Uncertainties and risk analysis in climate change adaptation

Key Messages

- Risk is a state of uncertainty where some possible outcomes entail an undesired effect or significant loss. Risk can also be defined as the potential, when the outcome is uncertain, for adverse consequences on lives, livelihoods, health, ecosystems, economic, social and cultural assets, services, and infrastructure.
- In general, three broad risk categories are usually used: acceptable risks, tolerable risks, and intolerable risks (which exceed a socially negotiated norm).
- In climate change, major risks lie in the failure to adapt to changes in the environment, leading to instability and insecurity of economic system(s) threatening adequate level of societal welfare.
- Climate change risk depends on climatic factors as well as decisions (intentional or unintentional) of agents governing interdependencies among climatic and socio-economic-environmental systems. Inadequate decisions (adaptation) can cause systemic risk propagating through all systems.
- Assessing and managing risks involve a number of steps: describing and modelling the systems to be managed; identifying hazards related to the system functioning; select the events that may initiate accident(s); analyse quantitatively the accident(s); evaluate risk and carrying out the decision making (or deliberative) process.
- Analysing and managing risks needs to rely on integrated modelling of system(s) and disaster(s) incorporating norms, stability and security constraints of the system(s), e.g. insurance bankruptcy; food norms; maximum probable flood, etc.
- Robust system(s) adaptation envisages actions and policies leading to timely adaptation with respect to all feasible adverse events and uncertainty scenarios.
- In the face of climate change uncertainty and risk, robust adaptation includes two main conceptual types of interdependent decisions: the ex-ante decisions taken before uncertainty is resolved and the ex-post decisions taken when additional information about uncertainty becomes available.

Context

Risk is the potential for consequences where something of human value (including humans themselves) is at stake and where the outcome is uncertain (Rosa, 1998). Traditional risk is represented by probabilities (chances) of some usually detrimental or catastrophic events (failures) and the magnitudes of associated losses, such as costs of failure, catastrophic losses, etc.

The assessment of climate change risks and the identification of optimal adaptation options are affected by several uncertainties, such as those surrounding future climate change impacts and future socio-economic development. The true range of existing uncertainty is hard to estimate as uncertainty in future climates is most often represented as the range of outcomes generated by different climate models run for a range of scenarios.

This Insight presents approaches to categorise and analyse risks for climate change adaptation. Policy and methodological developments

Acceptable, tolerable and intolerable risks and adaptation

Three categories of risks relevant to climate adaptation can be defined (Dow et al., 2013):

- Acceptable risks are risks deemed so low that additional risk reduction efforts are not seen as necessary.
- Tolerable risks relate to activities seen as worth pursuing for their benefits, but where additional efforts (adaptations) are required for risk reduction within reasonable levels.
- Intolerable risks are those which exceed a socially negotiated norm (e.g. the availability of clean
drinking water) or a value (e.g. continuity of a way of life).

Figure 1 maps these categories of risk on a two dimensional space. One can see that the type of risk depends on the degree of the potential impact and also its probability (frequency). The low probability catastrophic events can be of the same high degree of risk as very probable events with a moderate impact. The boundaries have a fuzzy structure due to qualitative definition of acceptable, tolerable, and intolerable risks. Those might have potentially some additional flexibility in interpretation also because of different opinions of stakeholders involved.

Figure 1. Acceptable, tolerable and intolerable risks (after Klinke and Renn, 2002; Renn and Klinke, 2013)

Risks that cannot be managed to remain within a tolerable level exceed the limit to adaptation and become intolerable. The shading around the limits indicates those actors’ views of what is acceptable, tolerable or intolerable risk may vary.

Adaptation may be seen as action aimed at maintaining the position of a given valued objective (such as a technical norm of flood protection) within a tolerable area relative to the risk-space depicted on Figure 1. One should mention that there is additional uncertainty in the existing literature relevant to limits to adaptation including inadequate consideration for social processes and values as well as conceptual ambiguity in defining limits.

In complex integrated systems, acceptable risk in one sector could propagate to a catastrophic event in a different one and, thus, create intolerable risk in the whole system. Technically, the adaptation must be defined with respect to nature of the system(s), interdependencies, types of risks, and appropriate measures and methods should be applied as further discussed below.

Risk analysis in climate change adaptation

Risk analysis involves first identifying malfunctioning, operative errors and external events that may cause accidents in the system (e.g. extreme flood possibly leading to a dam break). Then it requires analyzing in detail the accidents that are more critical from the point of view of their frequency and/or their consequences (e.g. systematically declining crop yields due to decreasing precipitation, or rare droughts entirely destroying the crop).

The final objective of risk analysis is to identify and quantify the impact of accidents and malfunctions of systems under study. That evaluation can reduce endogenous risk by leading to indications about the design of the system as well as facilitate the design and implementation of adaptation measures to address exogenous risks.

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Risk analysis contributes to the process of estimating the potential impacts of climate change and evaluating local vulnerabilities and adaptive capacities. Risk assessment can also provide a better basis for subsequent steps: the identification and appraisal of options, implementation, and monitoring and evaluation.
In climate change, major risks lie in the failure to adapt to changes in the environment, leading to instability and insecurity of economic system(s) threatening adequate level of societal welfare. The risks are affected by climatic and anthropogenic uncertainties, i.e. interdependencies between natural and human systems, decisions of agents, etc. Inappropriate adaptation decisions can further trigger risks propagation through interdependent economic systems, thus causing systemic risks, which magnifies the “initial” risks.

Systemic risk analysis and management of interdependent socio-economic, technological, environmental systems requires proper modelling of interdependencies involving risk indicators, such as e.g. security, reliability, safety constraints, characterizing potential catastrophic implications of climate change risks.

The analytical process of risk assessment for a system might be divided into five steps:

- Integrated systems description and modelling, e.g. integrated climatic and land use systems;
- Identification of natural (droughts, floods, heat waves, etc.) and man-made (maladaptation policies) events triggering systemic risks and endangering secure systems functioning;
- Quantitative analysis of the accident(s) deriving from initiating events (i.e., estimation of their probabilities/frequencies and consequences);
- Introduction of proper risk measures (security, safety, reliability, etc.) enabling secure systems functioning;
- Evaluation of feasible robust interdependent ex-ante and ex-post adaptation options

**Illustration 1. Presenting levels of risks for different climate change impacts**
The IPCC WGII AR5 Summary for Policymakers follows this qualitative definition of risk levels (termed moderate, high and very high). Levels of additional risks due to climate change were estimated for different types of climate change impacts depending on global mean temperature change (Figure 2). The color shading indicates the additional risk due to climate change when a temperature level is reached and then sustained or exceeded. Undetectable risk (white) indicates no associated impacts are detectable and attributable to climate change. Moderate risk (yellow) indicates that associated impacts are both detectable and attributable to climate change with at least medium confidence, also accounting for the other specific criteria for key risks. High risk (red) indicates severe and widespread impacts, also accounting for the other specific criteria for key risks. Purple shows that very high risk is indicated by all specific criteria for key risks.

![Figure 2. A global perspective on climate-related risk (IPCC, 2014).](image-url)
The projected impacts of climate change on burned areas in EU depend on a multitude of factors. The focus of this case study is the range of uncertainties coming from a limited subset of climate projections (long term daily weather projections) and on the possibilities to adapt. The standalone fire model (SFM) by Khabarov was applied to climate change projections reflecting the SRES A2 scenario of the Intergovernmental Panel on Climate Change (IPCC). The estimated potential increase of average annual burned areas in Europe under “no adaptation” scenario in the long term is within the range of 120-270% (by 2090s compared to 2000s). The short term projection is more moderate and is within the range of 25-60% (by 2050s compared to 2000s). Thus, SFM model has translated the uncertainty in specific subset of climate projections into the uncertainty ranges for projected burned areas increase. The application of prescribed burnings has the potential to reduce burned areas in 2050s and keep the increase in 2090s below 50% (all compared to 2000s). Improvements in fire suppression might reduce the climate change impact even further, e.g. boosting the probability of putting out a fire within a day by 10% would result in about a 30% decrease in annual burned areas. By taking more adaptation options into consideration, such as using agricultural fields as fire breaks, behavioural changes, and long-term options, burned areas can be potentially reduced even further.

However, as this modelling effort is limited in many aspects (active fire suppression is represented rather at a qualitative level, a wide variety of options is not taken into account, such as socio-economic and behavioural aspects. In the same time, all major types of uncertainties, such as aleatory (burned areas used for model calibration), epistemic (representation of fire spread), and paradigmatic (a few adaptation options) are well-represented here. Even though this study does not take into account all uncertainties on the input side, in its outputs it provides useful information on currently existing uncertainty range - in qualitative terms it can be described as – projected burned area increase in EU ranges from moderate to dramatic level in long term. Apparently, that type of uncertainty is a challenging factor in planning long-term adaptation as a wide uncertainty range might potentially lead to uncertain cost and benefit estimates for a particular long-term project.
Illustration 3. Agricultural yield estimates under different climate change projections - future irrigation water availability

Figure 4. Potential change in total production of maize, soybean, wheat, and rice at end-of-century given maximal use of available water for increased/decreased irrigation use on what are currently rainfed/irrigated areas in total calories (Elliott et al., 2014).

In an assessment by Elliot and his colleagues compared ensembles of water supply and demand projections from 10 global hydrological models (GHM) and six global gridded crop models (GGCM). The models project that in 2090s direct climate impacts to maize, soybean, wheat, and rice involve losses of 400–2,600 Pcal (8–43% of present-day total). Freshwater limitations in some irrigated regions (western United States; China; and West, South, and Central Asia) could necessitate the reversion of 20–60 Mha of cropland from irrigated to rainfed management by end-of-century, and a further loss of 600–2,900 Pcal of food production (in total resulting to 12–91% of present-day total). In other regions (northern/eastern United States, parts of South America, much of Europe, and South East Asia) surplus water supply could in principle support a net increase in irrigation, although substantial investments in irrigation infrastructure would be required.

Across seven GGCMs, five global climate models, and four representative concentration pathways, model agreement on direction of yield changes is found in many major agricultural regions at both low and high latitudes; however, reducing uncertainty in sign of response in mid-latitude regions remains a challenge. Uncertainties related to the representation of carbon dioxide, nitrogen, and high temperature effects demonstrated here show that further research is urgently needed to better understand effects of climate change on agricultural production and to devise targeted adaptation strategies. In this case, the uncertainty is higher for soybean and rice than for maize and wheat because they have more concentrated production areas and are therefore more sensitive to regional differences in GCM projections.

Main implications and recommendations

The management of risks is a core element of climate change adaptation. However, it is an impossible task to remove all risks. A pragmatic approach consists in reducing risks to tolerable levels. The nature and boundaries of tolerable risks depends on stakeholder perception and is influence by the nature of impacts considered but also the level of uncertainty in the system.

Risk analysis can improve climate change adaptation by helping the identification of potential “accidents”, their potential frequency and consequences. It should be seen as an inherent component of the characterisation of climate change impacts and vulnerabilities, and the selection and implementation of adaptation options.

Integrated (cross-sectorial) climate change risk analysis and management is important to carry out, as well as the consideration of complex multivariate analytically intractable risk distributions, long horizons of evaluations, strategic and operational planning and management of risks, which can help deriving robust solutions.

Bibliography

Further Information
A transparent overview and assessment of the relevant uncertainties for the main policy domains
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