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Adaptation to Climate Change: Do Not Count on Climate Scientists to Do Your Work[*]

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Executive Summary

Many decisions concerning long-lived investments need to take into account climate change. But doing so is not easy for at least two reasons. First, due to the rate of climate change, new infrastructure will have to be able to cope with a large range of changing climate conditions, which will make design more difficult and construction more expensive. Second, uncertainty in future climate makes it impossible to directly use climate model outputs as inputs for infrastructure design, and there are good reasons to think that the needed climate information will not be available soon. Instead of optimizing based on the climate conditions projected by models, therefore, future infrastructure should be made robust to most possible changes in climate conditions. This aim implies that users of climate information must also change their practices and decision-making frameworks, for instance by adapting the uncertainty-management methods they currently apply to exchange rates or R&D outcomes. Five methods are examined: (i) introducing long-term prospective exercises; (ii) selecting “no-regret” strategies; (iii) favouring reversible options; (iv) reducing decision time horizons; and (v) promoting soft adaptation strategies. I argue that adaptation strategies should not be assessed in an isolated context. In particular, it is essential to consider both negative and positive side-effects, including possible changes in future energy costs.

Adaptation to Climate Change: Do Not Count on Climate Scientists to Do Your Work

Stéphane Hallegatte

1. Introduction

Only a few years ago, most people thought that adapting our economies to changing climate conditions would not be necessary for decades. But there is now increasing agreement that many decisions already need to take into account climate change. Obviously, many decisions have only short term consequences or are only weakly climate sensitive. A factory that produces electronic devices has a lifetime of less than a few decades, and climate conditions will not be that different over this timescale. Also, such a factory is not highly sensitive to climate conditions, provided that it is not built in a flood plain or along a coastline. But many decisions come with a long term commitment and can be very climate sensitive. Examples of such decisions include urbanisation plans, risk management strategies, infrastructure development for water management or transportation, and building design and norms. These decisions have consequences over periods of 50 to 200 years. Urbanisation plans influence city structures over even longer timescales. These kinds of decisions and investments are also vulnerable to changes in climate conditions and sea level rise. For example, many building that are supposed to last up to one hundred years will have to cope in 2100 with climate conditions that, according to most climate models, will be radically different from current ones. So, when designing a building, architects and engineers have to be aware of and account for the future changes that can be expected. Also, Nicholls et al. (2007) showed that, in 2070, up to 140 million people and US$35,000 billion of assets could be dependent on flood protection in large port cities around the world because of the combined effect of population growth, urbanization, economic growth, and sea level rise. But previous coastal defence projects (e.g., the Thames Barrier) have shown that implementing coastal protection infrastructure typically has a lead-time of 30 years or more. Also, urbanisation plans can influence flooding risk only over many decades. This inertia suggests that action must begin today to protect port cities and to manage flood risk for impacts expected by the middle of this century. To be efficient, however, this action has to take into account sea level rise and possible changes in storminess linked to climate change.

Fortunately, there has been a significant rise in awareness worldwide about climate change. The positive outcome of this shift in awareness is that many architects, urban planners, water managers, and other planners are now concerned about how climate change will influence their activities. Climate change laboratories are well aware of this shift, as demands for information about future climates are becoming more frequent.

Even though this new awareness is very positive, it is hardly enough. Climate change represents more than a just change in climate conditions. For decision-makers, climate change represents, more importantly, a dramatic increase in uncertainty. In the past, the climate parameters pertinent to most activities could be observed and measured. Statistical analyses and optimization algorithms were able to produce “best” designs[1] as a function of known climate conditions. In the future, however, substantial climate uncertainty makes such methods more difficult to apply. It seems, therefore, that new decision-making methods have to be developed. This article discusses the issues we face in the development of these much needed methods.

2. Long-Term Investments and Climate Uncertainty

When designing climate-sensitive investments, like water management infrastructures, engineers are used to turning to national meteorological services that are often responsible for collecting weather data and creating climate data, i.e. statistical analyses of weather conditions. These climate data include simple information, like average annual temperature and precipitation, and very sophisticated ones, like statistics of meteorological extremes (e.g. heavy-precipitation probabilities). These climate data are then used, among many other parameters, by engineers to design infrastructure and buildings, by insurance companies to calculate premiums and capital needs, by farmers to choose crops and equipment, by national governments to assess energy security requirements, by local authorities to assess building permits, etc.

Now that it is widely believed that climate change will modify these climate data, these users turn to climate modellers to produce the equivalent of these observed climate data, but for the future climate. This approach, however, will not work.

The first problem arises from the speed of the expected changes. In Hallegatte et al. (2007), the authors proposed a measure of climate change using “climate analogues”. They showed, for instance, that the future climate of Paris in 2080 under the SRES A2 scenario could become the current climate of Cordoba (South of Spain). This would mean that a building built now to last 80 years would have to face, over its lifetime, the climate of Paris,

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[1] Given well-defined objectives.

then a warming climate, up to the current climate of Cordoba. For an architect, it is not more difficult (nor more expensive) to design a building adapted to the climate of Cordoba than to the climate of Paris. It is, however, more difficult (and more expensive) to design a building adapted to both, i.e. able to be comfortable around the year, cheap to heat in winter, and cheap to air-condition in summer, in this large range of climate conditions (see for instance Roe et al, 2005).

So, an immediate impact of climate change could (and should) be the additional cost of designing new infrastructure to be adapted to the full range of possible future climates instead of only the current one. Paying this price now, indeed, may be the only way of avoiding large building and infrastructure retrofitting costs in a few decades.

But this issue is only a tiny part of the problem. More problematic is the uncertainty in future climate. Ideally, indeed, climate models would be able to produce climate statistics for the future, from today to when a building or when infrastructure will need to be replaced. This is the information that engineers need to optimize future investments. Unfortunately, climate change uncertainty is significant, and it is impossible to provide the equivalent of historical climate data for future climates. Even more unfortunately, climate model outputs resemble actual climate data so much that the temptation to use them carelessly is large.

To illustrate this problem, consider the case of a water manager in Toulouse, in the Southwest of France. To know how to change his or her activities, he or she can ask climate modellers to provide model outputs for precipitation over this region up to 2100 and apply unchanged methodology with climate model outputs instead of climate data as inputs. Such a method could be dangerously misleading, however. Projections of future precipitation changes, for Europe have been summarized by the Fourth Assessment Report of the IPCC (2007). From a climate scientist point of view, these results are very satisfying, as the patterns of change are very similar for all models, with an increase in precipitation in Northern Europe and a strong drying in the Mediterranean basin. But a water manager is much less satisfied as he/she realizes that, according to these models, precipitations in Toulouse could remain unchanged (according to the GISS model) or decrease by up to 30 percent (according to the CNRM model). How should she/he react to the possibility of the latter change, which would clearly require large modifications in water management strategies and infrastructures, and to this uncertainty? The traditional decision-making tools have not been developed to face such a situation and must, therefore, be amended.

A first conclusion is that, in this situation, climate modellers have to very careful when they are asked to provide model outputs. Not everybody is familiar with climate change modelling, and one could easily take model outputs as a reliable input for infrastructure design. To avoid such misunderstanding, a simple solution is to distribute climate model outputs to end-users only from a shared platform, where all climate model projections are available in a common format. Such a platform would be an equivalent of the IPCC Data Distribution Centre, but for high-resolution results. The creation of such a distribution infrastructure would limit the risk of misuse of climate model results.

3. New Strategies to Adapt to New Climates

When a user is confronted with the multiplicity of model outputs, a natural reaction is to ask climate scientists to improve knowledge and understanding, to provide, as soon as possible, reliable forecasts of future conditions. Of course, one can expect that climate science will progress in the future and that the range of climate projections will narrow, making their use easier.

There is increasing evidence, however, that improved knowledge does not mean narrower projection ranges. First, even if models were perfectly accurate, uncertainty would not disappear. First, future levels of greenhouse gas emissions, which by nature cannot be forecasted, largely determine future climate change. But there are also large differences between the projections of different climate models that do not seem to be diminishing with time. The example of climate sensitivity, i.e. the increase in equilibrium global mean temperature when CO_2 concentration is doubled, is striking: the range of published estimates has remained essentially unchanged over three decades in spite of the improvement of climate models and our much better understanding of climate processes (see Roe and Baker, 2007). As another example, new evidence that land-based glaciers (such as those in Greenland) may respond more quickly to warming and in less gradual and predictable ways has recently reduced the certainty of the IPCC’s latest sea-level-rise projections. So, climate models may well be unable to provide the information current decision-making frameworks need until it is too late to avoid large-scale retrofitting of infrastructure. Also, climate models are based on a set of common assumptions, and therefore underestimate the full range of uncertainty.

If climate models disagree, will climate observations tell us which one is right? Unfortunately, even though they will eventually, they will do it quite late in the century. For instance, changes in precipitation patterns in the Mediterranean basin may remain undetectable by statistical methods until 2050 (IPCC, 2007). If we wait for climate change to be detectable and models to be fully validated, many investments designed before that time will be ill-adapted by the end of the century, with potentially large economic costs. Moreover, observations can be dangerously misleading: worst-case scenarios can arise from the difficulty in attributing observed changes to global climate change. For instance, multi-decadal variability can modify precipitation patterns over long periods. If these transitory modifications are understood by economic actors as anthropogenic climate change patterns, i.e. as permanent modifications, ill-designed adaptation strategies could be implemented and make the situation even worse than without adaptation.

Hurricanes are a good example of this situation, where observations cannot provide the required information: does the current high-activity level in the North Atlantic arise from climate change, as proposed by Emanuel (2005) and Webster (2005), or does it arise from multi-decadal variability as proposed by Landsea (2005)? In the first case, hurricane activity is likely to keep increasing in the future and ambitious adaptation strategies must be implemented without delay to reduce vulnerability. But uncertainty concerning the driver of the current level of activity makes it difficult to make appropriate decisions regarding protection infrastructure and land-use restrictions (Hallegatte, 2006). Here, observations will not be able to provide the needed information for many decades, and waiting for this signal would be a critical error.

Since climate models and observations cannot provide what current decision-making frameworks need, the only solution is to amend these frameworks to make them able to take this uncertainty into account. To do so, infrastructure should be designed acknowledging (i) that it will need to cope with a larger range of climate conditions than before; and (ii) that this range is and will remain highly uncertain. In such a context, optimizing infrastructure design for a given climate may not be the best strategy. If it were possible to attribute probabilities to possible future changes, probabilistic optimization strategies could easily be introduced. But these probabilities are not available; even though some have been produced at the regional scale (e.g., Giorgi and Mearns, 2003), they are still heatedly debated.

A better approach is to develop new strategies, especially those created to cope with the inherent uncertainties of climate change (e.g., Lempert and Schlesinger 2000). For instance, it is possible to base decisions on scenario analysis (e.g., Schwartz, 1996) and to choose *the most robust solution*, i.e. the one that is the most insensitive to future climate conditions, instead of looking for the "best" choice under one scenario (Lempert et al., 2006; Lempert and Collins, 2007). For professionals, these methods are consistent with those commonly used to manage exchange-rate risks, energy cost uncertainty, research and development outcomes, and many other situations that cannot be forecast with certainty. Such robust decision-making methods have already been applied in many long-term planning contexts, including water management in California (Groves and Lempert 2007, Groves et al. 2007). For most decision-makers, the novelty will be the application of these methods to climate conditions. This requires users of climate information to collaborate more closely with climate scientists and to adapt their decision-making methods to the climate change context.

4. Practical Solutions to Increase Robustness

Within this new decision-making framework, five examples of practical strategies that favour robustness over performance can be proposed.

First, the “institutionalization” of a long-term planning horizon may help anticipate problems and implement adequate responses. For instance, in the framework of the California Water Plan, all water suppliers that provide water to more than 3,000 customers in California have to carry out, every 5 years, a 25-year prospective of their activity, including the anticipation of future water demand, future water supply sources, and “worst-case” drought scenarios. These kinds of exercise are very useful because they force planners to think several decades ahead, they create contacts between economic agents and climate scientists, and they help shape strategies to cope with future changes. In the present situation, where parameters that used to be known become uncertain, a long-term planning horizon is key to determining where and how to change business practices.

Second, “no-regret” strategies, i.e. strategies that reduce vulnerability at negative, null or negligible costs, are often available and should be implemented. Better insulation of buildings is a typical example of such strategies, since this action increases robustness while energy savings can often pay back the additional cost in only a few years. But there are many other examples. For instance, to calibrate drainage infrastructure, water managers in Copenhagen now use run-off figures that are 70 percent larger than their current level. Some of this increase is meant to deal with population growth and the rest is to cope with climate change, which may lead to an increase in heavy precipitation over Denmark. This 70 percent increase has not been precisely calibrated, because such a calibration is made impossible by climate change uncertainty. But this increase is thought to be large enough to cope with almost any possible climate change during this century. This move is justified by the fact that, in the design phase, it is inexpensive to implement a drainage system able to cope with increased precipitation. On the other hand, modifying the system after it has been built is difficult and expensive. It is wise, therefore, to be over-pessimistic in the design phase. Often, when it is cheap, it is sensible to add “security margins” to design criteria, in order to improve the resilience of infrastructure to future (expected or unexpected) changes.

Third, it is wise to favour strategies that are reversible over irreversible choices. The aim is to keep as low as possible the cost of being wrong about future climate change. An example of a situation in which this criterion can be important is urban planning. When deciding whether to allow the urbanisation of an area potentially at risk of flooding if climate change increases river runoff, the decision-maker must be aware of the fact that one answer is reversible while the other is not. Refusing to urbanise, indeed, has a well known short-term cost, but if new information shows in the future that the area is safe, urbanisation can be allowed virtually overnight. Allowing urbanisation now, on the other hand, yields short-term benefits, but if the area is found dangerous in the future, the choice will be between retreat and protection. Retreat is costly, but often the best solution from an economic point of view. It is, however, very difficult politically, especially if urbanisation has been explicitly allowed. Protection is even more expensive, and it is important to consider the residual risk: protection is efficient up to the protection design. If the protection is overtopped or fails, like in New Orleans, human and economic losses can be very large (Hallegatte, 2006; Nicholls et al., 2007). So, allowing urbanisation is very difficult to reverse, and this strategy is highly vulnerable to the underestimation of future risks, which is the best argument for the alternative strategy.

Fourth, the uncertainty regarding future climate conditions increases rapidly with time. Reducing the lifetime of investments, therefore, is an easy way of reducing uncertainty and corresponding costs. This strategy has already been implemented in the forestry sector by choosing species that have a shorter rotation time. In other sectors, it is also often possible to avoid long-term commitment and choose shorter-lived decisions. For example, if houses will be built in an area that may become at risk of flooding if precipitation increases, it may be rational to build cheaper houses with a shorter lifetime instead of high-quality houses meant to last one hundred years.

Fifth, technical solutions are not the only way of adapting to different climates. Sometimes, institutional or financial tools can also be efficient. For instance, agriculture is very sensitive to water availability. If the variability of water availability is expected to increase, like in the Mediterranean basin where more droughts are found in climate model projections, adaptation in the agriculture sector can involve water management infrastructure, from water reservoirs to water transport or even desalinisation. These adaptation strategies, however, are highly dependent on future precipitation levels. Some of them, like water reservoirs, will be efficient if climate change remains moderate, but cannot cope with the most pessimistic projections. Facing a reduction in water availability, is it safe to invest substantially in adaptation projects that may become inefficient if the situation worsens? In these cases, other adaptation strategies can be explored, like insurance schemes (see, e.g., Linnerooth-Bayer et al., 2003; Hellmuth et al., 2007). If variability increases, it means that farmers will have to cope with more bad years, but their mean productivity may remain unchanged. Therefore, an insurance scheme that protects them against heavy losses when weather is unfavorable may be as efficient as “hard” adaptation options involving costly infrastructure.

In the same way, in hurricane-prone regions, it may be more efficient to implement an efficient warning and evacuation system combined with a strong (possibly expensive) insurance scheme than to protect all populations with seawalls and dikes. In the former case, the population is evacuated in dangerous conditions (e.g., an approaching hurricane) to avoid deaths and casualties, and material losses are paid by insurance claims. The insurance premium the population will have to pay to live in this at-risk area may be large, but remain lower than the cost of protecting the areas with dikes. Of course, warning systems are not flawless and it is always difficult to decide whether and when to evacuate, but the Katrina experience demonstrated that hard protection can also fail, with the most tragic consequences.

The key advantage of “soft” adaptation options, like insurance, warning and evacuation, is that they imply much less inertia and irreversibility than hard adaptation: an insurance scheme can be adjusted every year, unlike a water reservoir. The risk of “sunk costs” if climate projections are wrong is much lower for institutional and financial strategies than for technical adaptation projects, which makes them more suitable to the current context of high uncertainty.

A sixth proposition may be to wait until more information on future climate conditions becomes available. Many have proposed, for instance, to postpone decisions about greenhouse gas emissions constraints until more information on climate sensitivity is produced. For mitigation decisions like for other long-term decisions, unfortunately, such a strategy is likely to lead to delayed decisions made too late. Moreover, for many infrastructure decisions, waiting is not an option, since all climate-sensitive decisions cannot simply be delayed by decades. This last strategy seems, therefore, to have limited applicability.

A last point deserves to be mentioned. Adaptation strategies often have side-effects that can be either negative or positive. The ancillary benefits in terms of energy consumption of better building insulation are a good example of synergy between adaptation and emission reduction. But there are also conflicts between adaptation options, like the consequences for water availability of increased use of snow-making to compensate for shorter skiing seasons in mountain areas, or between adaptation and mitigation, like energy consumption from desalinisation plants. These side-effects can be large enough to modify the diagnosis on some adaptation options, and adaptation therefore must not be investigated in an isolated context.

In particular, many adaptation strategies that are appealing today imply increased energy consumption (e.g., desalinisation, air conditioning, water transport). In the design of adaptation strategies, therefore, future energy costs have to be taken into account: if there is a high carbon price in 2030, desalinisation plants using fossil fuels may become excessively expensive to run. Considering the huge investment cost of these plants, this possibility has to be accounted for in the decision-making process. Moreover, there is an unfortunate correlation between energy costs and climate change impacts. If climate change appears to be worse than expected in fifty years, indeed, stricter mitigation strategies are likely to be introduced at the international level, making energy costs and carbon price rise. Highly energy-consuming adaptation options, therefore, seem to be particularly non-robust, i.e. particularly inadequate given the present situation.

5. **Conclusion**

Climate change will influence the way everybody must think about weather. Over the next few decades, the main change global warming will bring us may not be the change in weather itself. It may be the uncertainty regarding future climate conditions, which was marginal during previous centuries and, therefore, was neglected in decision-making. Now, uncertainty in future climate change is so large that it makes many traditional approaches to designing infrastructure and other long-lived investments inadequate.

This paper makes the case that end-users should not expect climate scientists to solve this problem by providing certain and accurate climate forecasts in due time. Fundamental scientific uncertainty will prevent climate models from providing this information soon. Natural variability that makes it difficult to detect and attribute climate changes will also prevent observations from doing so.

End-users, therefore, have to change the way they make decisions, to introduce climate uncertainty in their everyday operations. In most cases, they know how to do so, since uncertainty is already at the heart of many economic decisions: energy prices, exchange rates, and future technological developments are volatile and uncertain, and cannot be forecasted with precision. In addition to this (already long) list, it is urgent to make sure that all the information climate scientists can produce is used. If uncertainty is taken into account in all long-term decisions, many infrastructure projects will be better adapted in the future, and climate change impacts will remain lower and more manageable (Hallegatte, 2007). Only such an anticipatory adaptation strategy can buy us the time we need to wait for (still-to-be-implemented) mitigation policies to become effective.

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