

Adaptation to climate change: A new paradigm for action or just old wine in new skins?

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Abstract: Climate change is affecting all social groups and all economic sectors. The main societal response options are generally categorized into mitigation of climate change, which refers to constraining the amount and magnitude of climate change by reducing anthropogenic emissions of greenhouse gases or enhancing their sinks, and adaptation, which comprises a wide range of measures by public and private actors to reduce the adverse impacts of current and future climate change. Both mitigation and adaptation will affect the economic and environmental conditions for architects and engineers, including reliability engineers. This paper explains key adaptation concepts, outlines key scientific and policy questions regarding adaptation and highlights some challenges for implementation, with a particular focus on reliability engineering. Adaptation to climate change includes many well-established practices from, e.g., disaster risk management, coastal management, natural resource management, spatial and urban planning, public health, and agricultural outreach. Thus, most activities considered in adaptation to climate change are not completely new. At the same time, adaptation to climate change is characterized by several unprecedented challenges and opportunities, including new hazards, new opportunities for action, new methodological challenges, new actors, and new ethical questions. As a result, effective adaptation requires close collaboration between scientists, policy analysts, policy-makers, and practitioners from public and private institutions. Responding to the rhetorical question from the title, this paper concludes that even though adaptation to climate change can often build on existing activities, it comprises much more than just old wine in new skins.

Key words: *Climate change, adaptation, resilience, reliability engineering*

1. INTRODUCTION

1.1. Climate change

Anthropogenic emissions of greenhouse gases and aerosols were the dominant driver of the observed changes in climate in recent decades. For instance, 12 out of the 13 warmest years globally since 1850 occurred between 1995 and 2007. Recent climate change comprises changes in average climate conditions as well as in climate variability. In general, climate extremes (such as maximum daily temperature and precipitation) have changed faster than climate averages due to an increase in climate variability. Changes in climate projected for the 21st century include rising temperatures and an increase in heat waves worldwide; rising sea levels; a global redistribution of precipitation, which further increases the current difference between dry and wet regions; a shift in storm tracks; melting of glaciers and warm permafrost soils; and stronger heavy precipitation events, longer drought periods, and stronger tropical cyclones in most regions [1].

1.2. Mitigation and adaptation

Global climate change is associated with substantial risks for society and nature. The two fundamental societal response options for reducing these risks are *mitigation* of climate change and *adaptation* to climate change. In the climate change context, mitigation refers to limiting global climate change by reducing the emissions of greenhouse gases or enhancing their sinks. Adaptation refers to actions targeted at the vulnerable system in re-

sponse to actual or expected climate stimuli which aim at moderating harm from climate change or exploiting opportunities. Table 1 presents key characteristics of mitigation and adaptation.

Table 1. Characteristics of mitigation and adaptation (adapted from [2]).

	Mitigation of climate change	Adaptation to climate change
Target systems	All systems	Selected systems
Scale of effect	Global	Local to regional
Lifetime	Centuries	Years to centuries
Lead time	Decades	Immediate to decades
Effectiveness	Certain	Generally less certain
Ancillary benefits	Sometimes	Often
Polluter pays	Generally yes	Generally not
Payer benefits	Only little	Almost fully
Monitoring	Relatively easy	More difficult

Mitigation has traditionally received greater attention in the climate change community than adaptation because mitigation of climate change can reduce the impacts of climate change on all systems across the globe and it is certain to be effective. Adaptation, in contrast, is the only option to reduce climate impacts in the near future. Furthermore, many adaptations can be implemented on a

local or regional scale, and they often have important ancillary benefits, such as reducing current climate-sensitive risks. The increasing interest in adaptation to climate change is reflected in the development of the theory and practice of climate change assessment, and in increasing consideration by governments, international organizations, and private businesses [3-5]. The benefits of adaptation, however, are limited to the targeted regions and sectors, its scope is limited (*e.g.*, it is hard to imagine how to protect the Maldives, with a maximum elevation of 2 m, against a 5 m sea-level rise), its effectiveness is less certain (*e.g.*, dykes and levees can break), and it puts the burden on those most vulnerable to climate change, which is in stark contrast to the polluter-pays principle.

Adaptation and mitigation are sometimes seen as alternative policy options, suggesting that it suffices to implement either of them. Because of the fundamental differences between mitigation and adaptation in terms of their spatial and temporal scales and other policy-relevant criteria, however, both mitigation and adaptation are required to reduce the impacts of climate change to an acceptable level.

Mitigation and adaptation can sometimes be mutually reinforcing (*e.g.*, planting trees to provide additional shade in warming regions) but they can also work against each other (*e.g.*, increasing air-conditioning powered by fossil fuels to cope with rising temperatures). Recently there has been a strong political interest in integrating the two options, as exemplified by the inclusion of a separate chapter on the interaction between adaptation and mitiga-

2. ADAPTATION TO CLIMATE CHANGE

2.1. Main policy contexts

Assessment of adaptation to climate change is relevant in three largely distinct policy and decision contexts [9-11]:

1. Global benefits, costs, and limits of adaptation:
As a result of the slow progress in mitigating climate change, there is increasing policy interest at the international level whether adaptation can reduce the need for mitigation to some degree. Scientific questions relevant in this context are: To what extent can adaptation reduce adverse impacts of climate change? What are the global costs of adaptation for different levels of climate change and of residual impacts? What are fundamental, economic, institutional, cultural, or other barriers to effective adaptation?
2. Prioritization of international adaptation assistance:
There is a large disparity between those countries with the largest responsibility for climate change and those most vulnerable to it [12]. Therefore, the United Framework Convention on Climate Change (UNFCCC) explicitly recognizes the responsibility of industrialized countries to assist developing countries in adapting to the impacts of climate change. Scientific questions relevant in this context are: What is the relative vulnerability of countries to climate change? What are the costs of adaptation to climate

tion in the IPCC Fourth Assessment Report [6].

1.3. Relevance of climate change for engineers and architects

Climate change has important implications for engineers and architects because it affects the planning (*e.g.*, location), design (*e.g.*, materials used), construction and operation of the built environment [7]. For instance, mitigation of climate change demands that new residential buildings be highly energy-efficient whereas adaptation to climate change demands that they are functional under present climatic conditions as well as under those prevailing during the lifetime of the building. For instance, a residential building with a design life of 100 years should provide thermal comfort and physical safety under present climate conditions as well as under conditions prevailing in 2100, because retrofitting is generally expensive.

While adaptation climate change provides substantial challenges for society and those professions concerned with the development of long-term infrastructure, it also provides large business opportunities for companies that develop innovative solutions for "climate-proofing" infrastructure. Reliability engineers are well prepared for adaptation to climate change because they have substantial experience with assessing and managing risks. However, current climate science cannot always assign probabilities to future climate scenarios at the spatial resolution relevant for adaptation [8].

change in different regions? How can the international community most effectively support adaptation policies in different world regions? How can adaptation to climate change be successfully mainstreamed into broader development policies?

3. Adaptation planning and policy-making:
Many public and private institutions are interested in adapting their activities so that they reduce the adverse impacts or exploit the potential benefits of climate change. Scientific questions relevant in this context are: What actions are recommended to reduce climate risks, considering their expected costs, benefits, and other criteria? How can they best be planned, implemented and funded?

While these three decision contexts are clearly related, corresponding adaptation assessments differ substantially in terms of their spatial scale, key questions, methodological approach, and the importance of normative values.

2.2. Adaptation concepts

Human adaptation to climate change is not a well-defined and delimited set of activities. The diversity of adaptation contexts is illustrated by the following key dimensions (partly based on [11]):

- Climate-sensitive domains: Adaptation is relevant for all climate-sensitive domains, including agriculture, forestry, water management, coastal protection, urban and spatial planning, public health, and disaster prevention.

- Type of climate hazards: Adaptation can be motivated by a diverse set of observed and anticipated climate hazards, including changes in average climate, climate variability, and climate extremes.

- Predictability of climatic changes: Some aspects of future climate change can be predicted with reasonably high confidence (*e.g.*, changes in average temperature), whereas others are associated with large uncertainty (*e.g.*, changes in hurricane tracks and intensity).

- Non-climatic conditions: Adaptation occurs against a background of environmental, economic, political, and cultural conditions that vary substantially across regions.

- Purposefulness: Adaptation can be either autonomous (*e.g.*, reducing physical activity during a heat wave) or purposefully planned (*e.g.*, adopting new building codes), whereby this distinction may depend on the perspective of the decision-maker. For instance, the installation of an irrigation system in the absence of specific policy incentives may be considered as planned adaptation from the perspective of the affected farmer but as autonomous adaptation from the perspective of a government agency.

- Timing: Planned adaptation can be either reactive (*i.e.*, after some impacts have been experienced) or proactive (*i.e.*, before major damage has occurred).

- Planning horizon: The time horizon of planned adaptation can vary considerably, from a few months (*e.g.*, adjusting crop varieties in response to seasonal weather forecasts) to many decades (*e.g.*, changing urban planning to reduce the urban heat island effect).

- Form: Adaptation involves a broad range of measures, including technical, institutional, legal, educational and behavioral measures. Research and data collection on climate change may also be considered as adaptation in a wider sense.

- Actors: Adaptation involves a wide range of people at different hierarchy levels in many public and private organizations.

The diversity of adaptation contexts implies that there is no one-size-fits-it-all approach for assessing, planning and implementing adaptation measures. Adaptation assessments need to flexibly apply different methodological approaches in order to produce knowledge that is relevant in a given decision context [13].

2.3. Planned adaptation

Planned adaptation to climate change refers to the use of information about present and future climate change to review the suitability of current and planned practices, policies, and infrastructure. Adaptation planning involves addressing questions such as: How will future climatic and non-climatic conditions differ from the past? Do the anticipated changes matter to present decisions? What is a suitable balance between the risks of acting (too) early and those of acting (too) late? Eventually, adaptation planning is about making recommendations who should do what more, less, or differently, and with what resources.

Planned adaptation to climate change comprises a wide range of measures, depending on the sector and the spe-

cific regional circumstances. Examples from various sectors include:

1. Water resources: *e.g.*, expanding reservoirs, changing water allocation and/or water pricing.
2. Agriculture and forestry: *e.g.*, crop switching, rain-water harvesting, improving irrigation efficiency.
3. Coastal protection: *e.g.*, coastal engineering, improved emergency planning, managed retreat.
4. Human health: *e.g.*, monitoring and survey of climate-sensitive diseases, strengthening public health.
5. Natural ecosystems: *e.g.*, establishing migration corridors, reducing non-climatic stresses.

Potential adaptation actions with respect to buildings and infrastructure include [7]:

1. Planning: *e.g.*, mandatory climate risk assessments for developments in flood plains.
2. Legislation: *e.g.*, new building codes, regulations for retrofitting of existing buildings, new rules for public procurement.
3. Innovation: *e.g.*, development of resilient materials and designs that are water-resistant, wind-proof, good thermal insulators and at the same time non-toxic and economical.
4. Knowledge diffusion: *e.g.*, improved professional training and development for architects, engineers and building contractors.

The most appropriate adaptation measures are not only determined by observed and anticipated climate change, but also by other factors that are important for present decisions, such as current climate risks and key non-climatic challenges. In those regions and sectors where climate variability already poses a significant threat, it is particularly important to consider the synergies of addressing current and future climate risks jointly.

The complex information needs for effective adaptation to climate change demand the collaboration across professional and disciplinary communities. Adaptation in the building sector, for instance, requires the collaboration of the academic community, public and private decision-makers, and practitioners such as urban planners, emergency managers, civil and structural engineers, and materials scientists.

One of the main challenges for anticipatory adaptation is uncertainty about future climate change. Ironically, those aspects of climate change that can be predicted most reliably often have limited relevance for current adaptation decisions. For instance, global climate models are comparatively good at forecasting changes in annual mean temperature for large spatial regions several decades in the future but managers of climate-sensitive resources may be more interested in changes in extreme precipitation events at regional scales in the coming decade. For some climate variables in some regions, even the direction of future changes may be unknown. Therefore, adaptation to climate change involves sequential decision-making under uncertainty, whereby the risks of acting early are weighed against those of acting late.

2.4. Role of governments

Adaptation to climate change often occurs autonomously, *i.e.*, without the need for policy interventions, because most adaptation actions yield short to mid-term benefits for those implementing them. For instance, insurance companies adjust their premiums in response to changing weather risks, farmers adjust their practices in response to failing harvests, water managers invest in additional water storage capacity in response to decreasing precipitation, and health managers adjust vaccination strategies in response to changing disease patterns. However, it would be premature to conclude that adaptation to climate change can largely be left to market-driven actions of self-interested actors. There are three main reasons why governments and international organizations have an important role to play in adaptation:

1. International and intra-national equity:
Adaptation by self-interested actors pays no attention to equity issues, such as differential responsibility for climate change and capacity to adapt. If adaptation were left to the markets, wealthy communities would be able to prepare themselves against the detrimental impacts of climate change but poor societies would have to bear the unmitigated impacts of climate change that was largely caused by others.
2. Provision of (new) public goods:
Effective adaptation at global, regional and local levels often depends on accessible information about current and future climate change and its likely impacts, on guidelines for the inclusion of climate change risks into current decision procedures, or on the availability of technologies that are robust against a wide range of climate conditions. Many of these goods are most effectively supplied by governments or international organizations. Examples for international public good are the IPCC, whose reports and main datasets are freely available on the World Wide Web and the Nairobi Work Programme under the UNFCCC, whose objective is to assist all Parties, in particular developing countries, to improve their understanding and assessment of impacts, vulnerability and adaptation to climate change; and to make informed decisions on practical adaptation actions and measures to respond to climate change. An example for a national public good is the United Kingdom Climate Impacts Programme (UKCIP), which provides climate and climate impact projections as well as adaptation guidelines to a diverse community of users in the country.
3. Climate-proofing of current government activities:
Governments are engaged in many climate-sensitive activities. They build and operate transport and water-related infrastructure, they run weather services and agricultural outreach agencies, they establish poverty reduction strategies, building norms and water-allocation rules, they regulate food processing and insurance industries, they run national parks, public health services and disaster preparedness agencies, and they provide international development assistance. These climate-sensitive activities are

generally governed by direct regulation rather than by market forces. Hence, decision-making bodies and executive agencies need to explicitly assess and consider the significance of climate change for their activities.

2.5. Is adaptation to climate change new?

Climate is a key factor for agriculture and forestry, housing, transport and other infrastructure, water and energy supply, tourism and recreation, hazards mitigation, and human health and wellbeing. Hence, many economic agents and public institutions have a long tradition in managing climate-sensitive resources under variable climatic conditions. Having said that, is adaptation to anthropogenic climate change actually something new?

Some aspects of adaptation to climate change are indeed not new. First, societies have always strived for making best use of the climatic resources in their region. They have also attempted to adapt to changes in climate conditions — sometimes more, sometimes less successfully. Second, most activities considered in adaptation to climate change are not new either. Adaptation includes well established practices from disaster risk management, coastal management, water resource management, spatial planning, urban planning, public health, and agricultural outreach. Finally, adaptation planning for climate change often applies established methods and tools from risk management [14,15].

Despite a long history of human adaptation to climate variability and change, global climate change has several unprecedented characteristics:

- Unprecedented climate conditions: Most regions have already or will soon experience climatic conditions that are unprecedented in modern human history.
- Unprecedented rate of change: The current and expected future rate of global climate change is unprecedented in modern human history, making adaptation to those changes particularly challenging.
- Unprecedented knowledge: Previous societies that experienced changes in climate had few means for understanding its extent, identifying its causes, and predicting its future path. The current generation, in contrast, enjoys real-time climate observations from around the world, it commands models that help separate the effects of various natural and anthropogenic forcings, and it has some knowledge about future changes associated with continued anthropogenic forcing of the climate system. This unprecedented wealth of knowledge about present and future climate change allows for planned, and even proactive, adaptation [16].
- Unprecedented methodological challenges: The assessment approaches applied by communities that traditionally deal with climate-sensitive risks and resources are not well equipped for dealing with the complex, uncertain, dynamically evolving hazard 'global climate change'. Recognizing that climate change undermines the basic assumption of stationarity that historically has facilitated management of water supplies and demands, several leading hydrologists have recently called for developing new non-stationary probabilistic models of

relevant environmental variables and to use those models to optimize water systems [17].

- New actors: The simplifying assumption of most managers of climate-sensitive resources that climate is stationary is no longer valid, in particular when decisions with long lifetimes are concerned. Adaptation to climate change thus requires attention and action by people who have not explicitly considered climate in their past decisions.

- New measures: Concern about climate change has triggered the development of new options for coping with unprecedented climate conditions. A spectacular example from the Netherlands involves the construction of floating settlements that can sustain repeated flooding [18,19].

- New ethical challenges: Greenhouse gas emissions in any one country affect the climate in every country of the world. However, the countries most responsible for climate change are generally not those most adversely affected by its impacts [12]. Therefore, climate change raises difficult questions regarding international equity.

2.6. Implications for action

Given the diversity of adaptation contexts, any adaptation assessment needs to be targeted at the specific circumstances of the particular decision situation. Nonetheless, decision analysis can provide some general principles for adaptation. Experience from past adaptation assessments suggests that the following principles are robust and important:

1. The larger the importance of climatic factors compared to non-climatic factors for a particular decision, and the larger the potential increase in risks due to climate change, the greater is the need for a detailed assessment of the risks associated with climate change.
2. The better the knowledge about future changes in climate risks, the more specific action is possible now.
3. The less experience exists in managing a specific risk, the greater is the need for new and additional action.
4. When current climate risks are large, addressing these risks in combination with future climate change is generally the most effective and efficient adaptation strategy.
5. If low-regret or no-regret options exist (*i.e.*, actions whose benefits exceed or are comparable to their costs under all plausible climate scenarios), planned adaptation does not necessarily depend on reliable climate impact projections.

Preliminary adaptation assessments typically identify more adaptation options than can reasonably be implemented in the short term given resource constraints. Hence, deciding what to do first is often as important as what to do at all. Adapting now involves risks because insufficient information about future conditions may limit the effectiveness or increase the costs of adopted measures whereas postponing adaptation involves the risk of higher damages that could have been avoided by early action. The larger the latter risks are compared to the

former, the more urgent is it to act now.

Various authors have identified criteria for the prioritization of adaptation measures [20-23]. There is general agreement that anticipatory adaptation is particularly favorable if climate-sensitive risks are already urgent now; if increasing risks are projected reliably; if future impacts are potentially catastrophic or irreversible; if decisions have long-term effects; and/or if adaptation measures have a long lead time. In contrast, postponing adaptation can be rational if current and anticipated future risks are moderate; if adaptation is very costly; and/or if timely response options are readily available.

4. CONCLUSIONS

This paper has presented a synthesis of current thinking about planned adaptation to climate change, with a focus on reliability engineering. Some of the lessons that have emerged from the pertinent literature on adaptation are as follows [24]:

1. Adaptation to climate change is necessary to reduce the risks from past and unavoidable future climate change.
2. The consideration of global climate change is particularly important for decisions with a long planning or policy horizon.
3. Adaptation to climate change involves a broad range of measures aimed at reducing vulnerability to a range of observed and anticipated climatic stimuli, including changes in means, variability and extremes.
4. Adaptation planning shares many common features with risk management but it involves unprecedented methodological challenges due to the uncertainty and complexity of the hazard.
5. Adaptation to climate change is highly context-specific as it depends on the climatic, environmental, social, and political conditions in the target region and sector.
6. Adaptation assessment has become more inclusive over time, integrating future climate change with current climate risks and other policy concerns.
7. Adaptation planning requires close collaboration of climate and impact scientists, practitioners from the affected sectors, decision-makers and other stakeholders, and policy analysts.
8. Adaptation cannot avoid all impacts of climate change. Hence, adaptation to climate change is not a substitute for mitigation of climate change.

The widespread adoption of research findings on adaptation is a social learning process. This process can be facilitated by the establishment of dialogues where research findings are shared (or co-created) with relevant stakeholders; the mobilization of public and private resources to implement effective adaptation measures; the creation of fora where knowledge of what works (not) and why can be exchanged across regions; and serious efforts to address the equity issues raised by the large disparity between the regions primarily responsible for and those most vulnerable to global climate change in international climate policy.

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