturity depending on the area of activity, allows us to see the orders of magnitude of the sums involved for all economic actors. We should not, however, be too quick to calculate a single cost for adaptation in France. Such estimations are difficult because they depend both on the warming level that we wish to consider (and there is much work to be done to quantify the extent of vulnerability for each warming level) and on the way in which we collectively choose to prepare (with many of these choices still to be taken, as strategic visions of adaptation are yet to be defined). For example, flood prevention measures for a road may require works totalling several million euros, whereas organizing temporary traffic closures during flooding episodes would mean accepting a lower level of service but would also be less expensive.

2. **Without a more ambitious adaptation policy, unplanned reactive measures often turn out to be the costliest for public finances, already accounting for several billion euros a year.** This expenditure includes the public cost of damage, the cost of repairing essential infrastructure and the cost of subsidies to overcome crisis. While in the short term a react and repair approach may sometimes seem simpler and cheaper than one based on anticipation, it is important to bear in mind that without structural adaptation, these costs will continue to rise and will cease to be exceptional. In addition to direct costs, there are wider socio-economic consequences (impacts on the healthcare system, labour productivity, the efficiency of transport networks, the trade balance, etc.) which will have an impact on the whole economy and reinforce territorial and social inequalities.

3. **Anticipation options are well understood and could be better deployed.** These include, for example, promoting adapted construction methods and appropriate architectural choices to maximize summer thermal comfort in buildings, even without air conditioning; reinforcing certain structures or organizing maintenance differently to improve the robustness and resilience of infrastructure; adjusting certain cultivation practices or generalizing agroecological measures to limit the effect of climate variability on agricultural production. These options can sometimes be implemented at a limited cost – particularly by incorporating adaptation into the specifications for already planned investment. Sometimes, however, they represent additional costs, or even require the mobilization of additional dedicated resources. We are just beginning to appreciate the magnitude of the costs associated with the various levers of anticipation that could be activated with varying degrees of ambition. However, the costs of more transformational forms of adaptation are difficult to identify.

# ABSTRACT

INITIAL ORDER OF MAGNITUDE ESTIMATES OF COSTS ASSOCIATED WITH ANTICIPATION MEASURES THAT COULD BE ACTIVATED WITH VARYING DEGREES OF AMBITION

**BUILDINGS**

- Systematically taking account of changes in heatwave risks could represent additional costs on top of already planned investment (for all actors combined) of between **€1 billion and €2.5 billion annually** for new construction, and up to **several billion euros annually** for existing buildings once investment in energy renovation is up to speed.
- Raising the level of ambition of risk prevention policies against flooding and swelling and shrinking soils would cost at least **a few hundred million euros.**

**TRANSPORT**

- Undertaking work to adapt the road and rail networks could require **between a few hundred million and a few billion euros annually** in additional investment over the next few decades (if, for example, the decision was made to increase the robustness of all water management structures). Above all, the issue will be about providing the means to take proper account of climate change in already planned investment, and to establish priorities within asset management strategies.

**AGRICULTURE**

- Around **€1.5 billion annually** may be needed over the next decade to deploy large-scale technical measures to maintain the yields of the main French crops, in a situation of increased climate variability.
- The costs of more structural changes to agricultural models remain difficult to assess.

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4 **Among the anticipation options, a number produce sufficient economic co-benefits to be intrinsically profitable, but this is not the case for all. This observation calls for a debate on the internalization of climate risks in economic models and the distribution of adaptation costs.** The scale of the socio-economic impacts often justifies proactive public intervention, which can take several forms: the direct payment of some adaptation costs by public budgets being only one possible option among others.

5 **In all cases, to ensure the best possible efficiency and distribution of expenditure, adaptation must be integrated into existing planning processes.** The challenge is to ensure that the right warming level, at the right time in decision-making and investment cycles, is always taken into account, so that we can avoid being subjected to future climate change impacts as well as overinvesting in very costly adaptation measures that are ultimately never likely to be economically justified. This requires a sequenced implementation of adaptation that considers the lifespan of investments and the reversibility of decisions, as well as a visible and stable distribution of responsibilities, to ensure that the incentives for taking action are clear to the various economic actors.

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# INTRODUCTION

## THE COSTS OF ADAPTATION, AN EMERGING BUT ALREADY CRITICAL ISSUE

As the transition to a global carbon-neutral economy has not been as rapid as hoped, it is now essential to take action both to reduce greenhouse gas emissions – mitigation to “avoid the unmanageable” – and to prepare for the impacts of climate change that are already here – adaptation to “manage the inevitable” *(Délégation sénatoriale à la prospective, 2019; Haut Conseil pour le Climat, 2021)*. Assessing the economic implications of the two dimensions of these policies is essential for steering action. Significant progress has been made in understanding the mitigation aspect, notably with the publication in 2023 of the report coordinated by Jean Pisani-Ferry and Selma Mahfouz on the economic implications of climate action. The issues surrounding adaptation are still emerging *(IGEDD, 2022; Pisani-Ferry and Mahfouz, 2023)*.[1]

Work carried out by I4CE and its partners has sought to make progress in estimating the costs to be considered in developing an adaptation policy, particularly in the context of preparing the Third National Adaptation Plan (PNACC3). The analysis presented below gives an account of what we can currently say about the economic implications corresponding to the different warming levels that make up the Reference Warming Trajectory, and the resources required for different levels of preparation for the impacts of climate change.

### SCOPE OF THE ANALYSIS

**> WARMING SCENARIO[2]**

Assumptions defined in the Reference Warming Trajectory (TRACC):[3]

- ➜ + 2°C for France in 2030 ;
- ➜ + 2.7°C in 2050
- ➜ + 4°C in 2100

**> RISKS**

Heatwaves, rainfall and flooding, forest fires, drought and swelling and shrinking soils[4]

**> SECTORS**

- ➜ **Building**
- ➜ **Land transport infrastructure:** national and departmental road networks; national rail network
- ➜ **Crop agricultural production** (excluding fodder crops)

**> GEOGRAPHIC SCOPE**

Mainland France

Given the relative newness of the subject – in terms of available data on vulnerabilities and adaptation options, and also regarding the progress of the debate on the responses to be provided – it is not possible to draw conclusions on the total cost of adaptation for France *(Cour des Comptes, 2024)*. We are, however, in a position to propose **a common framework to address this issue**; **to identify robust key messages** and **to provide initial orders of magnitude** for the three sectors studied.

1. The contributors to the Pisani Ferry-Mahfouz report note in the “Loss and damage and adaptation” section that “accessing the related loss and damage is a complex task: while the qualitative analysis of the associated risks is now well advanced, their quantification still needs to be refined.”
2. See https://www.ecologie.gouv.fr/trajectoire-rechauffement-reference-ladaptation-au-changement-climatique-tracc
3. The data (e.g. exposure figures, costs of impacts or adaptation) presented in this study come in part from scientific and technical studies expressing their results according to different emission scenarios (e.g. SSP-RCP) or global warming levels. For the sake of simplicity, we present these data using the nearest warming level for France as defined in the TRACC. For example, RCP8.5 results for 2050 will be used for a warming level of 2.7°C for France. This simplification may lead to a slight under (or over) estimation of the real impacts.
4. Coastal risks (erosion, marine flooding) have not been included in the analysis pending publication of work in progress, in particular by the French National Coastline Commitee.

# I. TWO KEY FACTORS IN ASSESSING THE COSTS OF ADAPTING TO CLIMATE CHANGE

**The costs of adaptation depend mainly on two factors. The most obvious is the warming level we wish to consider: the greater the warming, the greater the need for adaptation. However, the most decisive factor is the choice of the type and level of response to the risks.**

## 1. Above all, adaptation costs depend on how we choose to prepare

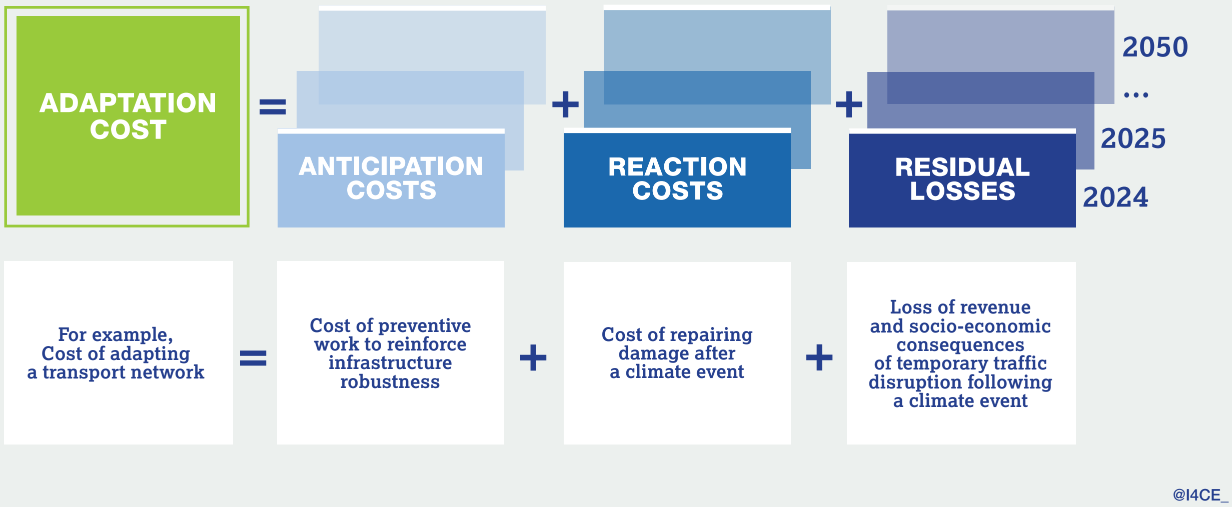
Estimating the costs of adaptation today can be difficult, primarily because such costs depend on the way in which we collectively choose to prepare for the impacts of climate change. For instance, if we anticipate that a particular stretch of road will become susceptible to flooding once a certain warming level is reached, we can opt for significant infrastructure improvements to mitigate such flooding, or we can implement temporary traffic closures during flood events. It is very likely that the first option will be more expensive than the second. This simple example illustrates that a predetermined trajectory of warming is not sufficient to calculate a single cost of adaptation.

Considering the situation where France has undergone a 4°C warming in 2100 means opening rather than closing the debate on the targets we aim to achieve and the type of adaptation we prefer: what level of service do we want to guarantee for a certain warming level? What forms of adaptation do we want to encourage – for example, adaptation on the scale of individual buildings or more concerted transformations on the scale of urban public spaces?

**Estimating the costs of adaptation requires the consideration of a certain level of effort, firstly to anticipate climate change and to reduce upstream vulnerability, and secondly to react to the impacts.** This level of effort must be calibrated according to the losses that can be minimized over different time horizons, but also according to other priorities and constraints, such as those related to politics or budgets. Assessing some of the factors in this equation are not straightforward, and nor are they always easy to compare *(Delahais and Robinet, 2021; Timbeau et al., 2023).*

**The costs and benefits of adaptation will be very unevenly distributed across the economy, depending on the choices made** – whether they are borne directly by households,  few major actors, the public authorities – leaving a considerable part of the decision to strategic and political negotiation. For example, an increase in the stringency of building regulations would mean that the cost of adapting buildings to the risk of swelling and shrinking soils issues would be shared by the project owners, whereas reactive responses are typically based on private insurance and backed by public reinsurance.

## TOTAL ADAPTATION COSTS: SUM OF THREE COST CATAGORIES OVER TIME




## **BOX:** WHY ARE THE COSTS OF INACTION NOT BEING DISCUSSED?

Much of the economic literature on climate change costs has historically sought to assess the costs of the impacts of climate hazards on the economy. These costs, which are assimilated to the "costs of inaction", are placed in perspective with those of action to mitigate and to adapt to climate change. These analyses, the principle of which has been summarized in several recent reports, are most often based on the establishment of damage functions linking temperature and economic losses *(Timbeau et al., 2023; Direction générale du Trésor, 2020; ADEME, 2023)*. Sectoral analyses also exist at the European level, for example on the costs of impacts on transport infrastructure and agriculture *(COACCH, 2020; JRC, 2022)*.

Literature reviews have aimed to summarize the conclusions that could be drawn for France *(Direction Générale du Trésor, 2020; 2023; Delahais and Robinet, 2021; Banque de France, 2022)*. In the "Loss and damage and adaptation" section of the economic implications of climate action thematic report, the following elements are summarized in particular:

"Excluding impacts on productivity, on human life, and on carbon emissions constraints in the event of $CO_2$ being released by natural carbon sinks, the total loss and damage would not exceed **€5 billion per year** [...] The monetary cost of the impact on human life (based on the statistical value of the latter) could be more significant over the same period (approximately **€20 billion euros per year**)" *(Timbeau et al., 2023)*.

We have not directly adopted these formulations of the costs of action and inaction here, as our objective is not to evaluate the suitability of action. Our aim is instead to provide a precise guide to adaptation costs on a scale ranging from a high level of anticipation of residual damage at one end, to more reactive forms of adaptation or damage repair at the other. A scenario of total inaction is largely hypothetical because every sector is already responding at least in part to the material consequences of climate change, even though these responses often tend towards the reactionary side.

**The main question to address when calculating adaptation costs is: what do we want to keep at all costs?** In other words, what are we willing to transform, what are we ready to give up? Anticipating everything – making all infrastructure and buildings completely robust; aiming for an agricultural system that is impervious to weather conditions – would be synonymous with over-investment, to the detriment of other important objectives such as controlling prices (for transport, food and housing) or other investments such as decarbonization. Conversely, zero anticipation would mean resigning ourselves to managing a succession of incidents or crises in a degraded condition and accepting a gradual decline in production or service levels. This would increase the risks around the safety of goods, people and the economy to a level that would quickly become politically unacceptable. It would also mean the loss of opportunities to adapt at lower costs.

## EXAMPLES OF POSSIBLE FORMULATIONS OF ADAPTATION OBJECTIVES TO BE ADOPTED

### BUILDINGS

- Minimum number of hours during which interior temperatures should not exceed a certain threshold – in new or renovated buildings – without recourse to air conditioning.
- Guaranteed continuity of public services during periods of extreme heat.
- Annual targets for the amount of public reinsurance (CatNat scheme) to ensure the sustainability of the system in a context of increasing risks.

### TRANSPORT

- Maximum recovery times following traffic disruptions (as already exist for the electricity network).
- Maximum number of days for which temporary speed reduction measures can be applied to a route.
- Traffic reliability targets (e.g. a maximum number of minutes for delays caused by weather conditions).
- Expected level of availability of at least one route under reasonable conditions (e.g. journey time).

### AGRICULTURE

- Guaranteed average yield over a set period.
- Annual production targets.
- Guaranteed self-sufficiency rate of 100% or more for most agricultural and food products.

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**A need to coordinate responses.** Although decisions must be taken with the best possible consideration of each context – and may vary according to the preferences of the different stakeholders – a certain level of coordination is necessary. The aim is to ensure that all decisions are consistent and therefore more effective: while an office building can be designed to remain comfortable up to a certain temperature, if employees cannot get to work due to a lack of functional transport, the benefit of the adaptation measure is lost. This also enables more far-reaching transformations to take place, which can only happen with shared strategies: a farmer cannot decide to grow sorghum instead of wheat if there are no downstream processing industries or markets for this new produce. The main advantage of defining a baseline for warming level is that it provides a coherent framework for analysis across several sectors and actors.

**The challenge lies in adopting a methodical approach to each domain – each transport route, each building type, each agricultural sector – in order to collectively define the desired level of production or service; to provide ourselves with the means to achieve the degree of robustness or resilience that is socially desirable; and then to design and scale the deployment of adaptation options accordingly.**

## 2. The warming level is also crucial

**Setting the warming level directly affects the scale of the problem to be considered –** the higher the level, the greater the stock of exposed and vulnerable assets – the kilometres of tracks or roads, the number of bridges or buildings, the number of hectares of crops. For example: while 48% of the building stock in mainland France would be exposed to high or very high risks with a temperature rise of 2°C, this percentage would go up to 93% with a 4°C increase.

**It is often impossible to know at exactly which warming level the various adaptation options will remain effective.** For example, certain measures to optimize irrigation may have initial success, but later become insufficient to maintain crop yields if the available resource becomes too low. Beyond certain warming levels, it is even likely that no effective adaptation options will be available (or at extremely high cost), and that we will reach what the IPCC describes as the "limits of adaptation".[5]

**Decisions based on the lifespan of each investment would mean that the right warming level can be considered at the right time, thereby leaving some room for manoeuvre**. For certain easily reversible decisions or short investment cycles, it is possible to periodically re-evaluate the level of effort according to actual warming levels. New opportunities to intervene will arise and it will be possible to reassess, if necessary, the need for robustness at that time. There is little to be gained by taking account of high warming levels that would not be reached for several decades. Road surfaces, for example, are renewed every 15 to 20 years, which leaves several opportunities for gradually raising standards. For other decisions, involving significant irreversibility, a much better option is to assume a warming of 4°C by 2100. For example, it is highly unlikely that a second large-scale campaign to renovate housing that has already been built will be carried out between now and the end of the century. This becomes particularly important when the cost of potential overinvestment is much lower than the consequences of underinvestment.[6]

### WHAT TIME HORIZON FOR WHICH DECISION?

**INVESTMENT DURATION**

| | 10 years → 2030 | 20 to 30 years → 2050 | More than 30 years → 2100 |
|---|---|---|---|
| | **Routine maintenance;** replacement of short-lived systems. | **Deep energy renovation work.** | **New building,** major modernization projects, work involving the redevelopment of public spaces; R&D programmes |
| | **Organizing maintenance** and crisis management. | **Carry out works, such as the renewal of road surfaces,** which have a lifespan of 15 to 20 years. | **Development of new infrastructure** and major renewal or modernization work, such as railways or engineering structures. |
| | **Routine investment decisions.** | **Strategic choices carried** when farms are established or transferred. Investment in sectoral development (training, brands, networks and food-processing tools). | **R&D programmes focusing** particularly on perennial crops. |
| **FRENCH SCALE WARMING LEVEL** | 2°C | 2,7°C | 4°C |

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5. "The point at which an actor's objectives (or system needs) cannot be secured from intolerable risks through adaptive actions." IPCC, 2022. Annex II: Glossary. In Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the IPCC Sixth Assessment Report.
6. In the case of nuclear facilities, for example – which is outside the scope of the issues addressed here – the scale of the potential consequences of an incident generated by a climate hazard means that even the least likely situations need to be anticipated. In such cases, it may even be appropriate to consider even more severe warming scenarios now, which, while currently considered less likely, are still possible. See for example, Senate, 2023. "Pour une approche systémique de l'adaptation des centrales nucléaires au changement climatique".

**Although these issues are only now emerging – and the first objective of the PNACC3 must be to accelerate the process of addressing them – it is already possible to draw robust conclusions on the costs to be expected for adaptation in France. These results are the first building blocks of work that will have to be part of an ongoing process.**

# II. ASKING THE QUESTION NOW ENABLES MORE EFFECTIVE ANTICIPATION AND COST SPREADING

## 1. With no additional anticipation: an adaptation that will be reactive and costly, particularly for public finances

**In each of the three sectors studied, the baseline pathway is often reactive and accompanied by consequences that have particularly heavy impacts on public finances and the economy.**

### THE MOST COMMONLY OBSERVED FORMS OF UNPLANNED ADAPTATION

**BUILDINGS**

- Increased and unorganized use of air conditioning in buildings, which has repercussions on energy bills and generates negative externalities (GHG emissions, reinforcement of urban heat island effect) – already represent **several billion euros annually** distributed across the economy.
- Repairs following climate hazards – for example, rectifying the foundations of buildings affected by cracking caused by the swelling and shrinking soils. Already costing an average of nearly **€2 billion annually** for homeowners insured against swelling and shrinking soils and flood risks.

**TRANSPORT**

- Repairs – often restoring to the original state – following extreme climate events – for example, **several hundred million euros** after Storm Alex.
- Increased maintenance activities to address the accelerated wear and tear on equipment caused by climatic stresses: lifespan of equipment can be reduced by several tens of percent.

**AGRICULTURE**

- Changes in cropping practices over time (e.g. shifts in cropping calendars).
- Emergency irrigation.
- Forced recourse to imports.
- Emergency compensation for losses to ensure farm survival. More than **€400 million annually** in compensation and support for agricultural crises linked to climate hazards in 2021 and 2022.

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**Generally speaking, these reactive measures do not entirely eliminate the losses generated by climate impacts.** Interventions on transport networks, for example, are not always immediate and lead to service reductions through the imposition of temporary speed restrictions or longer diversion routes during the period until the work is complete. Air conditioning is not accessible to all and does not eliminate health risks, leading to higher healthcare costs during heatwaves or the loss of productivity in many economic sectors.[7]

7. For more details on these subjects, see the CESE opinion "Travail et santé environnement: quels défis à relever face aux dérèglements climatiques?" (2023).

**These losses are often partly covered by the public authorities through crisis support or public insurance mechanisms.** Indeed, once damage has been caused, a high level of expectation is placed on public officials – elected representatives, government bodies or local authorities. It is therefore not unusual for decisions to be taken on an emergency basis, not only to ensure the safety of people and property, but also to restore certain service levels as quickly as possible and to minimize the impact on the economy and public opinion. Direct coverage of costs is therefore the most immediate solution. For example, the day after Storm Alex hit the Alpes-Maritimes Department, the French President announced the release of **several hundred million euros for reconstruction** *(CGEDD and IGA, 2021).*

➜ **As the impacts of climate change intensify, and without raising the level of anticipation, we can expect a continuous increase in costs and in the need for intervention to repair what we have not anticipated. These needs will increase pressure on public authorities and budgets, sometimes to the detriment of other priorities.** For example, extra spending on repairs to transport infrastructure is often at the expense of planned investment in improvements[8]; repairs to buildings affected by climate change impacts puts a strain on public insurance mechanisms[9]; agricultural crises impact the cash flow of farms, slowing down investment in the transition.[10]

## 2. However, anticipation options have been clearly identified and could be better deployed

Options for reducing upstream vulnerability are available today, and while these options cannot eliminate all repair costs and residual damages, they would minimize the impact of climate hazards on populations, territories and the economy.

Firstly, **organizational measures** would enable us to maximize the potential of windows of opportunity to account for climate changes and to optimize our responses. However, these options involve **additional investment** to increase the robustness of work already scheduled (e.g. to renovate buildings or modernize infrastructure), to address hot spots of vulnerability, to deploy preventive solutions and even to prepare for more far-reaching transformations (by investing in new agricultural sectors, for example) *(I4CE, 2022).*

These options can sometimes be deployed at limited cost – in particular by incorporating adaptation into the specifications of already planned investments.

8. "The increase in natural risks is creating competition in the allocation of funds to the detriment of traditional maintenance", (Cour des comptes, 2022, 42)
9. See for example CCR, 2023. "Conséquences du changement climatique sur le coût des catastrophes naturelles en France à horizon 2050" and Sénat, 2023. "La sécheresse ébranle les fondations du régime CatNat".
10. I4CE. 2024. "Estimation des dépenses publiques liées aux crises agricoles en France entre 2013 et 2022" ; Cour des Comptes. 2023. "La politique d'installation des nouveaux agriculteurs et de transmission des exploitations agricoles"

## ADAPTING PROJECTS AND ALREADY PLANNED INVESTMENTS

### BUILDINGS

- Revision of thermal regulation for buildings and risk prevention plans to ensure new construction takes the future climate into account. (For new buildings, for example, the extra cost of adapting to heatwaves is estimated at between 2% to 5%).
- Incorporate adaptation targets into the specifications for already planned energy renovation projects. For example, for housing, provisional targets resulting from the revision of the SNBC leads to a need for 900,000 deep renovations per year: taking into account the futur heatwaves leads ton additional costs of 10% in this operations.

### TRANSPORT

- Updating technical standards to ensure that all new transport system developments are adapted by design.
- Incorporate adaptation objectives into specifications for renewal and modernization projects, so that work programmes can be adjusted accordingly.
- Already scheduled projects should enable work to proceed on a large proportion of the network in just a few years.
- Additional costs vary depending on the operation, and can be virtually insignificant or represent increases of only a few percent.

### AGRICULTURE

- Implementation of recommendations arising from resilience analyses during a farm succession – a period often accompanied by new investment in production facilities.
- 43% of farmers are now over 55 and are likely to retire and sell their farms within the next 10 years.

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For other cases, specific works on the existing structure may also be necessary.

**Room for manoeuvre varies depending on the situation.** For example, while it is easy to devise policies with varying degrees of ambition for adapting existing buildings to heatwaves by drawing from a well-known range of existing solutions, this is less the case when it comes to the swelling and shrinking soils, as the range of options is more limited, with very few preventive solutions that are not still experimental or too costly in relation to the amount of asset exposure.

## NOT ALL ADAPTATION OPTIONS HAVE A CLEAR ECONOMIC MODEL

### ECONOMIC CO-BENEFITS

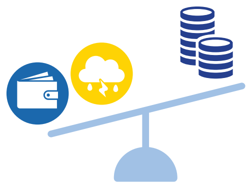
**Some measures (which can be described as "no-regret") generate economic co-benefits which are in themselves sufficient to justify their introduction**. This is the case, for example, with certain incremental agricultural adaptation measures which, even before providing protection from climate events, improve nominal yields.

**> MEASURES CAN BE DIRECTLY PROFITABLE**

### RISK REDUCTION BENEFITS

**Some measures can be justified as risk reduction measures, when it is clear that the costs of anticipation are lower than the costs of repairs for the project owner.** This is the case, for example, with measures to better account for the risks swelling and shrinking soils for new buildings in high-risk areas, where reinforcing foundations is much less costly during construction than making repairs once damage has been observed.

**> ACTION CAN BE JUSTIFIED AS RISK REDUCTION MEASURES**



### SOCIO-ECONOMIC BENEFITS

**Some measures will never be profitable for a building owner, an infrastructure manager, a farmer or a private insurer who,** in some cases, would not save money by anticipating rather than waiting and repair damage. This does not mean that the best option in these cases is not to take any anticipative action, but that adaptation cannot be based on strictly economic grounds, but instead must take account of socio-economic externalities, i.e. costs and benefits that are more widely distributed across the economy. For example, the cost of repairing a railway line following flooding might not justify upstream improvement work, but the consequences of temporarily interrupting traffic is likely to be unacceptable for users and the local economy. Anticipation then becomes a political choice reflecting a collective preference.

**> ACTION CAN BE JUSTIFIED IN TERMS OF SOCIO-ECONOMIC EXTERNALITIES**

**Lastly, some measures have no economic model or socio-economic justification in the current situation at today's level of knowledge.** For these, the relevance of adaptation measures must be reassessed as new information emerges. In the case of swelling and shrinking soils, deploying the existing preventive solutions on all houses at risk would require a very high overinvestment (potentially reaching several tens of billion euros). This far exceeds the cost of addressing the damage each year. The information available at present means that it is difficult to target the most vulnerable homes.

**> ACTION MAY NEVER BE WORTH THE BENEFITS IT MIGHT BRING**

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→ **The conclusion of this work emphasizes that without proactive organized action, it is highly likely that the adaptation trajectories adopted will be the most costly for public finances and the least satisfactory from a socio-economic perspective. Better anticipation will often lead to significant reductions in total costs and, above all, spread these costs more evenly. Numerous anticipation options have been identified and are beginning to be costed, but they still need to be combined within adaptation strategies that are designed on the basis of reliable vulnerability analyses. Implementing these strategies could cost several billion euros a year for all actors involved. While some options will be intrinsically profitable, this will not be the case for all, leading to the opening of a debate on financing adaptation in France.**

## BOX: FURTHER STUDIES NECESSARY

To provide more precise figures on adaptation needs, two types of information are currently lacking and should be the subject of in-depth sectoral work:

1. **Better objective assessment of the vulnerabilities at different levels of warming.** As well as identifying the risks, we need to better define the thresholds of robustness: which events (e.g. late frosts that can damage fruit harvests), which situations (e.g. extended periods of dry or wet weather that can affect building foundations) and which conditions (e.g. daytime temperatures above 35°C that can damage road surfaces) cause systems to start malfunctioning, economic models to become unbalanced, etc.

2. **Efficiency analyses (prior to cost-effectiveness analyses) of the various adaptation options.** It remains difficult to precisely quantify the benefits that can be obtained by deploying adaptation measures in real-life situations (for example, how adding solar screens to buildings can affect air-conditioning requirements during heatwaves).[11]

11. The first elements of this type have been identified for the agricultural sector as part of this project.

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# SECTORAL **CHAPTERS**

## → Buildings

Authors: **Guillaume Dolques** *(I4CE)* with the participation of **Cristhian Andres Molina Calderon**, **Sakina Pen Point** and **Morgane Moullié-Chauvet** from the Observatoire de l'Immobilier Durable *(OID)*

## → Land transport infrastructure

Authors: **Vivian Dépoues** *(I4CE)* with the participation of **Marine Lericolais, Michael Gonzva, Sébastien Bucourt** *(SETEC)* and **Thibault Laconde** *(Callendar)*

## → Agricultural crop production

Authors: **Vivian Dépoues**, **Lucile Rogissart** and **Joséphine Despres-Diry** *(I4CE)* with input from the modelling work carried out by **Florent Baarsch**, **Camille Sansonnet**, **Issa Awal** et **Vhiny Mombo** *(FINRES)*

# BUILDINGS


## Abstract

The majority of existing buildings have not been designed to cope with current and future climate risks. Events in recent years have provided a good illustration of the level of (in)adaptation of the building stock. In 2022, for example, **€2.9 billion** in insured damages was recorded as a result of drought *(CCR, 2023a)*. This figure was on average only €466 million per year during the 2000s. As the climate changes, the exposure level of the building stock will increase sharply and, if no adaptation measures are taken, the consequences will similarly increase: a 2.7°C warming is expected to result in annual damages amounting to **€3.3 billion per year**; with health impacts during heatwaves at this same warming level estimated at between **€7 and €12 billion per year**, part of which is attributable to buildings.

Confronted with these phenomena, a form of reactive adaptation is already underway, which is being implemented just before, during or immediately after crises: heatwaves are driving households to install air conditioning, which already represents a significant investment, averaging around **€3.5 billion annually** for housing; floods and drought damage is covered by insurers who, for the most part, fund work to restore buildings to how they were originally. These forms of adaptation raise questions because some of them have the potential to generate negative externalities, while other are already close to their limits, as is the case with the reinsurance system, which is already stretched beyond capacity.

When it comes to adapting to heat waves, alternatives are already available: solutions other than air conditioning are already known. Above all, planned investments in other areas (such as deep energy renovation and new construction) already offer co-benefits for adaptation. Going a step further will entail additional costs and therefore additional investments will be needed – between **€1 billion** and **€2.5 billion annually** for new buildings and **€4.4 billion annually** for existing buildings once energy renovation investment has reached its full potential – while also enabling the limiting of health impacts and the use of air conditioning, which is likely to become unavoidable at a warming of 4°C.

Regarding the swelling and shrinking soils, there is a need for targeted prevention measures and for research into new solutions, because the currently available options for existing buildings, which are either costly or experimental, do not enable to conclude to a better adaptation scenario.

Finally, for flood and forest fire risks, the key question concerns territorial dynamics: while measures can be deployed at the building level, it is primarily at the level of districts or towns that collective action becomes more coherent, and for this reason strengthening such action is particularly important.

To go further, a number of organizational measures could be implemented immediately to support industries, develop solutions and drive adaptation policies. Some of these needs have already been estimated and we believe they remain relevant today: **€31 million annually** for heatwaves, **€100 million annually** for the swelling and shrinking soils and **€125 million annually** for floods.


## Buildings have not been designed to cope with climate hazards: the economic consequences are already visible

The majority of buildings were constructed at a time before prevention planning was on the agenda (for floods or forest fires), and nor were there specific construction provisions to protect against extreme heat, flooding or the risks caused by the swelling and shrinking soils. Although provisions now exist to prevent building in the most at-risk areas, they do not yet take future climate change into account: **risk zoning is based on the current climate, while thermal regulation use the 2003 heatwave as the reference for an extreme.[12] Most importantly, the question of how to adapt the existing building stock is the subject of little discussion, particularly regarding renovation projects.**

12. Taking account of prospective rather than historical data when drawing up and updating risk prevention plans, building standards, town planning schemes, etc. is one of the major challenges for adaptation. The proposed Reference Warming Trajectory (TRACC) now provides a consistent framework for doing this. The challenge now is to ensure that this trajectory is used correctly in all of these reference frameworks, standards, plans, etc. The National Plan for Adaptation to Climate Change (PNACC3), due to be adopted in 2024, could provide some answers in this respect.

**There have already been significant direct consequences, as well as an upward trend in the costs incurred in recent years.** These include damage caused by floods and droughts. For example, the average annual cost of the impacts of drought is currently estimated at **€726 million**, compared with **€466 million** in the 2000s. Socio-economic impacts (some of which are attributable to buildings) have also been observed, particularly during heatwaves: health impacts, reduced productivity, etc.

## Without improving our level of anticipation, we can expect rising costs and socio-economic consequences for buildings and communities

Climate change will inevitably increase the exposure of buildings to extreme climate events by impacting on already exposed areas for longer and with greater intensely and, more significantly, by impacting on additional areas that have not yet been affected. Work carried out in partnership with the OID has enabled these trends to be studied at temperature rises of 2°C, 2.7°C and 4°C *(OID, 2024)*.

### BOX: EXTRACT FROM THE ANALYSIS CARRIED OUT BY THE OID:

| PERCENTAGE OF BUILDINGS AT HIGH AND VERY HIGH RISK | HEATWAVES | DROUGHT | FOREST FIRES | PLUVIAL FLOODING |
|---|---|---|---|---|
| + 2°C | 48% | 35% | 30% | 31% |
| + 2.7°C | 70% | 69% | 39% | 46% |
| + 4°C | 93% | 78% | 43% | 48% |

**> HOW EXPOSED ARE BUILDINGS IN FRANCE AT A 4°C INCREASE? (OID, 2024)**

**HEATWAVES:**

- Almost the entire country (>90%) will be heavily or very heavily exposed. Urban areas will be most affected (96%).
- Urban areas that are currently only slightly to moderately exposed will become very heavily exposed (e.g. Caen, Le Havre, Calais, Dunkirk, etc.)..

**DROUGHTS AND SWELLING AND SHRINKING SOILS:**

- More than two thirds of France will be very heavily exposed (compared with 12% at a 2°C rise), with significant geographical disparities.

**FOREST FIRES:**

- Risks are currently concentrated in the south of France, with 80% of Mediterranean areas exposed to very high to exceptional levels of risk.
- At a 4°C rise, almost half of the country will be highly or very highly exposed.
- Rural and suburban areas will be particularly affected.

**PLUVIAL FLOODING:**

- The northern and north-eastern regions will be the hardest hit: more than half the buildings will be very heavily exposed.
- In urban areas, more than half of the surface area will be very heavily exposed.

## Action is already underway, but it is insufficient in the face of climate change

**We are already seeing initial forms of adaptation, which can be described as reactive** since such steps generally take place just before, during or immediately after major events. For example, during heatwaves, households and businesses invest in air conditioning equipment (and also fans). The costs of these adaptations are often not considered in concrete terms, but they are nonetheless very real.[13] Such equipment is already having a significant impact (in terms of energy consumption, greenhouse gas emissions, increased heat in urban areas, etc.), which will continue to increase as such measures continue to be deployed *(ADEME and Coda Stratégie, 2021)*. At the current rate, it is possible that by 2050 almost the entire building stock could be supplied with such equipment.[14] Another example of reactive adaptation is when floods or the swelling and shrinking soils cause insurers to pay compensation, which is used to repair or reconstruct buildings, usually to previous standards.

13. An initial estimate made as part of this project put the current level of investment in air conditioning systems and reversible devices (which also provide heating) at around **€3.5 billion a year.**
14. It is estimated that 1.3 million appliances are currently sold each year (ADEME and Coda Stratégie, 2021). This corresponds broadly to the number of homes that would need to be equipped each year for 95% of the housing stock to be equipped by 2050.

**These forms of adaptation nevertheless raise questions.** Either because they generate negative externalities, or because they are already close to their limits, as is the case for the French CatNat scheme (which reinsures damage linked to drought and flooding):

> "*A typical case of maladaptation would be the large-scale deployment of air conditioning […]. This solution would have two harmful consequences: first, it would increase $CO_2$ emissions, which would exacerbate the impact of climate change; second, it would increase the temperature outside of buildings."* **(Cour des comptes 2024)**

> "*It is estimated that the cumulative cost of claims for drought between 2020 and 2050 would be €43 billion, a threefold increase compared to the previous three decades. The CatNat scheme would therefore no longer be able to generate enough reserves to cover claims by 2040."* **(Sénat 2023)**

| THE IMPACT OF CLIMATE CHANGE ON BUILDINGS… | …TODAY | …TOMORROW, IF ACTIONS ARE NOT TAKEN TO IMPROVE ANTICIPATION |
|---|---|---|
| DIRECT IMPACT ON THE BUILDING ECONOMY | Deployment of air conditioning: **€3.5 billion annually** for housing. | The rate is already high and if the trend continues then almost all of the building stock will be equipped by 2050. |
| | • **€726 million annually** on average for swelling and shrinking soils (*CCR, 2023b*) **(€2.9 billion** in 2022, *CCR, 2023a*) + uninsured losses (between **€630** and **€840 million annually,** *Senate, 2023*).<br>• **€979 million annually** on average for floods *(CCR, 2023b)*. | • **€2.1 billion annually** on average for swelling and shrinking soils at 2.7°C.<br>• **€1.2 billion annually** on average for flooding at 2.7°C *(CCR, 2023b).* |
| WIDER CONSEQUENCES FOR THE ECONOMY AND THE POPULATION | Health impact of heatwaves in France estimated at between **€22 and €37 billion** for the period 2015/2020 *(Santé publique France, 2021).* | Possible doubling of health impacts during heatwaves: **€7 to €12 billion annually** on average at 2.7°C *(OID, 2023).* |
| | Loss of productivity recorded during heat waves: **0.2%** over the 1981-2010 period in Europe *(García-León et al., 2021).* | **1.6%** of Europe's GDP at 4°C, with considerable variation: **3%** on average for the Mediterranean regions and up to 8% for those worst affected *(Szewczyk, Mongelli, and Ciscar, 2021).* |
| | Negative externalities due to air conditioning *(ADEME and Coda Stratégie, 2020)*:<br>• 15.5 TWh *(2020)*;<br>• 4.4 Mteq$CO_2$ *(2020)*;<br>• Increase of between 0.25°C to 1°C in Paris temperatures during the period of use *(Météo France, 2010)*. | • Electricity consumption would double in a trend scenario (*ADEME and Coda Stratégie, 2021*);<br>• GHG emissions are not expected to increase significantly, due to anticipated regulatory changes on refrigerant gases (F-Gaz directive);<br>• Increase of 0.5°C to 3°C in Paris if there is a doubling of the number of units. |

## Planned investments that offer co-benefits for adaptation, especially if the warming level remains limited (close to the current climate)

In reality, we are not starting from scratch. Every year, public and private investment is needed to make buildings more efficient (an average of €9.1 billion in annual investment needs between now and 2030 for new construction[15] and €44 billion annually to meet energy renovation targets, I4CE 2023) and to prevent certain risks: every year around €200 million is earmarked for floods.[16] These investments, initially planned outside of any climate change consideration, often have significant adaptation co-benefits: energy renovations, such as insulation or ventilation, usually improve thermal comfort in summer *(Viguié et al., 2020; OID, 2021)*, while prevention helps to reduce the number of insurance claims *(CCR, 2023c)*, etc.

> ***"Mitigation and adaptation can go hand in hand. Thermal renovation of housing that incorporates thermal comfort in summer [...] makes it possible both to reduce emissions and to better withstand heatwaves."*** **(HCC 2021)**

### **BOX:** AN OVERLY OPTIMISTIC OUTLOOK, EVEN BEFORE THE ISSUE OF ADAPTATION AROSE

Taking planned energy renovation investment for granted to define the need for additional investment in adapting buildings is already optimistic. At the moment, France is not meeting its energy renovation targets: for housing, 900,000 deep renovations would be needed annually by 2030 to meet objectives, a level that is well above the number of deep renovations financed by MaPrimeRénov', which currently stands at around 66,000. The additional requirement necessary to achieve the 900,000 deep renovations target is estimated at around €27 billion a year *(I4CE, 2023).*

However, by not taking climate change into account when making these investments, there is a risk of missing out on measures that could have been implemented at the same time or designed differently. For example, installing solar protection or changing the type of insulation could enhance building performance. Neglecting climate considerations may result in buildings with inadequate thermal comfort or counterproductive measures such as achieving very good draft-proofing without enabling ventilation at night. This observation is reinforced at projections of higher temperatures.

> ***"Even if these climate change mitigation regulations contribute concomitantly to the objective of adaptation, it seems necessary and urgent to complement them with measures specifically targeted at this objective."*** **(Cour des Comptes 2024)**

15. This amount corresponds to annual investments in items that contribute to the energy performance of new buildings: insulation, joinery, ventilation, heating systems, etc.
16. Not all of these investments can be atributed to buildings: risk prevention also concerns development projects, awareness-raising initiatives, etc.

## Alternatives for more proactive adaptation are available

**In terms of adapting to heatwaves, an additional effort is required to ensure that the building stock is better adapted.** This means incorporating the future climate into existing policies and investments, rather than trying to design a dedicated policy: it means raising the issue of adaptation at crucial investment moments, which may entail additional costs. We are assuming an additional cost of between 2% and 5% for new buildings and 10% for deep energy renovations that go beyond current regulations on the issue of summer thermal comfort.[17]

FOR ADAPTATION TO HIGHER TEMPERATURES:

| | **NEW BUILDINGS THAT GO BEYOND REGULATIONS** BY IMPLEMENTING MORE STRATEGIES FOR THERMAL COMFORT IN SUMMER | **MORE AMBITIOUS RENOVATIONS** IN TERMS OF THERMAL COMFORT IN SUMMER |
|---|---|---|
| HOUSING | **Additional €0.7 to €1.8 billion annually** | **Additional €3.1 billion annually** |
| TERTIARY BUILDINGS | **Additional €0.3 to €0.7 billion annually** | **Additional €1.3 billion annually** |

*Amounts expressed as additional needs in relation to the public and private investment required to achieve carbon neutrality objectives (I4CE 2023), average over the period 2024-2030.*

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**This additional effort, although necessary, could prove insufficient if France experiences a warming of 4°C.** In other words, once a certain warming level is reached, it becomes difficult (or even impossible in certain climatic regions) to do without air conditioning. Nevertheless, the available evidence suggests that a staggered approach is preferable to retain some manoeuvre room: adaptation measures remain genuinely effective in improving thermal comfort in summer, enabling the resort to air conditioning to be avoided in the short term (and in the long term in certain climatic zones) and, above all, to greatly limit its usage *(ADEME et al., 2023; Viguié et al., 2020).*

**Regarding the swelling and shrinking soils for existing buildings, currently available solutions remain costly or experimental and do not enable us to draw conclusions on the best adaptation scenario that would be economically plausible:** given the scale of exposure and the costs of the options,[18] a highly proactive policy that aimed at adapting all housing at risk would quickly add up to costs of tens of billion euros per year.[19] This does not mean, however, that the issue of prevention should be neglected and the debate restricted only to addressing the damage. But it does mean that further work is needed to improve our understanding of potential solutions[20] and of building vulnerability, so that we can define an effective and targeted prevention policy.

**Flood and forest fire risks are essentially local in nature:** while measures can be deployed at the building level, it is primarily at the level of districts or towns that collective action becomes more coherent, and could be reinforced. It is at these levels that the policies (and therefore the costs) of adapting to these risks must be discussed, while the potential for action at the building level remains limited.

17. These additional costs may correspond to additional work carried out at the time of the operation (e.g. for new builds: installation of geothermal heat exchangers, for renovation: installation of solar protection) or to work carried out differently because climate change is taken into account (e.g. for new builds: construction of dual-aspect dwellings, for renovation: change in insulation thickness or material, different sizing of the ventilation system, etc.). These "generic" additional cost assumptions may conceal major disparities between projects. Nevertheless, we feel they are useful for providing an initial budgetary assessment of the cost of adapting buildings to heatwaves. They are the result of an in-depth analysis of existing elements in the literature and discussions within technical commitees. See the dedicated publication : https://www.i4ce.org/publication/vagues-chaleur-couts-adaptation-batiments-climat/
18. CEREMA (2022) estimates that 10.4 million homes are currently exposed to a medium to high risk. The cost of available preventive solutions often represents several tens of thousands of euros per house (Cour des Comptes, 2024a).
19. If we applied the costs of preventive solutions to all the homes at risk.
20. One example is the France 2030 call for projects on the prevention and remediation of building disorders caused by the swelling and shrinking soils.

## Exiting the default pathway involves short-term measures

While more proactive adaptation options exist, getting away from the default pathway will not happen without proactive action. A number of measures are needed to achieve this. First and foremost, such action involves organizational measures to support the industry, improving our understanding of the actors involved, investing in research and experimentation, and driving adaptation policies:

### PROPOSED ORGANIZATIONAL MEASURES TO SUPPORT CHANGES IN PRACTICE[21]

| HEATWAVES | SWELLING AND SHRINKING SOILS | FLOODING |
|---|---|---|
| • A package of actions worth **€31 million annually** to improve knowledge and stakeholder support, to invest in research and test existing solutions, etc. *(I4CE, 2022a)* | • Creation of a steering and coordination body: **€0.5 million annually**;<br>• An initial commitment of **€100 million annually** to fund prevention *(Ledoux 2023).* | • Allocate a number of FTEs to operate the flood risk prevention policy: two additional FTEs per flood prevention action programme (PAPI) **€12 million annually.**<br>• Maintain level of prevention that keeps pace with expected changes in risks: **€113 million annually** *(I4CE 2022b).* |

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In the medium term, legislation and incentives (risk prevention plans, environmental regulations and energy renovation grants) will also need reviewing to account for climate change. Without waiting, the lever of public procurement could be used to anticipate these changes.

21. Some of these measures were costed in a previous project, one of the aims of which was to identify the budgetary measures to be taken to prepare, strengthen or operationalize adaptation actions that are already ready (I4CE 2022b).

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# LAND TRANSPORT INFRASTRUCTURE: NATIONAL AND DEPARTMENTAL ROAD NETWORKS; NATIONAL RAIL NETWORK


## Abstract

The French rail and road networks are strategic infrastructures whose reliability is a key factor in both territorial cohesion and economic vitality. The level of adaptation of these infrastructures to climate change is also a condition of resilience for the economy in general.

The already planned investments to maintain and renovate these networks will help in their adaptation, particularly by eliminating maintenance backlogs. However, these improvements will prove insufficient beyond warming thresholds that are unfortunately plausible.

Should we fail to anticipate the future, we will be faced with an increasing annual bill for repairing damage caused by climate hazards (post-hazard reconstruction or the reduced lifespan of equipment) and a deterioration in service levels. Storm Alex in 2020 or the summer heatwaves of 2019 and 2022 has given us an idea of the reality of these costs – which amount to **hundreds of millions of euros annually** – which would increase in future.

There are, however, solutions for reducing upstream vulnerability to enable better anticipation of most of the risks associated with climate change. Some of these solutions can be deployed at the same time – and at a moderate extra cost – as other work already planned, such as modernization. Other options require additional investment that could represent **hundreds of millions or even billions of euros**, which would have to be part of intervention strategies that have yet to be developed, on the basis of more precise vulnerability studies.

In all cases, organizational adaptation measures must be implemented to ensure that managers, operators and organizing authorities are as well-equipped as possible to deal with climate change. These measures to develop expertise, planning, monitoring capacity, intervention and coordination represent several **tens of millions of euros annually** in terms of additional expenditure, but would ensure that the billions invested in transport infrastructure are put to good use.


## Networks are becoming more robust, but this is unlikely to be enough to cope with the level of climate change expected

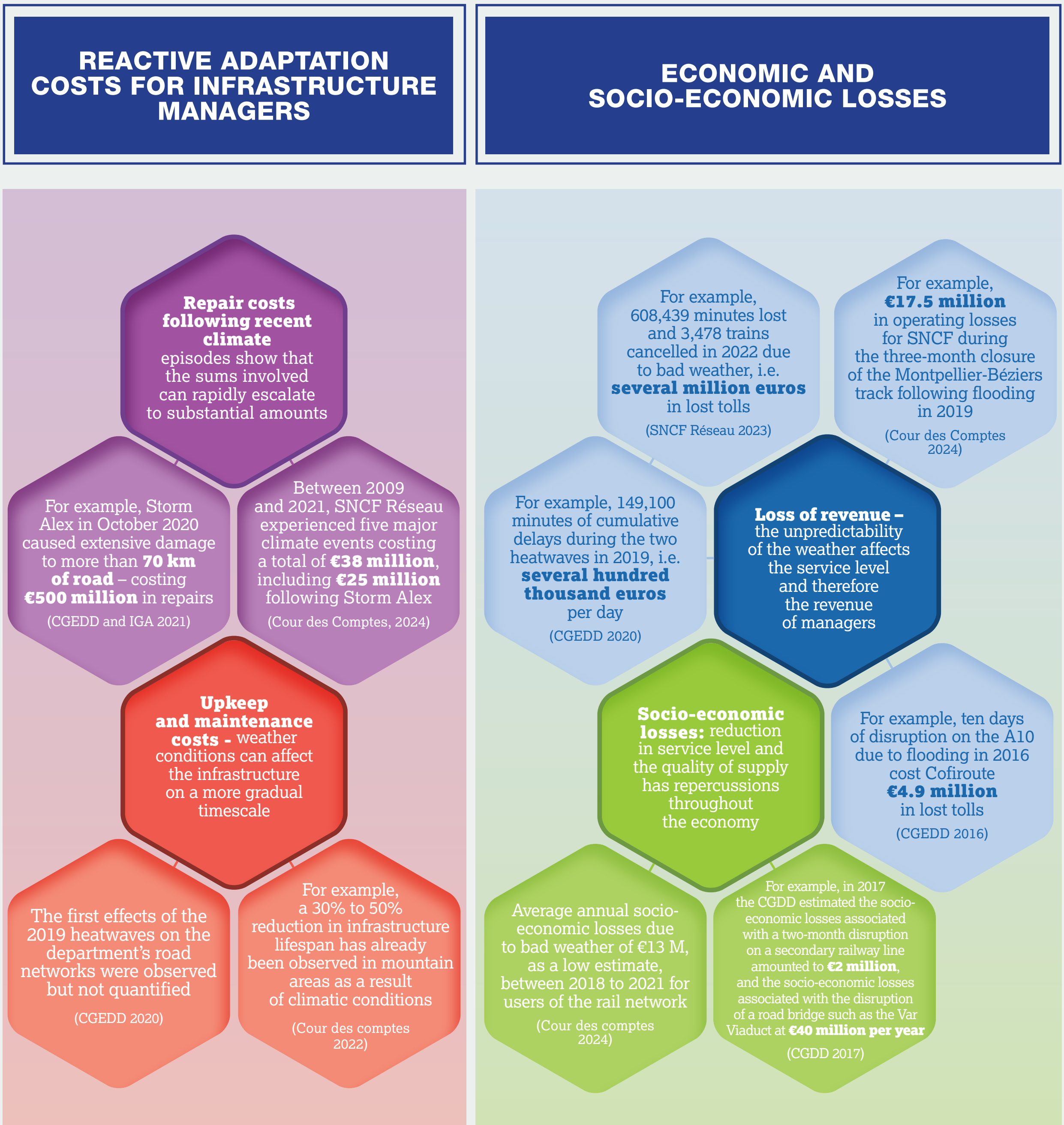
**Regular maintenance to ensure networks are in good working order is the first condition for adaptation.** The recent surge in investment programmes – in rail regeneration, for example – is generating a major co-benefit in terms of adaptation. In fact, the work carried out is enabling the elimination of vulnerabilities linked to age and the deployment of equipment designed to more exacting standards. Conversely, the risks associated with climate change impacts increase vulnerabilities whenever delays in maintenance, servicing or renovation accumulate.

**However, current modernization and renewal programmes will not guarantee sufficient adaptation – particularly for higher warming levels.** On the one hand, these programmes do not cover all of the vulnerable components of networks (road renewals do not, for example, include the upgrading of drainage works). Secondly, while today's reference systems and standards take better account of the current climate,[22] they do not systematically incorporate future climate projections and could therefore lead to under-sizing or inappropriate technical choices. The risk is that network operators will always be “one step behind” *(Cour des Comptes, 2024)*.

22. For example, the temperature range taken into account when laying new rails has already been adapted following the 2003 heatwave.

## Without further anticipation, we can therefore expect a continued rise in the costs incurred

### TWO TYPES OF COSTS ALREADY SIGNIFICANT AND A TREND ON THE RISE[23]

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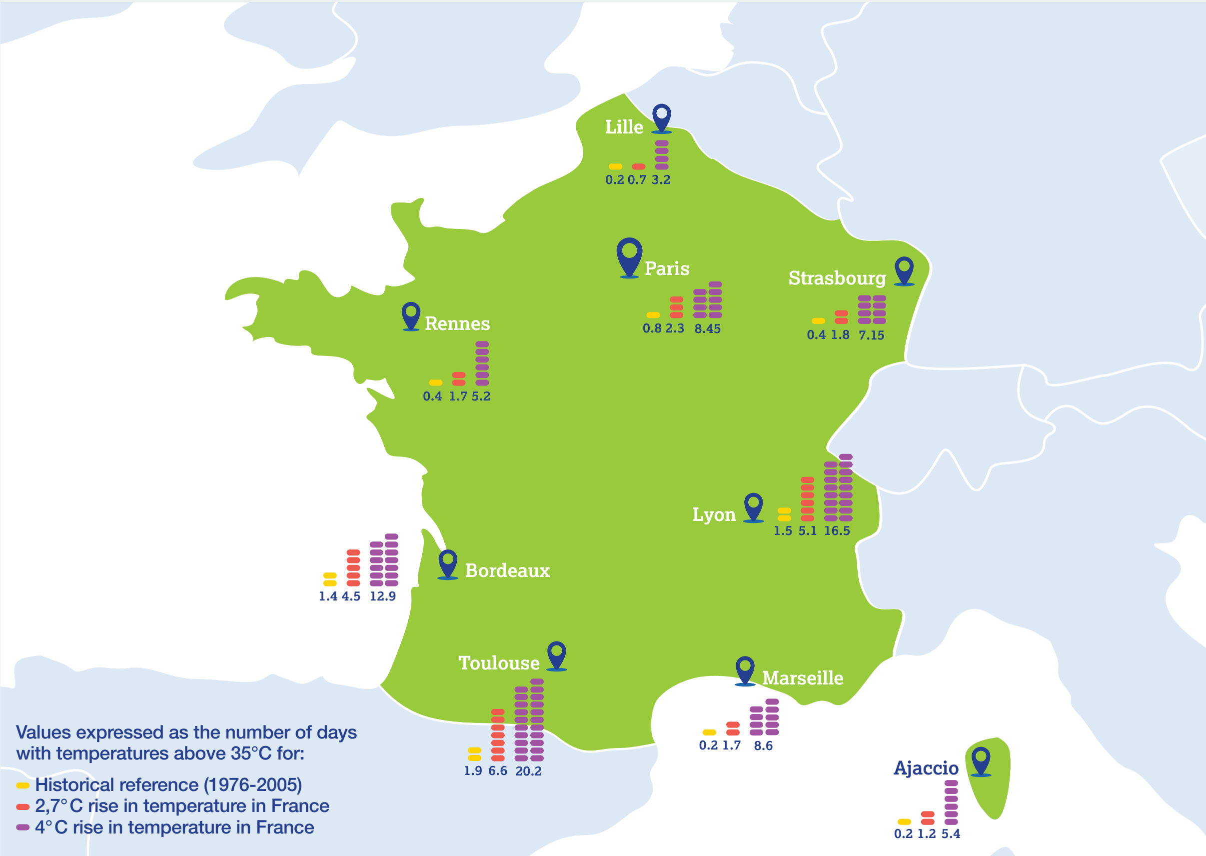
23. To date, there is no prospective modelling of the evolution of the costs of the impacts of climate hazards for transport infrastructure in France of the same type as those carried out by the CCR on the building stock or the electricity network. The development of such modelling would be very useful.

## The factors that generate these costs will increase with climate change

### EXAMPLE: NUMBER OF DAYS WITH TEMPERATURES ABOVE 35°C ACCORDING TO WARMING LEVEL

(TEMPERATURES ABOVE WHICH CERTAIN COMPONENTS OF TRANSPORT SYSTEMS CAN BE DAMAGED OR FUNCTION LESS WELL)




Source : I4CE based on https://pnacc3.climint.com/ (Callendar)

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*Climate change is also leading to an increase in the frequency and extent of flooding.”*
**(GIEC 2022)**

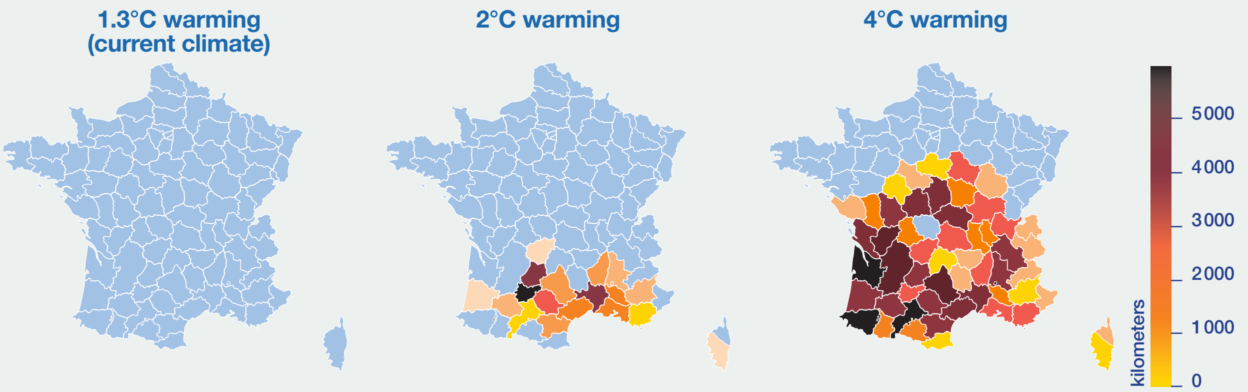
*Global warming of 3°C is likely to cause an increase in the intensity of extreme daily rainfall in France, particularly for a large proportion of the northern half of the country, while uncertainty will increase in the southern half.”*
**(HCC, 2024)**

**This will inevitably increase the proportion of vulnerable networks and therefore the need for repairs and maintenance, as well as the risk of losses if nothing is done to reduce the vulnerability of upstream infrastructure.**

EXAMPLE: PROPORTION OF NETWORKS EXPOSED TO HIGH OR VERY HIGH RISKS DUE TO HOT WEATHER

| | CURRENT CLIMATE | FRANCE AT 2°C | FRANCE AT 4°C |
|---|---|---|---|
| RAIL NETWORK | 1% | 2% | 46% |
| ROAD NETWORK | 2% | 11% | 75% |

**Example:** departmental roads exposed to temperatures > 35°C for more than 10 days a year on average




Source: Callendar analysis[24]

Heatwaves and flooding are currently the costliest risks for transport systems. However, they will also be affected by increases in other risks (forest fires, Swelling and shrinking soils, landslides, coastal erosion, etc.). More detailed vulnerability analyses will be needed to assess these changes in greater detail, taking local contexts into account.[25]

## There are options for better anticipation

Without necessarily reducing the level of risk to zero, various anticipatory options are already available to minimize impacts and keep costs under control. These options can be deployed over time in an organized way, to share the burden evenly among the actors involved:

24. Callendar is a French start-up specializing in climate risk assessment. As part of this study, it carried out geographical analyses of the exposure of transport networks to different climate hazards. http://callendar.tech/
25. SNCF Réseau has already carried out initial studies on its network, concluding that, in the absence of adaptation, there will be a significant increase in irregularities (ranging from a doubling in 2050 to an elevenfold increase in 2100 depending on the warming scenario (Cour des Comptes, 2024)). More detailed studies based on the assumptions of the reference warming trajectory are planned. For the national road network, a national vulnerability study has been initiated and should be completed in 2025.

| RELATIVELY LIMITED ADDITIONAL COSTS FOR EXISTING PROGRAMMES | LOW BUT CRITICAL ORGANIZATIONAL COSTS | POTENTIAL NEED FOR DEDICATED INVESTMENT PROGRAMMES |
|---|---|---|
| • **New infrastructure adapted by design.**<br><br>• **Integrating adaptation into regeneration and modernization programmes[26]:**<br><br>There is a lack of precise data on the additional costs associated with the integration of more stringent requirements into construction/renovation programmes. While the European Adaptation Strategy mentions an additional cost of 3%[27], this may conceal the full diversity of situations. Sometimes there are no additional costs at all, whereas sometimes they can be very high – for example, the use of more resilient asphalt mixes increases costs by 15-20%, or even higher if, for example, a bridge is used instead of culverts.<br><br>*For reference: 1% of annual investment in rail infrastructure represents around €50 million annually; 1% of public authority road spending represents €90 million annually.* | Hard adaptation measures can only be successfully deployed if they are preceded and accompanied by organizational measures. These are often inexpensive, "low-regrets" measures. They include, for example:<br><br>> Using management tools to take better account of climatic parameters in planning, operation and maintenance (e.g. monitoring climate services, predictive maintenance);<br><br>> Strengthen each infrastructure manager's organizational capacity (e.g. diversification of skills, strengthening of response capabilities).<br><br>➜ These organizational costs represent several **tens of million euros a year.[28]** | Based on the results of a vulnerability study, specific issues could be identified. Depending on the strategic choices made in response, additional investment may be required. For example:<br><br>> Targeted work on network hot spots (e.g. insulation of electrical substations);<br><br>> Restoration of road drainage works:<br><br>– Works costing from **€2 million** (for simple culverts) to **€40 million** for complex engineering structures;<br><br>– Numerous structures of various types may be affected: for example, more than 2,500 known culverts on the national road network. |

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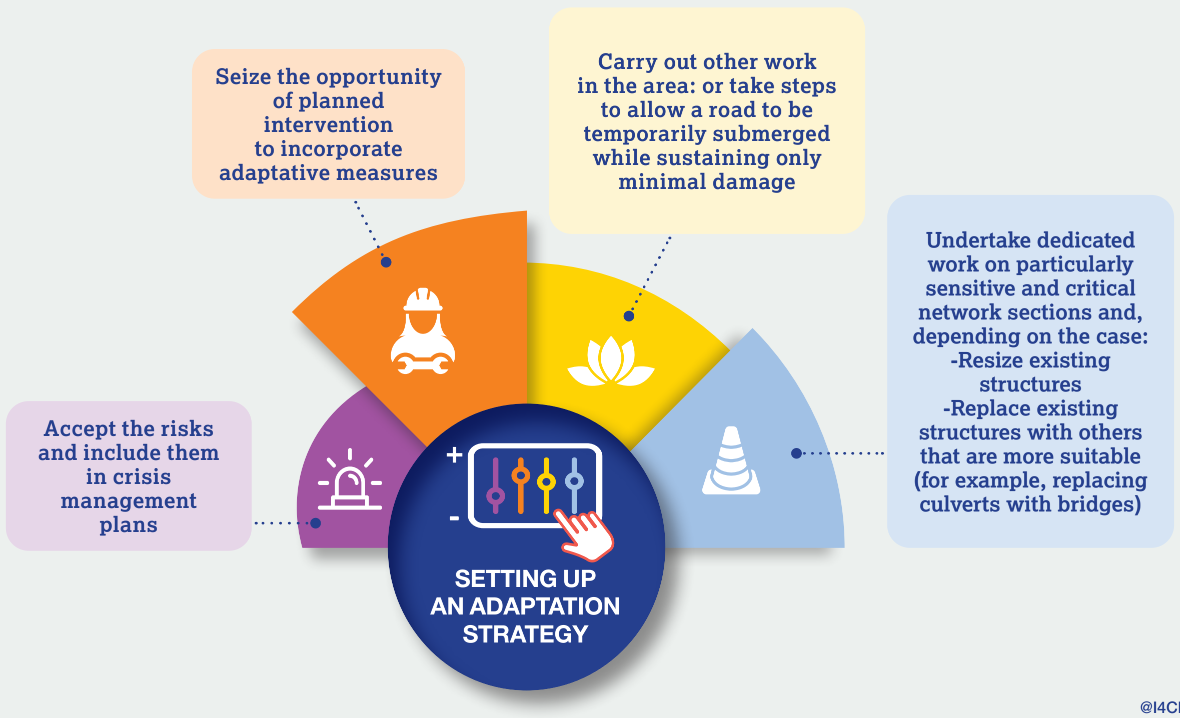
➜ **The current challenge is to determine the right size for the service level deemed socially desirable:**

***For example:***
Redesigning all the water management structures that protect infrastructure from flooding could cost hundreds of millions, or even billions of euros, and would involve very high impact work. But this is not the only possible strategy – on a case-by-case basis, it is possible to combine different response levels:

26. The Cour des Comptes gives the example of "the rail maintenance temperature, set as standard at 25°C throughout the rail network, [which] could be raised during all track renewal operations in regions most exposed to extreme heat" *(Cour des Comptes, 2024).*
27. The assumption of 3% additional cost is that used by the European Strategy (2021) based on international references. This indicative value should not be over interpreted. Feedback that is more specific to the French context would be useful – we have not been able to document this precisely, as examples of projects that take adaptation into account in their design generally do not compare their costs with or without accouncing for climate change.
28. This estimate was made as part of this project on the basis of the costs of individual actions that we were able to gather during interviews or deduce from the literature. For example, we have estimated that a 20% increase in vegetation management costs (corresponding to the type of low-risk extension hypotheses that we have been able to formulate elsewhere, QuantiAdapt, 2022) would represent more than **€30 million euros annually** for an operator such as SNCF Réseau. This figure will have to be specified in light of each operator's own strategies.

COMPOSING AN ADAPTATION STRATEGY: A COMBINATION OF OPTIONS




To date, regulatory requirements and economic incentives have not been sufficient to bring about comprehensive adaptation strategies. Given the importance of road and rail networks to the national economy and regional cohesion, more proactive public policies are needed to structure these debates and formulate decisions *(Cour des Comptes, 2024)*. These policies must be based on precise vulnerability analyses that are genuinely appropriate for managers and operators. Mobilizing the **several million euros** needed to conduct these analyses,[29] which can and should be budgeted for, is the first step in building adaptation programmes that are commensurate with the climate changes underway.

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29. A general vulnerability study on the scale of a regional network costs several hundred thousand euros, while more detailed analyses (e.g. high-performance hydrological studies) cost around €3,000 to €5,000 per km.

# AGRICULTURAL CROP PRODUCTION


## Abstract

The impact of climate change on French agriculture is already evident, in the form of yield losses, material damage and loss of income. In response, public measures are being taken to mitigate some of these costs. Very recent flooding in northern France, prolonged periods of drought, and the late frosts of recent years have all given insight into the sums involved, which are already running **into billions of euros annually**.

The overall trend is that climate change is having an increasingly negative impact on crop production. Confronted with this reality, the sector is gradually adapting, preferring to make incremental changes. Various public policies are also contributing to this reactive adaptation, particularly by supporting action such as agroecological measures or R&D efforts that offer co-benefits in terms of adaptation, or through plans aimed at improving crisis response. These policies mobilize budgets of **between ten and a hundred million euros annually**.

However, these adaptation measures remain insufficient, and a consensus is emerging in favour of a more proactive approach. The levers for such action have been identified, but their deployment costs are poorly understood. An innovative analysis carried out by FINRES as part of this project identified combinations of measures from a raft of technological solutions that would deliver net production benefits at up to a 4°C temperature rise in France. The total cost of these measures (which only cover a fraction of the available adaptation levers), should they all be deployed on farms across France with no changes in crop rotations, would be in the region of **€1.5 billion annually** over the next decade.

For limited warming levels, incremental adaptations could be sufficient, but beyond that, more significant transformations will have to be undertaken. Assessing the investment needed for these transformations is complex, as they involve a systemic change in the agricultural model.


## Climate change impacts on French agriculture have already been proven

A number of reports have reached the unambiguous conclusion that climate change impacts on French agriculture are already being felt:

> “*Impacts are clearly perceptible already, and the trend is accelerating.*”
> **(CGAAER 2023)**

> “*In France, the consequences of climate change on crop and livestock yields are already visible, and will continue to grow.*”
> **(HCC 2024)**

**These impacts are accompanied by significant costs for the sector.** These costs affect the incomes of farmers, food sovereignty in France, export capacity and food prices. They take the form of yield losses that lead to falling incomes and material damage – particularly to perennial crops and machinery – which already amount to **billions of euros per year**.

In its 2024 report, the High Council on Climate gave an overview of the recently identified costs:

## OVERVIEW OF THE COSTS OF IMPACTS IDENTIFIED BY THE HIGH COUNCIL ON CLIMATE (2024)


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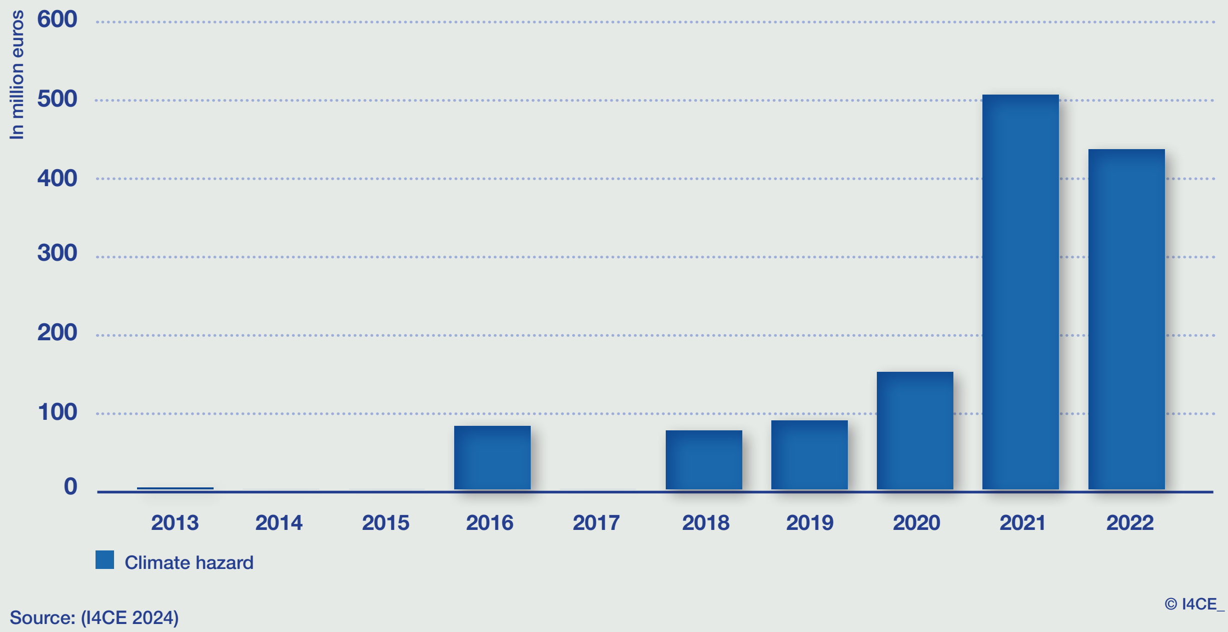
Given the economic, commercial and political importance of the agricultural sector in France, various public measures are regularly undertaken to cover some of these costs. This public management of risks takes several forms, such as public subsidization of the crop insurance scheme – up to **€600 million a year** – or one-off aid, for example, in the form of exemption from social security contributions. As noted in an I4CE study, public expenditure on climate-related hazards has risen sharply in the last five years:[30]

EXPENDITURE ON COMPENSATION AND MANAGEMENT OF AGRICULTURAL CRISES LINKED TO CLIMATE HAZARDS




Source: (I4CE 2024)

The observed increase is "essentially linked to recurring episodes of widespread drought in many regions of France. Some of the larger sums stem from major publicly-funded intervention following frosts (**€410 million in 2021**, for example)" *(I4CE 2024)*.

## An increasing trend overall

Although a level of uncertainty remains regarding the precise impacts of climate change on French agriculture[31] – which may vary considerably from one production type to another, and from one region to another – the overall trend is for an increasingly negative effect on production:

> ***"With global warming of around 2°C by 2050, without additional adaptation, crops in France would be exposed to additional yield losses, particularly summer crops such as maize."*** **(HCC 2024)**

30. The amounts shown in this figure are a minimum: a significant proportion of expenditure is not directly identifiable as "weather-related".
31. Among the main factors of uncertainty are water availability and the proportion of the $CO_2$ fertilization effect. Figures may also vary depending on the indicators considered: such as the effects on average yields, on the frequency and intensity of climate extremes, on variability around the average.

## Adaptations are already underway

**Confronted with climate change impacts that have already been observed, the sector is adapting spontaneously – favouring incremental changes so far, without any fundamental shift in production models** *(HCC 2024; CGAAER 2023)*. These adaptations take the form, for example, of changes to the farming calendar (such as earlier drilling or harvesting), choosing more drought-resistant varieties, making initial efforts to diversify or changing practices – for example, pruning vines and trees to lessen frost damage risks. It is very difficult to assess the costs to farmers of these adaptation measures, which are implemented over time and vary widely in nature.

### PUBLIC POLICIES ARE ALSO CONTRIBUTING TO THE INCREMENTAL ADAPTATION OF AGRICULTURE

#### POLICIES WITH ADAPTATION CO-BENEFITS

Some initiatives that are already underway, which are supported by working towards other objectives (e.g. sectoral decarbonization), have proven co-benefits in terms of adaptation. These include:

- **Investment in sectoral economic development:**
  - > For example the France 2030 call for projects to finance agricultural machinery: **€212 million** *(Cour des Comptes 2024).*
- **Support for agroecological measures** from regions, water agencies, CAP "eco-schemes" and dedicated programmes *(CGAAER 2022)* :
  - > For example, "Hedgerow program" **€110 million per year.**
- **Research and Development efforts,** with a particular focus on genetic improvement.

#### MEASURES TO IMPROVE EMERGENCY MANAGEMENT

Faced with climate change impacts, a number of plans with significant budgets have been drawn up in recent years, including:[32]

- **French "Water Plan", to irrigate more land without using more water:**
  - > **€30 million a year** devoted to supporting water-efficient farming practices (emergence of low-water consumption sectors, drip irrigation, etc.)
  - > Creation of an agricultural irrigation investment fund with **€30 million annually** to support the renovation of irrigation assets, substitution reservoirs and water-saving projects, or the use of treated wastewater.
- **Agricultural insurance reform:**
  - > Doubling of the subsidy for insurance and compensation for crop losses: from **€300 to €600 million annually.**

As the CGAAER (2022) notes, **"consolidating and strengthening support for these dynamics is a first type of 'essential' adaptation,** particularly in certain sectors that still have 'considerable' needs – for example, the research needs of arboriculture."

**However, this form of adaptation is likely to be insufficient, and growing consensus is emerging in favour of more proactive action:**

> *"However, it must be said that, despite a real increase in awareness, the response from the agricultural sector is not yet sufficient."* **(CGAAER 2023)**

> *"The adaptation of agricultural activities to the negative effects of climate change is reactive, and not sufficiently transformative to ensure resilience to address the multiple factors that are generating impacts that will continue to intensify."* **(HCC 2024)**

32. This list is not intended to be exhaustive, and other schemes could also be cited, for example other calls for projects under the France 2030 programme, such as protection against climate hazards **(€175 million)** or certain actions financed *via* the special allocation account for agricultural and rural development as part of the adaptation plan presented by the Chambers of Agriculture.

## Well-known adaptation options

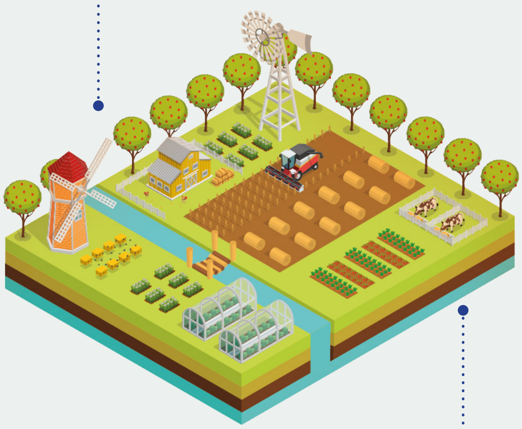
**The levers for more ambitious adaptation action have been clearly identified.** There is no single answer, but instead a range of solutions – "changes in crops, cultivation practices, cropping systems, genetic improvements, permanent soil cover, and irrigation where resources allow" *(CGAAER, 2023)* - that are specific to each territorial context.

As part of the "Varenne de l'eau" project on water and climate change adaptation, a group has drawn up an inventory of 100 technical levers to be used at three main levels – farms, fields and livestock (not covered here). In addition to research and innovation efforts, three main areas for action have been identified: (i) action on water resources; (ii) genetic selection; and (iii) changes in farming practices.

### LEVERS FOR ADAPTATION AT THE FARM AND FIELD LEVELS

**ACTING AT THE FARM LEVEL**

**ADAPTING CROP ROTATION**
- Diversify species and varieties grown,
- Adopt a stress avoidance strategy
- Choose adapted species or varieties
- Adapt the size and shape of fields

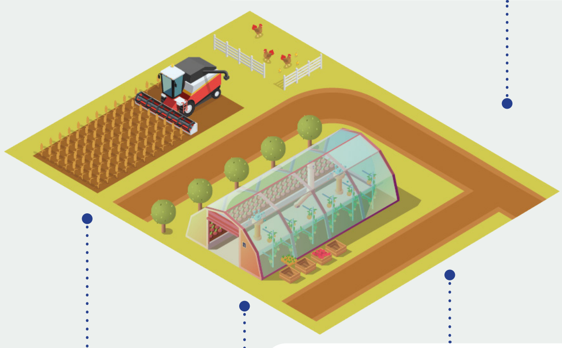


**MANAGING WATER RESOURCES**
- Mobilize renewable water resources
- Ensure a good distribution of water supply and limit losses
- Manage irrigation

**ACTING AT THE FIELD LEVEL**

**IMPROVING SOIL PROPERTIES**
- Adapt soil management practices
- Add organic matter to soil
- Limit compaction

**OPTIMIZING MANAGEMENT OF PERENNIAL CROPS**
- Increase sun protection
- Optimize grafting techniques
- Optimize planting



**GROWING UNDER COVER**
- Grow in the shade
- Control the green-house climate

**ENSURING MAXIMUM SOIL COVERAGE**
- Encourage the use of cover crops
- Field mulching

**ESTABLISHING AGROECOLOGICAL INFRASTRUCTURE**
- Maintain field margins
- Plant and manage trees

*Based on the infographic "What are the levers for climate change adaptation? Managing water and heat stress" Varenne agricole Eau et Changement Climatique*[33]

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33. Infographic produced by the ACTA, APCA and INRAE Research Innovation Transfer national coordination unit dedicated to speeding up the dissemination and transfer of solutions for the benefit of the agroecological transition, in collaboration with RMT ClimA. For more information, visit www.geco.ecophytopic.fr. (2022).

**Estimating the costs of deploying multiple solutions at scale to best mobilize these different levers remains a challenge. Nonetheless, some initial assessments have enabled us to pinpoint the orders of magnitude involved:**

An original analysis carried out as part of this project by the start-up FINRES[34] has identified combinations of measures from a range of technological solutions (see box) that would deliver net production benefits at warming levels up to 4°C. The total costs of these measures, if they were to be deployed across all French farms and with no changes in crop rotation, would be in the region of **€1.5 billion annually** over the next decade. These results also show that irrigation-based adaptation measures are often far from being the most attractive, primarily because of the energy and maintenance costs involved.[35]

## **BOX:** FINRES ANALYSIS[36]

The analysis carried out by FINRES used a machine learning process to create a statistical model for each crop that links yields to a set of climate variables. These models were applied to establish yield projections for different levels of global warming, based on the most recent regional climate projections, initially without adaptation measures and then by testing different measures and combinations of measures to select which were the most effective at increasing yields and protecting against losses linked to climate hazards.
The analysis was conducted for nine crops – soya bean; winter wheat; irrigated and non-irrigated maize; vines; sunflower; sorghum; field pea and sugar beet – with the intension of representing the main production types in France.[37] The work was carried out according to "geographical clusters" (i.e. areas that share climatic and physical characteristics: e.g. extensive plains, hills, mountains) and covered 86% of the French agricultural area.
The adaptation technologies tested were: irrigation; windbreaks (artificial or natural by using agroforestry); shading (artificial or natural by using agroforestry); and glasshouses. Very precise costing was carried out for all combinations of measure, making it possible to obtain average national-level net benefits in terms of adaptation for a ten-year period.
One of the conclusions of the analysis is that the benefits of some adaptation measures do not offset their costs, although this does not necessarily mean they are irrelevant, but that the decision on whether or not they should be implemented goes beyond purely economic considerations. This observation makes it possible to introduce the necessary discussions on the distribution of adaptation costs and financing methods. Some parameters that are not included in this analysis, such as effects on the trade balance or the social and environmental importance of agriculture, must also be taken into consideration.

Only some of the available adaptation technologies are examined in this analysis. Further studies would be needed to assess, for example, whether changes in crop rotation or crop substitution (e.g. replacing maize with less water-intensive crops in certain regions) could enable production levels to be maintained at lower costs *(DIVAE 2023)*.

34. FINRES specializes in modelling the costs of adaptation in the agricultural sector https://finres.org/about-us/
35. This does not take into account the costs of the collective infrastructure that would be needed to capture, store and transport the resource. As an initial order of magnitude, the CGAAER gave the following estimate for 2022: "Currently, three billion cubic metres of water are abstracted, based on the assumption that this volume will be doubled by additional storage (retaining winter water for the summer) at an average price of €6 per cubic metre, representing an investment of **€18 billion**."
36. Detailed results by region and by crop will appear in a dedicated publication in 2024.
37. For reasons of data availability and the time constraints associated with the study, it has not been possible to deal with the fodder crops that are essential for French agriculture, but these could be developed further.

## Lack of consensus on the level and pace of the required transformation

These initial assessments provide information on possible action, but do not point to a single adaptation pathway. Faced with changing climate risks, there are a number of potential approaches depending on the objective being pursued. Two main pathways are frequently contrasted *(CGAAER, 2023)*, each corresponding to a specific adaptation rationale:

| | |
|---|---|
| **PATH 1: PURSUING HIGH YIELDS WHILE ACCEPTING THE RISK OF GREATER EXPOSURE TO CLIMATIC AND ECONOMIC HAZARDS.** | **Incremental adaptation of the current model.** A combination of incremental measures and progress to offset the negative impacts of climate change to maintain a high level of performance for as long as possible. |
| **PATH 2: CHOOSING MORE RESILIENT OR MORE CONSISTENT PRODUCTION, AT THE COST OF LOWER AVERAGE YIELDS.** | **A more transformative pathway.** Some actors consider that maintaining the current model is not a viable option: it is too costly; too optimistic regarding the effectiveness of adaptation measures, or the conditions for their implementation (e.g. water availability); and does not adequately consider other environmental issues (e.g. impacts on biodiversity, landscapes, water quality and greenhouse gas emissions).<br><br>These actors therefore advocate a more systemic transformation of the agricultural model, even if it means calling certain fundamentals into question, for example by acting on demand for certain products (consume less, export less): "stable production, moderate consumption."<br><br>This vision of adaptation entails diversifying varieties and practices and reducing yield targets in optimal conditions to move towards lower yields that are more stable over a longer period, despite major disruption. |

The National Low-Carbon Strategy (SNBC), which sets a course for the agricultural system for the coming years, anticipates farm-level change but remains optimistic about agricultural yields, which are assumed to be constant for all production methods until 2050. To compensate for climate change impacts, this assumption relies on considerable technical and genetic improvement, along with changes in farming practices, to a degree that has not been described *(INRAE2023; Schauberger et al. 2018)*.

### Is this approach satisfactory in the long term?

The various reference reports already cited suggest that this is not the case:

> ***However, the agricultural sector "cannot be satisfied with half-measures, [and] will have to embark on genuinely structural changes. Genetic improvements and technical and technological advances alone will not suffice."*** **(CGAAER 2023)**

> ***Beyond global warming of 2.5°C, transformational adaptation will be needed to lower risks and help overcome the soft limits to adaptation.”*** **(HCC 2024)**

> ***According to INRAE, incremental adaptations will probably not be enough to cope with the climate changes forecast for the second half of the 21st century. It will be necessary to strengthen the resilience of production systems through more far-reaching transformations.”***
> **(Cour des Comptes. 2024)**

**Incremental adaptations could be sufficient for limited warming levels, but transformations will be necessary if warming exceeds these levels.** Even if decision-making horizons in the agricultural sector are often less than ten years, some options have a longer-term impact and relate to periods when the level of global warming could be higher. For example, when entrants take over a farm and decides on the direction of their business, they do so so in the expectation of a career that will go beyond 2050. Similarly, a component of the agri-food sector cannot be organized in a matter of months: experimenting with new crops, developing processing industries and opening new outlets all require the creation of long-term relationships with multiple actors, shaping markets for years to come. R&D cycles are also spread over long periods: for example, the HCC states that “the development of new breeds or varieties takes seven to ten years on average”. These decisions therefore need to account for the possibility of a temperature rise of at least 3°C in France, and therefore adaptation measures that are more transformative than those deployed to date.

**Assessing the investment needed to bring about such transformations is particularly difficult, because it is no longer a question of knowing the costs of one-off actions, but rather the “full costs of a change of system, which by its very nature means that our references are obsolete”** *(CGAAER 2023)*. It therefore becomes virtually impossible to separate the costs of adaptation from the more systemic costs associated with reorienting the entire economy of a sector towards a new model.

**A number of specific costs can be identified, but these only represent the ascertainable costs of a complete overhaul of the sector’s economic model**. For example, in 2022 CGAAER estimated the cost of supporting changes in practices, such as diagnostics or farm advice, at €150 million annually over four years *(CGAAER 2022).*

Costs that have yet to be assessed include, for example, investment in new production,[38] processing and distribution capacity, and expenditure on training or compensatory measures for those who lose out as a result of the transition. The costs of such transformations must be considered against the recurring costs of maintaining the current model.

38. By way of illustration only, the CGAAER estimated that by 2022 investment in replanting alone would cost **€600 million** to relocate 10% of French orchards *(CGAAER 2022)*.

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