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The economic effects of climate change

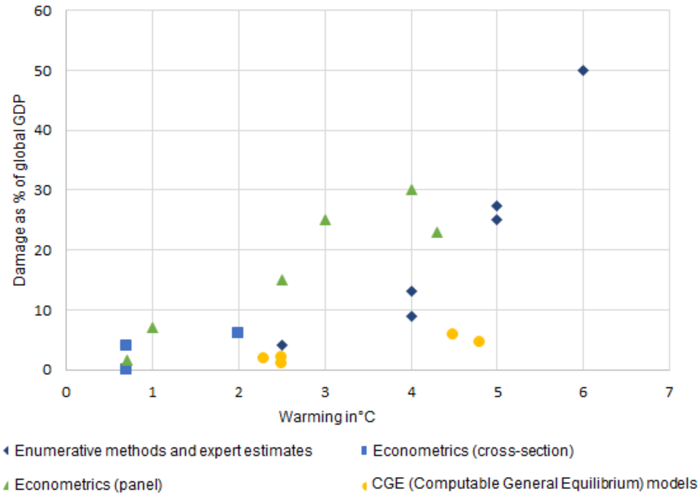
- Scientific consensus, including that of the Intergovernmental Panel on Climate Change (IPCC), has identified man-made greenhouse gas emissions as the cause of climate change. Without a determined effort to reduce these emissions, the living environment could be significantly altered during the 21st century. The cost of climate inaction can be estimated by assessing the economic and social effects of these changes.

- There are both theoretical and practical difficulties in assessing these effects: historical data linking economic activity and climate conditions is scarce and of inconsistent quality, while the large panel of potential economic and social impacts as well as the feedback loops between them make precise quantification uncertain. However, the available scientific evidence posits that climate change is likely to have a significant negative effect on global GDP. Uncertainty about the magnitude of this effect can be seen as another risk factor. Everything we know about climate change suggests that many of its effects remain unknown.

- The available studies at regional level also reveal substantial inequalities: countries closest to the equator may not only experience greater global warming, but may also be hardest-hit by its indirect effects (on health and on social and political stability) notably due to the weakness of their institutions and the predominance of agriculture, the most impacted sector. However, given the multiple transmission channels (epidemics, financial stability, trade, migration), no country stands to gain from climate change.

- Whether calculated using a cost-benefit analysis (by comparing the economic impacts of warming to the cost of reducing emissions) or from an insurance perspective (by considering warming as a risk), these studies argue for proactive public policies in favour of reducing emissions, which must be coordinated at European and global level.

Summary of damage as estimated in the academic literature



Source: Revue de littérature – DG Trésor.

Note: this graph summarises the results of 20 scientific papers providing estimates of the impact of climate change on global GDP. These estimates do not take into account all possible transmission channels of a rise in temperature on the economy nor the interactions between effects and can be considered as underestimates.

Since the establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988, a scientific consensus has emerged that climate change is caused by human activities, and in particular by man-made greenhouse gas emissions. Their effects are notably reflected in the rise in the average surface temperature of the earth's land and oceans, which, according to the IPCC, has already increased by an average of 1°C since the pre-industrial era. If current emission trends continue, warming is expected to reach between 3.2 and 5°C by 2100. In addition to temperature increases, climate change may also be characterised by structural modifications in the climate, such as changes in precipitation and humidity levels, or by an increase in the frequency and intensity of extreme weather events. Increasing concentrations of greenhouse gases could also have other effects on the environment, such as changes in ecosystems, ocean acidification, and rising water levels caused by the expansion of the seas and melting of ice.

These climate changes and their consequences on the living environment are likely to affect human activities, particularly the economy. The Stern Review on the Economics of Climate Change,[1] which was published in 2006 by the British Chancellor of the Exchequer, was the first to estimate the economic cost of different climate scenarios. Since then, the IPCC's work has clarified and enhanced global warming scenarios – whose outlook has worsened – and numerous analyses have been carried out to better estimate the economic impact of climate change. A review of this work, whether its approach is macroeconomic (1) or microeconomic (2), makes it possible to highlight the lessons to be drawn from it in terms of public policies (3).

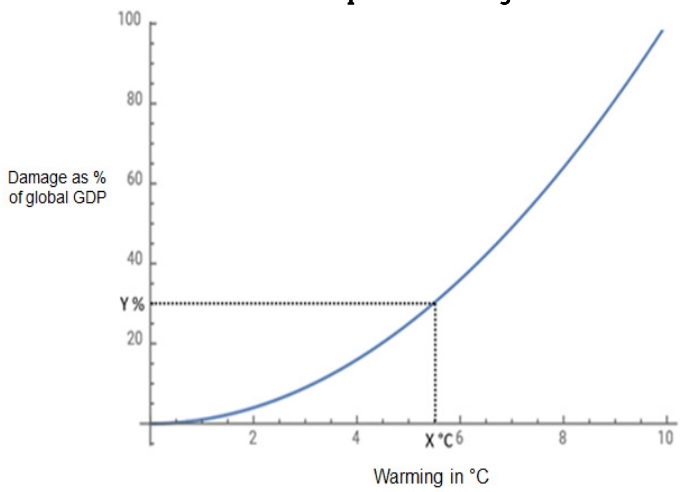
1. The macroeconomic effect of climate change

1.1 Resources for assessing effects on activity

The effect of climate change on activity can be estimated using the climate damage function, a model established by William Nordhaus. It links economic damage, estimated in points of GDP, and the rise in average temperatures, the primary phenomenon associated with climate change (see Chart 1).

An empirical estimation of this damage function is difficult because of the complexity of the underlying physical phenomena and the lack of historical precedents. The correlation between a region's GDP and its local temperature is indeed not informative, since the correlation between those variables is not necessarily causal: while a higher temperature may locally explain less intense activity, it is not out of the question that this may also be the result of a different economic history, especially since human settlement in the pre-industrial era primarily took place in the most temperate zones. Furthermore, the lack of a sufficiently long and accurate time series on temperature increases and economic activity reduces the accuracy of estimates: for example, while there is some evidence that damage is disproportionately greater for very large warming events,[2] only limited warming data is available.[3]

Chart 1: Theoretical example of a damage function



Source: Autors.

How to read this chart: The damage function presented here is not a true damage function originating from the literature, it is a theoretical example. Warming of X°C implies Y% loss of GDP compared to a scenario without climate change. If Y is negative, then it means that global warming benefits the economy.

The different methodologies in the economic literature try to overcome these problems (see Box 1). However, the results of the estimates remain, in any case, very tentative (*cf.* 1.3).

(1) *Cf.* J. Célestin-Urbain (2008), "The long-term economic consequences of climate change", *Trésor-Economics* no. 30.

(2) There are threshold effects beyond which impacts can be disproportionately magnified. By way of illustration, according to Mora *et al.* (2017), "Global risk of deadly heat", in *Nature Climate Change*, 75% of the world's population could be exposed more than 20 days per year to so-called "potentially deadly" climatic conditions in a warming scenario of around 4°C in 2100.

(3) The scientific literature has identified the existence of non-linearities that may disproportionately accelerate certain effects of climate change: this is why the damage curve is generally considered to be non-linear. However, the nature of this non-linearity is the subject of debate.

Box 1: The three main approaches to estimating the economic effects of climate change

The economic literature uses three different methodologies to estimate the economic effects of climate change.

The enumerative approach consists in the aggregation of empirical estimates at sector level to calculate the damage function at the global level across all sectors using a principle of currency conversion: physical impact predictions made by climate scientists are assigned a market value. For example, based on the effects of the rise in temperature on wheat yields estimated in the literature, the enumerative approach allows to deduce a monetary impact of warming on wheat production. There is a risk that this method underestimates damage because (i) it only factors in channels that have been quantified, which are not necessarily exhaustive, and (ii) it generally relies on the assumption of a quadratic damage function, which is likely to underestimate damage at high temperature levels and does not account in particular for the significant impact of extreme events whose frequency and intensity will increase with temperature.

Computable General Equilibrium Models (CGE models) offer a dynamic representation of the economic system of a country or several interconnected countries, each system having a sectoral breakdown and representative agents (consumers, government, producers) making optimised economic decisions. CGE models have the advantage of taking into account the reorganisation of economic activity related to climate change. However, the calibration of these models raises several issues: it is not always possible to provide an empirical basis for the model's chosen parameters, and their possible estimation is based at best on small-scale shocks, which limits the credibility of the model when it is used to simulate major changes. Moreover, with a few exceptions, they model reallocations of activity across sectors without taking into account their cost; moreover, they ararely dynamic, which may limit estimated damages.

Econometric approaches can be used to calibrate damage functions using cross-sectional or panel data. Cross-section methods infer the impact of climate change from observed differences between regions of different average temperatures. This approach does not factor in transition costs and raises the issue of causality. Panel methods, on the other hand, use the warming that has already taken place to carry out more robust estimates that better address these two issues. This latter method is the most widely used today. However, this approach assumes that an effect on GDP of a short-term change in climate conditions is a good approximation of the effect of a long-term climate change. However, short-term adaptation behaviours (teleworking, etc.) that are captured by this type of estimate are not necessarily all reproducible in the long term, which limits their credibility.

1.2 A negative effect whose magnitude is uncertain

The chart on the first page presents various estimates of the GDP impact of climate change drawn from the literature, based on different methods or data sets, all subject to the methodological limitations discussed above. Assuming constant environmental policies, the central IPCC scenario predicts a temperature increase of 2.5°C in 2050 and up to 5°C in 2100 compared to the pre-industrial period. In this scenario, the collected estimates all lead to a negative effect at global level, but with a magnitude that varies widely. Some methods estimate an effect of –15% of GDP in 2050 and –30% of GDP in 2100, while others suggest more limited effects (–4% in 2100 and even a zero effect in 2050).

The variability of the estimates depending on the methods used (see Box 1) reflects the limits of the methods and their complementarity:

- The use of panel econometrics, one of the newer methods, seems to lead to significantly higher levels of damage. The structure of the panel data allows the short-term effects of climate change to be taken into account. These estimates therefore capture short-term adaptation costs and immediate effects on growth in greater detail than methods based on static comparisons.
- "Enumerative approaches generally result in lower impacts than econometric methods. They are limited by the absence of many sectors and countries in the enumeration. Extrapolated to global level from impacts generally estimated in developed countries, which are less affected (as a proportion of GDP) than developing countries, the results are therefore *a priori* biased downwards.
- The computable general equilibrium model estimates are generally lower than those of other methods. These models do indeed predict long-term market adaptations to climate change, but they cannot take into account the costs of transitions or extreme events.

1.3 Effects that are very likely underestimated

Climate change is systemic and affects all human activity. It has no known historical precedent in terms of magnitude and speed. Estimating its effects on the basis of necessarily fragmentary data is likely to result in a significant underestimation of total impacts.

One of the most difficult aspects of this estimation is the inclusion of transition and adaptation costs. Indeed, while it is possible to imagine what the world economy would look like in a warming context by comparing activity in different climates, there is no historical example of the costs associated with the transition from one state of the economy to another. Only econometric models and enumerative methods capture a portion – presumably limited – of these negative effects.

The difficulty in quantifying the impacts of natural disasters (floods, droughts, storms, giant fires, etc.) due to global warming also greatly limits damage estimation methodologies. Climate change is expected to lead to an increase in the frequency and intensity of extreme events, but the uncertainty about their magnitude, as well as the diversity of their effects depending on land use, makes it difficult to estimate their cost in the general context.

On the other hand, while most studies use continuous damage functions, the existence of possible threshold effects could make damage functions more non-linear. In particular, labour productivity, crop yields or ecosystem services provided by the environment could come up against physical and biological constraints as warming progresses, implying rapid downturns beyond which the adaptive capacities of societies would be significantly reduced, which could lead to massive drops in activity above certain temperatures.

Above all, however, beyond the uncertainties in estimating damage, the uncertainty inherent in climate scenarios must be emphasised.[4] The existence of numerous non-linear mechanisms in the physical dynamics of the climate, either delayed dynamics or threshold mechanisms, make the existence of "tipping points" possible, i.e. levels of warming whose crossing could massively accelerate, intensify climate change, or even render it irreversible. These points include the melting of Greenland, Arctic and Antarctic ice, the melting of permafrost, the reduced circulation of certain currents in the Atlantic, the decay of carbon sinks in the Canadian boreal forests and the Amazon, etc. To the extent that the tipping points have a probability of occurrence that increases with the level of warming and that they partly feedback on each other, some studies consider chain reaction scenarios possible, leading to eventual accelerated warming.

2. Sector, geographic and socio-economic impacts

2.1 Sector impacts

The macroeconomic vision must be complemented by a microeconomic analysis, which makes it possible to grasp the different channels of transmission of climate change on activity and the strong sectoral heterogeneity of the effects of climate change.

Given its dependence on climatic conditions, agriculture is a particularly vulnerable sector. Warming and changes in precipitation patterns are expected to have a direct negative effect on agricultural yields in most regions, affecting almost 90 per cent of the population by 2100.[5] Production losses on hotter days and the proliferation of insects or bacteria attacking crops may be the main causes of these lower yields, which may also be more uncertain due to increased climate variability. Eventually, the quality of agricultural production will also be affected.[6] If, in the medium term, adaptation can occur through changes in crop and livestock types, short-term losses and adaptation costs would likely be high. However, the quantification of effects remains uncertain due to their heterogeneity across crops, activities and regions, as well as possible threshold effects related to ecosystem degradation. Conversely, the increase in the concentration of carbon dioxide in the atmosphere would, conversely, contribute to plant growth, without this being able a priori to offset the other negative effects of associated climate change.

(4) It is important to note in this respect that the initial results of the simulations that will be used in the next IPCC assessment report tend to show that the rise in temperature at unchanged policy levels will be greater than predicted in previous assessments, by an additional 1°C. These new results are therefore expected to accentuate the damage mentioned above over the given time horizon.
(5) Lauric T. *et al.* (2019), "Escaping the perfect storm of simultaneous climate change impacts on agriculture and marine fisheries", *Science Advances*, 5(11).
(6) Thus, for a warming of 2.5°C by 2050, the zinc, iron and protein content of many food crops should decrease by about 10%, while the nutritional content of farmed meats may be compromised by disease and heat stress.

The energy and infrastructure sectors could also be particularly affected. Energy demand follows a U-shaped curve: it is higher when temperatures are low (due to heating) and high (due to cooling). The effect of global warming on demand may therefore be far from unequivocal. The effect on energy production, on the other hand, might be negative in the short term, since rising temperatures are expected to reduce the efficiency of the thermodynamic cycles of gas, nuclear and solar thermal power plants, as these efficiencies are highly dependent on the temperature of the associated cold source (atmosphere or water). The decrease in water resources could also threaten the cooling of power plants located on waterways.

The construction, building, housing and transportation sectors are also expected to suffer significant damage. In addition to heat stress or increased precipitation, the increased frequency of extreme weather events is expected to have consequences for the construction and maintenance costs of both buildings and infrastructure. Some transport infrastructure could even become unusable, such as port infrastructure in the event of a rise in sea levels, or waterways as a result of the loss of water resources due to reduced rainfall.

International trade could be affected not only by the direct impact on infrastructure and changes in transport costs due to ice melting and natural disasters, but above all by the adjustment of comparative advantages resulting from climate change, which would modify productivity distribution across regions and ultimately trade flows. The economies that are least diversified and most exposed to climate change could see their production costs increase more rapidly than those of their trading partners, which would result in a reduction of their relative competitiveness and a deterioration of their trade balance. Trade in agricultural goods would be the most affected by these changes, followed by labour-intensive sectors such as textiles or energy-intensive sectors such as metallurgy.

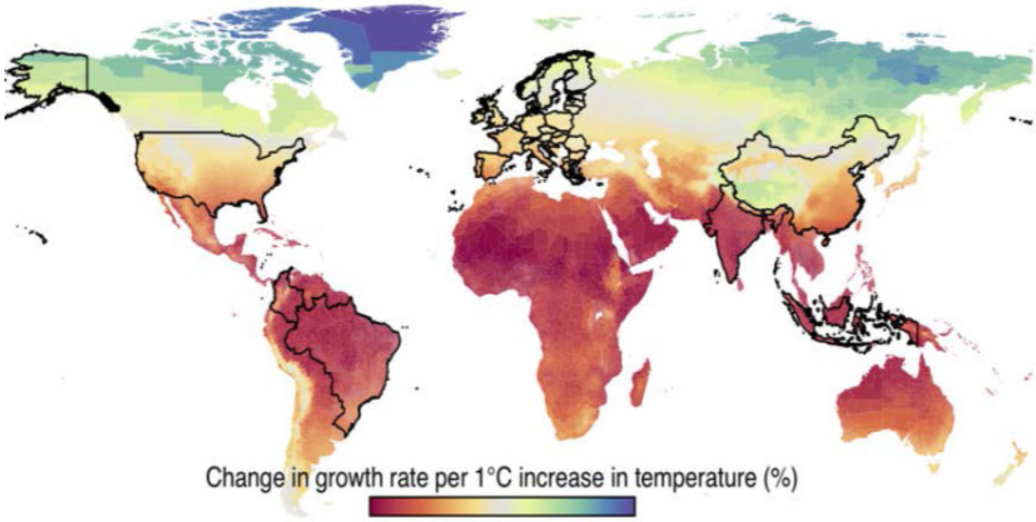
Finally, the financial sector could be among those most affected by climate change. Rather than operational risks, which are expected to remain rather low in the banking or insurance sector, climate change is expected to generate physical risks that would be transmitted to the financial sector through the depreciation of the value of affected assets. The insurance sector could be particularly exposed to these risks. The *Caisse Centrale de Réassurance*[7] estimates that the increase in the frequency and cost of extreme events will raise the claim rate on insured assets by 50% in mainland France by 2050. In the short term, correlated violent events could generate large and concentrated losses that could lead to the failure of certain insurance companies. In the long term, the existence of recurring extreme events could lead to certain risks being uninsurable, which would in turn heighten the negative effects of a natural disaster by limiting reconstruction.

2.2 Geographic impacts

Since episodes of very high heat (above 30°C) are considered to be the climatic events that cause the most economic damage, countries with the hottest climates would be mechanically the most vulnerable.[8] These countries are also those whose economies are most dependent on the agricultural sector, which is itself particularly subject to climate risk. Regions close to the equator (African, Central American and South and South-East Asian), which account for nearly 53% of world agricultural production) are likely to be more severely affected than those located in high latitudes, whose agriculture would even benefit from warming thanks to a longer growing season and an increase in cultivatable areas.

(7) Report published by the CCR in September 2018 entitled "Conséquences du changement climatique sur le coût des catastrophes naturelles en France à horizon 2050".
(8) Hsiang & Kopp (2018), "An economist's guide to climate change science", *Journal of Economic Perspectives*.

Chart 2 : Heterogeneity of the short-term effect of local global warming on GDP growth



Source: Burke, M. & Tanutama, V., 2019. Climatic constraints on aggregate economic output. NBER Working Paper Series n° 25779.

Box 2: Effects for France

France, as it benefits from a temperate climate, is one of the countries for which it is not clear whether the direct economic impact of climate change is positive or negative.[a] In particular, in the agricultural sector, climate change could show slightly positive effects in the north and north-east, while yield decreases would appear in the south and south-west due to the combination of excessive temperatures and droughts.[b] However, estimates at national level capture only the direct effects of climate change (including direct health damage). It would be highly imprudent to consider that under conditions of very high global warming some temperate countries could experience only low damage. Indeed, the very high damage that may be suffered by the vast majority of other countries in such a scenario would have global repercussions through the channel of foreign trade and spreading political instability.[c]

a. See for example Burke M. & V. Tanutama (2019), "Climatic constraints on aggregate economic output", *NBER Working Paper Series* no. 25779. Moreover, the Senate has estimated the cost of the 2003 heat wave at between 15 and 30 billion euros, with economic repercussions on a multitude of sectors. Reference: Senate report: https://www.senat.fr/rap/r03-195/r03-195_mono.html.

b. For example, the wine sector could experience considerable variations in yield, with increases of more than 35% in Burgundy and losses of up to 25% in Languedoc-Roussillon.

c. The 2011 flooding episode in Thailand, which destabilised the region's automotive industry (including as far away as Japan) and led to a global shortage of hard drives for several months, shows that the indirect effects of climate change cannot be considered of secondary importance.

2.3 Socio-economic effects

Beyond economic impacts, major changes in the living environment are expected to have significant effects on human health and social stability. These could have a significant feedback effect on the economy. While such effects are more difficult to predict and quantify, they potentially count among the most important impacts of climate change.

Higher temperatures, more frequent extreme events (heat waves, natural disasters) and indirect effects of the deterioration of natural ecosystems (emergence of diseases) can have a significant impact on human health. Mortality rates are generally considered to follow a "U" curve with temperature: it increases sharply at very high or very low temperatures. Since human settlement is concentrated in already temperate or warm regions, rising temperatures are expected to have an upward effect on average mortality rates. For example, Deschênes and Moretti (2009)[9] estimate that the mortality rate would increase by 2% per degree above 32.2°C in the United States. Moreover, the proliferation of certain diseases transmitted by animal

(9) Deschênes O. & E. Moretti (2009), "Extreme weather events, mortality, and migration", *The Review of Economics and Statistics*, 91(4).

species such as mosquitoes (malaria, dengue fever, etc.) or through the ingestion of contaminated food or water (cholera and other diarrhoeal diseases) could be facilitated by rising temperatures. Difficulties in the agricultural sector could make food security more precarious in some countries, especially in the face of the threat of repeated extreme events, thus aggravating these health risks. Thus, according to the World Health Organization, climate change could, between 2030 and 2050, cause approximately 250,000 additional deaths per year in the world due to malnutrition, malaria, diarrhoeal diseases and heat stress.

Moreover, in view of their likely magnitude, the economic effects of climate change listed above could also have major consequences in terms of political and social stability, particularly if they result in migration. However, while there appears to be evidence of a causal relationship between drought, conflict and subsequent migration over limited periods of time,[10] in general, degradation of land or freshwater supplies does not appear to be a significant determinant of conflict at this time. The impact of climate change on migration, estimated through mapping the risks of flooding, land degradation or freshwater reserves degradation, is clearer. For example, the International Organization for Migration[11] estimates that 250 million to 1 billion people could be on the move as a result of climate change by 2050. Most of this displacement is expected to take place close to affected locations or within the same country. The impact on emigration is more difficult to assess since this decision responds to multiple rationales where climate change generally only plays an indirect role. Moreover, the populations most affected by climate change, particularly in Africa, do not always have the financial resources that allow them to emigrate.

3. Consequences for public policies

To understand the complexity of these results with a view to public action, two main approaches emerge: one, developed in particular by William Nordhaus,[12] calculates the cost of climate change mitigation in relation to the value of avoided foreseeable damages; the other, developed by Martin Weizmann[13] among others, views climate action from an insurance point of view, interpreting uncertainties as risks.

The insurance approach is based on the fact that, while everything we know tells us that climate change is harmful, almost everything we know we do not know suggests that it could be much worse: global warming mitigation therefore has an option value. Indeed, beyond the impacts on market goods and services, which represent the bulk of the effects analysed so far, climate change may also have impacts on non-market sectors (social life, education), whose economic implications are very difficult to anticipate, whatever the methodology used. The indirect impact of this social-political damage (increase in inequalities due to the uneven capacity to adapt to short-term shocks, increase in conflicts, migrations, etc.) is probably poorly taken into account in the estimates presented above.

The few available studies[14] suggest that these indirect effects could be massive, and largely exceed direct effects. This is a typical case of uncertainty distribution where extreme values cannot be excluded (also called "fat tails"). Risk aversion combined with the existence of fat tails could lead decision-makers to implement bold mitigation and adaptation measures that go beyond what the average estimates would recommend. The cost-benefit approach, on the contrary, seeks to design an optimal emission reduction trajectory that balances present reduction costs with avoided future damage, in order to maximise economic activity throughout the transition. By construction, this trajectory weighs little or even ignores the possibility of a very serious but unlikely event. The approach adopted in France is median between these polar cases and consists of setting a target (carbon neutrality in 2050) as well as estimating a shadow price of carbon corresponding to these objectives: this value is then used to guide public investment.[15]

(10) A recent analysis (Abel G., Brottrager M., Cuaresma J. C. & R. Muttarak (2019), "Climate, conflict and forced migration", *Global Environmental Change*, Volume 54.) shows that these links between climate shocks, migration and conflict were not significant over the period 2006-2015. However, the links would be significant if we restrict ourselves to an empirical analysis of the 2010-2012 period only. Indeed, this period corresponds to the concomitance of significant migratory flows of asylum seekers from Syria, the countries that experienced the Arab Spring, and sub-Saharan Africa, which is plagued by numerous conflicts and droughts.
(11) IOM (2008), "Climate Change and Migration: Improving Methodologies to Estimate Flows", *International Organization for Migration*.
(12) W. Nordhaus (2012), "Economic policy in the face of severe tail events", *Journal of Public Economic Theory*, 14(2).
(13) M. L. Weitzman (2012), "GHG targets as insurance against catastrophic climate damages", *Journal of Public Economic Theory*.
(14) See, for example, the meta-analysis of 60 quantitative studies by Hsiang *et al.* (2013), which shows that the risk of conflict increases with increasing deviations in average precipitation or temperature.
(15) "*La valeur de l'action pour le climat*", report of the commission chaired by Alain Quinet, France Stratégie, February 2019.

Whether one takes a "cost-benefit" or an insurance approach, the academic literature agrees on the fact that the damage avoided by global emission reduction policies exceeds by far the cost of these policies (around 1% of GDP, for example, according to Stern). This cost can moreover be reduced by economic spin-offs of investment and innovation policies implemented to mitigate climate change.

The implementation of these mitigation policies must factor in the social cost of greenhouse gas emissions and, ultimately, to a significant reduction in the consumption of fossil fuels. To be effective, coordinated action at global level is necessary.

Adaptation to climate change (e.g. strengthening infrastructures and institutions in charge of risk management) and a better mapping of risks also remains a crucial issue for public policies. In addition to the local economic benefits of such measures (reduction of future damage), it is essential to anticipate and contain potential sources of economic and political instability, likely to be spread by foreign trade, financial markets or massive population movements.

Benjamin Carantino, Nicolas Lancesseur, Mounira Nakaa, Mathieu Valdenaire

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Editor in chief:
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(01 44 87 18 51)
tresor-eco@dgtresor.gouv.fr

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