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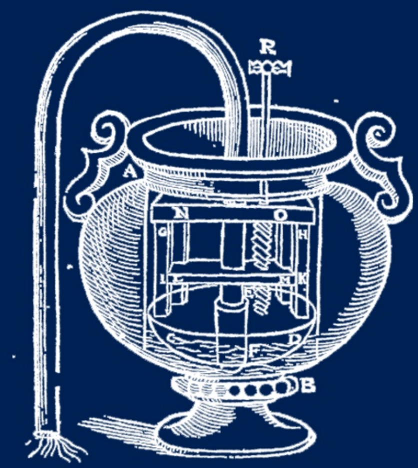
Climate change adaptation planning: tools and methods for effective and sustainable decisions



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Climate change adaptation planning: tools and methods for effective and sustainable decisions

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ABSTRACT
Climate change is a crucial challenge to sustainable development. Climate greatly contributes to setting development conditions and constraints, considerably affecting the availability and quality of natural resources and local environment. Besides mitigation efforts, adaptation strategies and measures are needed in the attempt to reduce the expected negative impacts of global warming, to increase the resilience of the communities and to take advantage of the positive effects. However, despite the urgency of adaptation policies, the multitude of national and sub-national adaptation strategies and plans have not been implemented evenly. We argue that this may well be connected to the fragmented and often puzzling theoretical framework of adaptation, along with the high level of uncertainty that characterises the ratio between the costs of climate change impacts and the benefits of adaptation measures, while there are also issues concerning accountability problems and ownership of the adaptation process. In this paper, we discuss some of the most relevant tasks for the identification of effective, sustainable, and integrated adaptation strategies. The aim is to help public decision-makers in the definition and implementation of measures, considering the peculiar vulnerabilities and development objectives of local communities.

KEYWORDS: climate change adaptation; decision support tools; climate risks; adaptive capacity; uncertainty; flexibility.

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1. Introduction – Tools and methods for climate change adaptation decisions

Climate change adaptation has been recognised as a key challenge for sustainable development (United Nations - UN, 2015; United Nations Framework Convention on Climate Change - UNFCCC, 2015; United Nations Office for Disaster Risk Reduction - UNDRR, 2015) and the scientific community emphasises the urgency of adaptation strategies and tangible measures in order to prepare our economies and social systems for these challenges (Intergovernmental Panel on Climate Change - IPCC, 2018; IPCC, 2019; IPCC, 2022). In the last report on climate change impacts, adaptation and vulnerability (IPCC, 2022), IPCC maintains that human-induced climate change has caused widespread and adverse impacts and related losses and damages to nature and people, beyond natural variability. With high level of confidence IPCC affirms that frequency and severity of extreme events have increased (especially hot extremes, heavy precipitation events, droughts, and fire weather), with negative impacts on food and water security. Furthermore, damages and irreversible losses to ecosystems are larger, in extent and magnitude, than estimated in previous IPCC assessments. With high level of confidence, approximately 3.3/3.6 billion people live in contexts that are now highly vulnerable to climate change.

These impacts will increase in the future if emission pathways lead to scenarios with global warming higher than +1.5°C, causing unavoidable increases in multiple climate hazards and risks to ecosystems and humans. Species extinction risk will vary from 3% to 14% of the species assessed in a +1.5°C scenario to a 3% to 48% in a +5°C future. Water availability, especially snowmelt, will decrease in mid-term futures, with different rates in the various climate scenarios, as well as for extreme weather events, such as floods and droughts. Additionally, climate risks are also becoming more complex and interrelated. Sometimes, climate hazards will occur simultaneously, and multiple climatic and non-climatic risks will interact, resulting in compounding overall risk and risks cascading across sectors and regions (IPCC, 2022). For example, sea level rise, combined with storm surge and heavy rainfall will increase compound flood risk.

The relevance assigned to climate change adaptation has stemmed from three key sources. First of all, the impacts of climate change are increasingly evident and are bound to worsen in the next years also due to weak mitigation efforts and commitments by global nations (according to the Climate Action Tracker November 2021 update). The economic costs of climate change are expected to increase, with significant uncertainties, especially concerning local level effects (Heal and Millner, 2014; Hallegatte et al., 2012; Heal and Kristrom, 2002; Pindyck, 2007; Markandya et al., 2014). Secondly, there are dramatic distributional challenges, where the poorest citizens and most vulnerable countries will be those significantly hit by these effects, widening the already existing gap with wealthier classes. Lastly, adaptation policies require leadership from public administrations at all levels in order to provide climate data and knowledge, funds and technical support to citizens and the private sector. This is crucial in the sectors heavily influenced and exposed to climate change hazards where decisions involve long-term planning, long-lived investments and some irreversibility in choices (e.g. water infrastructures, land use planning, coastline and flood defences) (Hallegatte, 2009).

The increased relevance of adaptation has been followed by a global proliferation of political strategies, plans, measures and financial pledges by states and local administrations (e.g. National and Regional Strategies, National Adaptation Programmes of Action, National Adaptation Plans, Sustainable Energy and Climate Action Plans). However, despite this increase of policy commitments, the implementation of adaptation measures has been uneven (Wise et al., 2014; Berrang-Ford et al., 2011; Ford et al., 2011; Ford et al., 2015; Lesnikowki et al., 2015) and the monitoring process of these strategies is an ongoing and intricate issue (Tompkins et al., 2018). IPCC (2022) affirms (with high confidence) that adaptation gaps exist between current levels of adaptation and levels needed to respond to impacts and reduce climate risks. Large part of adaptation efforts analysed by IPCC is fragmented, small in scale, incremental, sector-specific, designed to respond to current impacts or near-term risks and focused more on planning rather than implementation. Furthermore, adaptation is unevenly distributed across regions. Ford et al. (2015) reviewed a number of studies on adaptation policies stating that "while adaptation has appeared on the political agenda, implementation is lacking, with policies often labelled as adaptation having limited concrete effects on reducing vulnerability or reflecting rebranding of existing policies focused on risk reduction" (p. 802). They maintain that the lack of an organised practice of implemented adaptation measures in itself becomes a barrier for the development of adaptation policies, having limited estimates on the effects of the interventions and few examples of effective solutions. However, few analyses exist on the monitoring and assessment of adaptation policies and these studies mainly rely on self-reported communications coming from national or local authorities (namely the National Communications to the UNFCCC, the official websites of the public administrations, or bottom-up commitments collected by international networks such as Regions Adapt or the Covenant of Mayors) (Lesnikowski et al., 2015; Araos et al., 2016; Berrang-Ford et al., 2021).

This uneven implementation of adaptation measures is connected to a series of constraints and limits (Thomas et al., 2021) associated to varying scales of adaptation efforts: Economic (existing livelihoods and economic structures); social/cultural (social norms, values, worldviews, education); human capacity (individual, organisational, and societal capabilities to set and achieve adaptation objectives); governance, institutions and policy (existing laws, procedural requirements and institutional arrangements); financial (lack of financial resources); information/awareness/technology (lack of access to information and technology); physical barriers; biological (temperature, precipitation, extreme events). Another important barrier to the implementation of adaptation measures is the presence of uncertainty about the expected local impacts of climate change and about the effectiveness of adaptation solutions. There is a "cascade of uncertainty" that proceeds from the differences between the plurality of possible socio-economic futures and related greenhouse gas emissions scenarios to the prediction of the local impacts of climate change by running climate and impact models (Wilby and Dessai, 2010). Moreover, economic losses connected to climate impacts will generally increase non-linearly with global warming levels, thus adding another layer of uncertainty.

In this article we attempt to point out some important practices recurring in the scientific and grey literature for the definition of effective and location-specific adaptation strategies and measures: the framing of adaptation and related dimensions, focusing on the meanings of adaptation approaches in practice; the identification of key local vulnerabilities and adaptation goals; the relevance of a comprehensive multi-level governance; the importance of identifying solutions to face climate change uncertainty. The peer-reviewed literature and the grey literature on adaptation is broad. We do not aim here to be exhaustive, nor do we presume to have developed a systematic literature review. Rather, we intend to present some approaches for the adaptation policy-making that appear to be recurring in adaptation literature, hence contributing to the very definition of adaptation itself. The tools and approaches here presented may be relevant for the public sector policymakers who need an introductory toolbox for the development of adaptation strategies and measures.

2. Defining the concept of adaptation

Even though the IPCC harmonised the scientific literature on adaptation in its Assessment Reports, several authors still present the abundance of conceptualisations and definitions about adaptation (Schipper, 2007; Hall, 2017; UNFCCC LDC Expert Group, 2012, Sherman et al. 2016; Fankhauser, 2017). There is no universal meaning of adaptation (UNEP, 2018; Berrang-Ford et al. 2019) and each decision-maker has its own singular view of adaptation, and his adaptation needs. Tompkins et al. (2018) highlight that adaptation is frequently a wide continuum of coping actions to develop and change, dealing with climate challenges, thus becoming difficult to distinguish between climate policies and conventional development strategies.

Climate change adaptation is an intricate multidimensional topic. The counterpart of adaptation in the field of fighting climate change, namely mitigation, is a more straightforward concept, defined as "a human intervention to reduce emissions or enhance the sinks of greenhouse gases" (IPCC, 2022, p. 2239). Furthermore, despite some inevitable challenges in the monitoring and reporting phases, the evaluation of the implementation of mitigation measures is by some means unequivocal, requiring the computation of the amount of greenhouse gases reduced in relation to a baseline period.

On the contrary, the adaptation framework can be somewhat puzzling. Such topic has emerged to face the current and expected effects of climate change that cannot be avoided by means of mitigation policies (such as some technical solutions to cope with rising sea-levels or the increase in the severity of natural disasters). However, this concept has progressed and expanded since the initial framework designed in the United Framework Convention on Climate Change (UN, 1992) and various conceptualisations have emerged. Adaptation was initially defined as "all those responses to climate change that may be used to reduce vulnerability" (Burton et al., 1998, p. 5.1) or the "efforts to reduce society's vulnerabilities to climate change" (Pielke, 1998, p. 161). During the 1990s, the conceptualisation of adaptation was limited to technical responses to specific climate change impacts or related vulnerabilities, with a sector-based approach and often as synonymous to resilience.

In later years, there was a shift to wider mainstreaming strategies, with trans-sector and transboundary approaches, focusing on building adaptive capacity through more general developmental measures (Rasul and Sharma, 2016). However, the evolution of the conceptual framework has fallen short of resolving a certain level of ambiguity regarding the boundaries and scope of adaptation policies. The Paris Agreement (2015) identified a global adaptation goal presented as "enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change with a view to contributing to sustainable development" (p. 9). This multi-target perspective integrates the concepts of adaptive capacity, resilience, vulnerability and sustainable development, becoming more comprehensive, but also making itself broader and more general (Magnan and Ribera, 2016). Tompkins et al. (2010) present a categorisation of adaptation structured on three main objectives instead of one particular definition. These objectives are: i) reduce socio-economic vulnerability and build capacity to address any adaptation deficit; ii) address present and future disaster risk; iii) build long-term social ecological resilience. Fankhauser (2017) observes that adaptation has different meanings across disciplines: In the disaster risk reduction framework, the concept of adaptation is often used in place of resilience, whereas in the development literature, adaptation is usually replaced by "climate-resilient development". The distinction between adaptation and development is particularly subtle in developing countries. The Adaptation Gap Report (United Nations Environment Programme - UNEP, 2018) claims that there is a vast and complex landscape of adaptation legislation and policy, and that certain areas of policy see adaptation and development blending into one another without clear-cut boundaries. The conceptualisation of adaptation presented by the Government of Rwanda (Republic of Rwanda, 2011) is an example of this ambiguous relationship between adaptation and development policies: "Additional activities are needed to prepare for climate change. This typically involves specific interventions (larger storm drains or new crop varieties) but can also involve broader social or economic strategies (migration to urban centres could be an adaptation strategy in some contexts)" (p. 13).

Hall (2017) discusses the epistemic ambiguity of climate change adaptation and the effects of this confusing framework. The author emphasises two main views: i) the development view, which fundamentally considers adaptation every activity that directly or indirectly increases the resilience of the community; ii) the narrow view, which includes the adaptation measures that are strictly aimed at facing climate change impacts. In the review by Sherman et al. (2016), three main approaches to adaptation policies have been identified: i) the Technocratic Risk Management, where adaptation is distinct from normal development and it is a specific response to climate change, additional to baseline development; ii) the Pro-Poor Vulnerability Reduction, where adaptation needs are integrated into existing development in order to increase the adaptive capacity of the local communities and the welfare of citizens; iii) the Sustainable Adaptation, which integrates adaptation in a development that is socially and environmentally sustainable and where adaptation becomes an opportunity to address failures in the current development pathway.

The Assessment Reports by the Intergovernmental Panel on Climate Change (IPCC) have systematised the concept of adaptation, becoming a landmark for the climate change research community and the policy makers working on climate change strategies. In the last Assessment Report (AR6) adaptation is defined as: "The process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities" (IPCC, 2022, p. 2216). IPCC frames adaptation as a process, an approach highlighted also by other contributions, such as the United Nations Development Programme - UNDP ("a process by which strategies to moderate, cope with and take advantage of the consequences of climate events are enhanced, developed and implemented", UNDP, 2004, p. 36) and Berrang-Ford et al. (2019), who speak of adaptation "efforts" (i.e., "what a government is actually doing in response to the vulnerabilities it faces and its adaptation goals, and also the ways in which governments discuss, mobilise and organise for adaptation", p. 441). This concept of adaptation efforts includes both process-based (e.g. changes in the decision-making procedures) and output-based concepts (a specific investment increasing the resilience of a local community, e.g. new irrigation systems). Furthermore, IPCC clarifies that adaptation policies should be aimed at both present and predicted climate ("in response to actual and expected impacts" – Moser and Ekstrom, 2010, p. 22026); and that it should also focus on the possible positive effects of climate change on society ("cope with and take advantage of the consequences of climate events" – UNDP, 2004, p. 36).

Besides the categorisation of adaptation by the IPCC, the adaptation epistemic framework has been enriched by a far-reaching application. Adaptation has been categorised as transformational or incremental (the former changes the fundamental attributes of a system in response to climate and its effects) (Field et al., 2014; O'Brien, 2012); anticipatory (i.e. planned and deliberate decisions to prepare for potential effects of climate change) or reactive (Füssel, 2007, Fankhauser et al., 1999); purposefully planned (i.e. policies developed by governments or other public institutions as a result of a planning process) or autonomous (Füssel, 2007; Fankhauser et al., 1999; Wilson et al., 2020) (Table 1).

Table 1. Classification of the adaptation policies

	Dimensions	Examples
Goal	Climate oriented	Dissemination of climate information to make farmers aware of the effects of future climate changes
	Development oriented	General training for farmers on more sustainable agricultural practices
Source	Public/planned	Public incentives for a new irrigation system
	Autonomous	Spontaneous changes of the crops according to new climate conditions
Orientation	Outcome oriented	Building a dam to manage the increasing of water shortage periods
	Process oriented	Introducing periodic assessments of climate tendencies and future scenarios inside the decision-making processes on the management of water resources
Shape	Transformational	Conversion of river embankments, using natural solutions and ecosystem services
	Incremental	Increasing the height of river embankments

3. Climate change impacts and vulnerability analysis

Assessing the impacts and risks generated by climate change tendencies and expected future scenarios is an important step for developing location specific and effective adaptation measures. In this regard, vulnerability and risks assessments offer a systematic approach to the issue and multiple potential advantages and collateral benefits. Several approaches have been proposed to vulnerability assessments throughout the years, some providing a general framework, some focused on certain sectors (e.g., agriculture, infrastructure, etc.) or environments (e.g., urban areas, coastal areas, alpine environments).

Even the framework of vulnerability assessment is intricate, with various approaches coming from varying disciplines, such as the socio-economic or the engineering viewpoints. This also happens for many other related concepts, such as resilience, hazard and risk (Modica and Zoboli, 2016). A long-discussed issue among the scientific and practitioner community is, for instance, the differences and boundaries between vulnerability and resilience (Cutter et al., 2008), as one could easily be tempted to consider the two as simply being mutually opposite and complementary concepts. Therefore, parallel communities have developed, who produce resilience (and especially community resilience) analysis on the one hand and vulnerability assessments on the other.

The evaluation of the site-specific vulnerabilities and potential risks brought forward by climate scenarios has been included in both AR4 (2007) and AR5 (Field et al., 2014) IPCC Assessment Reports. Given the revision of the framework provided by IPCC AR5 in 2014, the concept of vulnerability came to constitute just one of the components of risk, together with exposure and hazards. Thus, it could now be considered more appropriate to speak about risk assessment. In fact, the two sets of definitions expressed by AR4 and AR5 are fairly similar: vulnerability is initially described in AR4, as “the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change” (p. 883). In AR5, that becomes “the propensity or predisposition of a system to be adversely affected” (p. 128). More interestingly, the two definitions diverge substantially as they proceed and explain what vulnerability then (AR4), and risk now (AR5), are a function of. In AR4, vulnerability is “a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity”. Whereas, in AR5 vulnerability is per se independent from climate signals, but still “encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt”, the latter concept now formalised as “adaptive capacity”. Risk is instead defined, almost with a mathematical approach, as “the potential for consequences [= impacts] where something of value is at stake and where the outcome is uncertain (...). Risk results from the interaction of vulnerability, exposure, and hazard (...)" (p. 127). Exposure is now referring to population and assets exposed to the risk, whereas the term was referring before to the climate signals and magnitude generating the impact. The formulation in terms of functions and factors casts the basis for a methodological approach to the assessment of the involved dimensions, as well as for a quantitative perspective. The IPCC AR6 (2022) confirmed the framework developed in the AR5 and it collocates the concept of risk central to all the three AR6 Working Groups.

In Table 2 we provide an example to illustrate the definitions more concretely.

Table 2. Dimensions of vulnerability assessment

Theme: Forest Ecology and management			
Factor	**Example**	**AR4**	**AR5**
Climate signal	Increase in the number of heatwaves events (days)	Exposure	Hazard (climate signal)
Direct impact (physical)	Heat and water stress for plants	Potential impact	Hazard (direct impact)
Indirect impact (environmental, socio-economic)	Loss of value, loss of landscape, etc.	Potential impact	Hazard (indirect or intermediate impact)
Presence of elements potentially affected	Area (or volumes) of woodland within the evaluated territory	(Implicitly included in sensitivity)	Exposure
Characteristics of the system or the exposed elements	Health status of the woods, characteristics of the local species	Sensitivity	Vulnerability (sensitivity)
Final outcome of the assessment	Climatic suitability of the woodlands in the territory, adequacy of forestry plans	Vulnerability	Risk

(Source: modified from the original GIZ/EURAC, 2017)

As Kelly and Adger (2000) notice, vulnerability assessments as quantitative methods head in the direction of defining the magnitude of a threat, or climate-related risk: in other words, they can map an attempt at the quantification of the hazard and the associated risk, thus establishing the basics for a metric of adaptation. Nevertheless, even without a quantitative dimension, the process itself of identifying and characterising the vulnerability factors in a system grant the recognition and analysis of issues that negatively affect an exposed element and can therefore contribute to the solution (e.g. low efficiency of irrigation systems, when assessing the risk of water scarcity; a poor rate of green/grey areas in a neighbourhood, when assessing the vulnerability to heatwaves in an urban area). The Impact chains approach is an emerging mixed quantitative-qualitative methodology for the assessment of climate risks (Birkmann et al., 2013; Arabadzhyan et al., 2021). It strongly counts on the engagement of local stakeholders, communities, private entities, and public departments officials responsible for the policies, in order to identify the connections between climate drivers (e.g. the increase of the average temperature) and related risks, highlighting the context and sector-specific determinants of vulnerability and adaptive capacity. This approach is recognised as increasing the acceptability of the risk assessment, compared to the top-down approach with generic indicator schemes (Zebisch et al., 2021), and it sets the scene for a participatory identification of potential entry points for the adaptation measures.

4. Participatory processes for the identification of site-specific adaptation goals

Climate change adaptation is closely connected to both local vulnerabilities but also to the development objectives and priorities of the local population. Adaptation goals are distinct dimensions from vulnerability profiles. According to Berrang-Ford et al. (2019), government adaptation efforts do not arise autonomously from vulnerability assessments but are filtered through the definition and prioritisation of goals and targets.

Eriksen et al. (2015) highlights the role of citizen preferences and development objectives, affirming that adaptation should be viewed as a political process ("processes through which individuals and collectives cooperate and collude to order and govern everyday affairs", p. 524), not just a technical issue. They argue that what counts as "adaptive" is always political and contested. What is seen as good adaptation policy by one group may be seen as a short-sighted measure by another part of the community. Hulme (2010, 2011) calls for increased inclusion of local knowledge and local perspectives and priorities in the decision-making sphere.

The adaptation priorities can be influenced by various local dimensions, such as which group of society is engaged in the decision-making process; the cost-effectiveness of adaptation actions; who bears the costs and reaps the benefits; the risk attitude of the target communities; the level of economic development and the presence of other goals and objectives competing with those generated by climate change (Findlater et al., 2022). Social and cultural factors are essential for the definition of adaptation needs (O'Brien and Wolf, 2010; Adger, 2003; Adger et al. 2013). Societal values, world views, and cultural norms and behaviours influence which adaptation option is considered useful and urgent. Thus, two local communities may assign different judgments upon the importance of environmental resources or the significance of a traditional economic activity.

There are methods and strategies to increase the dialogue between the scientific community and local knowledge and needs brought by communities and governments. Where Impact Chains are used for the engagement of local stakeholders in the climate risk assessment, Participatory Scenario Planning (UNEP, 2014; Flynn et al. 2018) is instead frequently used in natural resource management, to outline multiple alternative futures in a way that spans a key set of critical uncertainties, using quantitative and qualitative methods and data, and examining adaptation options (Oteros-Rozas et al., 2015). Community Based Adaptation (CBA) is another participatory methodology to identify site-specific adaptation solutions, combining scientific data about climate scenarios and impacts with local knowledge about key vulnerabilities to climate risks and traditional coping strategies (Forsyth

, 2013). CBA is defined as "a community-led process, based on communities' priorities, needs, knowledge, and capacities, which should empower people to plan for and cope with the impacts of climate change" (Reid et al., 2009).

5. Multi-level governance

The accountability of measures is a key issue of the adaptation framework (UNEP, 2018) According to Pielke (1998) adaptation "refers to adjustments in individual, group and institutional behaviour", showing the practice of adaptation is yet again rather uneven though, with adaptation strategies and commitments from national governments to local administrations, sometimes lacking a clear distribution of responsibilities. The identification of the proper administrative level responsible for the implementation of an adaptation measure is a complex task. Notwithstanding that at the offset, in the 1980s, climate change was a national and international policy issue, nowadays, it has become increasingly evident that regional and local dimensions are essential for the design and implementation of both mitigation and adaptation measures (Organisation for Economic Co-operation and Development - OECD, 2009). Adaptation policies directly relate to the specific local impact of climate change, while mitigation policies are a global issue, regardless of where they may be carried out. Thus, in the adaptation context, the sub-national level is essential for the definition of effective adaptation interventions.

However, each administrative entity has its own specific role in the adaptation framework. In the 2018 Adaptation Gap report, UNEP observed that the achievement of the global goal on adaptation heavily relies on action by national governments. Governments have multiple roles in regulating, incentivising and providing adequate public services and overcoming structural, informational and economic barriers to adaptation. National level seems to have a prominent role in the coordination of effort, but sub-national governments have a predominant role in the implementation of adaptation commitments (Amundsen et al., 2010). Interesting results have emerged from the surveys made in Lesnikowski et al. (2015) and in Araos et al. (2016). The former created a database of adaptation actions developed by countries and reported in the UNFCCC National Communications; the latter analyses the adaptation measures designed by urban areas. The two studies distinguish two kinds of measures: i) groundwork measures, which are preparatory measures and enablers of subsequent adaptation actions; ii) adaptation level actions, policies that directly reduce the vulnerability of a target community. These inquiries confirm the different role that state and non-state actors have in the adaptation area. Lesnikowski et al. (2015) observe that 73% of the national measures considered fall within the groundwork measure category, and just 23% could be considered tangible adaptation actions. The Araos et al. (2016) study examines 997 adaptation measures coming from urban areas with more than 1 million inhabitants (just 74 out of 401 urban areas reported adaptation measures) and it finds that 72% can be considered measures that affect the vulnerability of the community, just 28% remain in the groundwork sphere. This comparison suggests that the local level is used to develop tangible adaptation actions, whereas at higher administrative levels adaptation policies are mainly focused on the creation of enabling conditions and helpful institutional environments.

The effectiveness of the relations between different administrative levels of governments and the harmonisation of the adaptation duties are usually considered an issue of Multilevel Governance (MLG). Corfee-Morlot et al (2009) maintains that MLG requires narrowing or closing the policy gaps among levels of government via the adoption of tools for vertical and horizontal cooperation. However, MLG is not intended to be merely an integration between international, national and local governments. UNEP (2018) identifies three possible opportunities for MLG: i) vertical, between levels of governments; ii) horizontal, such as between Ministries and Departments; iii) between multiple actors, such as state, non-state, private organisations, over a specific issue. The coordination among different departments and ministries of the same administration grants the opportunity to integrate various competencies and perspectives increasing the synergies between policies, reducing conflicts and externalities on other department goals and possibly developing win-win solutions with cross-cutting benefits (for instance, the use of snowmaking to compensate the lesser amount of snowfall in the winter season could provoke water shortages for other sectors and conflicts). The aggregation of different administrations on a specific adaptation goal is also crucial and there are several examples, such as the Climate Change Adaptation Strategy for the Danube Basin (http://www.icpdr.org/main/climate-adaptation-strategy-adopted). Furthermore, different networks have been established in order to coordinate and increase the adaptation efforts by specific groups of public and private actors (e.g. the European Covenant of Mayors on Climate and Energy, the Global Covenant of Mayors for Climate and Energy, C40, Compact of States and Regions).

6. FACING UNCERTAINTY WITH ALTERNATIVE DECISION CRITERIA AND DECISION-MAKING PROCESSES

One of the most significant challenges facing the development and implementation of climate change measures is connected to the presence of uncertainty associated with the future local impacts of climate change, especially in the long run (Wilby and Dessai, 2010). Uncertainty has been defined as the lack of probability distribution to describe the possible future states of the world (Knight, 1921). Making decisions based on uncertain data on days of rainfall, average temperature, frequency of natural disasters, is particularly demanding and decision-making processes struggle to identify effective solutions. Thus, new decision criteria have been appeared besides the most traditional criteria such as cost-efficiency or multi-target effectiveness (Hallegatte, 2009; Dittrich et al., 2016; Watkiss et al., 2015) and new decision-making processes have been proposed and tested.

6.1. Robustness

Robustness is defined as “decisions that are insensitive against variations of the problem’s parameters, which generally refer to an ensemble of future climate and socio-economic scenarios” (Giuliani and Castelletti, 2016, p. 410). However, there is no unique metric for robustness, which is influenced by the degree of pessimism/optimism of the decision-maker. The process of robust decision-making can be typified by different combinations of two key decision criteria: regret and satisfaction (Herman et al., 2015). Regret quantifies the cost (not necessarily monetary) of choosing incorrectly and it can be measured as the possible deviation from its expected outcome. Satisfaction refers to the tendency of decision-makers to seek outcomes that meet one or more requirements but may fall short of achieving optimal performance. Five possible rules for robustness may be identified: maximin metric (focusing on the worst possible performances of the measures, among all possible scenarios and selecting the option with the best/worst performance), maximax metric (considering the best performances and selecting the measure in the highest position), optimism-pessimism rule (assessing measures through the weighted average of the pessimistic and optimistic performance), minimax regret metric (focusing on the regret between the performance resulting from the best alternative of a specific state of the world and the performance of the selected option), the principle of insufficient reason (which indicates that in the absence of information on the probabilities associated with the different states of the world, the decision may be taken by assigning equal probability to all the states) (Giuliani and Castelletti, 2016; Wald, 1950; Hurwicz, 1951; Savage, 1951; Laplace, 1951; Lempert, 2019). The plurality of robustness metrics suggests the need to have a dialogue between researchers, who make the economic assessment of the policy, and decision-makers, in order to understand risk attitude and the preferences of the latter to select the most appropriate decision criteria.

Robust Decision Making (RDM) and Portfolio Analysis (PA) are decision-support tools aimed at finding robust adaptation strategies and measures. RDM (Lempert et al, 2003) uses computer software to assess adaptation strategies among hundreds of possible futures. These scenarios are developed varying from some key parameters. Climate change could be one of the most decisive parameters. Initially used for military purposes, nowadays there are various applications to the climate change environment and adaptation policies (Lempert et al., 2006; Lempert and Groves, 2010, Lempert, 2019). PA is instead a methodology coming from the world of Finance (Markowitz, 1952), which aims at evaluating portfolios of investments based on their economic return and risk. Diversification of non-perfectly correlated investments in portfolio can reduce the variance of the return of the investment in the future, identifying the allocation of resources that can guarantee more robust outcomes. Although this tool has been widely used for financial investments, it has several applications even in the resource management framework and in the evaluation of climate change measures (Alvarez et al., 2017; Matthies et al., 2015; Castro et al., 2015; Ando and Mallory, 2012; Fraschini et al., 2022). Info-Gap Decision Theory (Ben-Haim, 2019) is another tool used to assess robust measures. An information gap is here intended as the gap between what is known and what needs to be known in order to take reliable and responsible decisions (Marchau et al., 2019; Ben-Haim, 2019).

The application of the criteria of robustness may also lead to the identification of the so-called no-regret or low-regret measures. These are measures able to guarantee desirable results in every climate scenario, regardless of the severity (or even the existence) of climate change impacts and they are usually recommended as an important element in adaptation strategies. IPCC (Field et al., 2014) defines low regrets policy as: "A policy that would generate net social and/or economic benefits under current climate and a range of future climate change scenarios" (p. 125). There are various reasons why these measures might not yet have been developed by an administration regardless of their win-win outcome. Hallegatte (2009) identified three specific obstacles: i) financial and technological constraints, especially in developing countries; ii) lack of information and transaction costs at the community level; iii) institutional and legal constraints.

6.2. Flexibility

Another important dimension for the effectiveness of adaptation decisions is flexibility. When the effects of climate change are uncertain and can compromise the efficacy and expected outcome of the policy, flexibility gives the opportunity to reshape the intervention coherently with new conditions (Hallegatte, 2009). When new information that can emerge in the future, there can be a benefit in postponing some irreversible investments, waiting for more detailed and comprehensive knowledge. The development of an urban area might provoke irreversible impacts on the local ability to cope with floods or it may be dangerous for the life of some threatened natural species. Since there is uncertainty connected to the evolution of some important climate components, such as the amount of the precipitation and the average temperature (Wilby and Dessai, 2010), the additional enlargement of the urban area can be postponed, due to its irreversibility, and it could be assessed again after some years. Thus, flexibility fundamentally consists of imagining the policy over a series of decision points distributed throughout the future, rather than constraining the decision-making process and the design of the policy to the present.

There are essential tools and strategies for the definition of flexible policies, such as Real Option Analysis (ROA), where the option value represents the economic value of flexibility (Hallegatte, 2009), and decision trees. Such have usually been used for the representation of possible alternative solutions and the definition of diverse steps for decisions that can be postponed within a sequence of future interventions, instead of being wholly implemented at time zero. These methods also give rise to the opportunity to avoid lock-ins, where the investment made is irreversible and cannot be modified in the attempt to face the newer climate conditions. There are various examples of ROA application to climate change adaptation decisions, such as the works by Woodward et al. (2014) and Buurman et al. (2016) focused on the strategies to manage flood risk.

Alternatively, another interesting framework for the definition of decision trees and farsighted strategies to cope with the variety of climate change scenarios is the Adaptation Pathways (AP) methodology (or Dynamic Adaptive Policy Pathways – DAPP). The Adaptation Pathways approach has different methodological frameworks (Haasnoot et al., 2012; Haasnoot et al., 2013; Siebentritt and Stafford Smith, 2016; Werners et al., 2021), but it is generally characterised by the anticipated definition of a decision tree with various possible pathways that are made by different adaptation tipping points. These are the points where a particular course of action is no longer adequate for meeting the plan's objectives and a new measure is therefore required, creating alternative, sometimes connected, adaptation pathways, with different combinations of measures. Several applications in case studies exist: the management of a river delta (Haasnoot et al., 2012; Haasnoot et al., 2013); the development of a coastal protection system (Barnett et al., 2014), the identification of adaptation measures to face heat stress in urban areas (Zandvoort et al., 2017). The Adaptation Pathways methodology has two relevant strengths: i) the definition of the pathways requires the decision-makers to imagine future long-term developments of their community and to consider the related impacts of climate change, reflecting on the trade-offs of each pattern and possibly avoiding lock-ins; ii) it is a straightforward and appealing way to present a sequence of adaptation policies and the possible effects of climate change.

6.3. Iteration

The reliability and precision of climate models for climate projections and the quantity and quality of information available on expected climate scenarios and impacts are continuously updating. Scientific knowledge of climate change is also rapidly changing. Currently, we have diverse global and regional climate models, with different levels of downscaling of the climate projections and the IPCC is publishing its 6th Assessment Report (2021-2022), just after the publication of specific reports on climate change effects on Land (2019) and Oceans (2019).

Therefore, traditional decision-making procedures, with long-time monitoring frameworks and scarce integration with new scientific findings on climate and the effects on natural resources might well be inefficient in this new dynamic context. Alternative decision-making processes have recently been proposed. An approach in this area is the Iterative Risk Management framework - IRM (otherwise Adaptive Management – AM, or Adaptive Policy-Making – APM, or Dynamic Adaptive Planning - DAP). IRM is an established approach that uses a monitoring, research, evaluation and learning process (cycle) to improve future management strategies (Watkiss et al., 2015). IRM is based on the idea that current decisions are fundamentally limited by imperfect knowledge and cognitive bias and cycles of revisions are thus necessary to improve the performances of selected interventions. Decision-makers, under IRM, are expected to be flexible in their approach, and accept new information as it becomes available, or when new challenges emerge, and not be rigid in their responses (Field et al., 2014). IPCC (2014) defines Adaptive Management as "a structured process for improving management policies and practices by systemic learning from the outcomes of implemented strategies, and by taking into account changes in external factors in a proactive manner". IRM is designed to learn and incorporate new information and thereby improve future decision-making. This process is constituted by an ongoing assessment, action, reassessment, and response that will continue – in the case of many climate-related decisions – indefinitely. IRM is most relevant for medium-long-term strategies where there is a potential to learn and react.

There are various applications of IRM/AM methodology, therefore it is complicated to identify a straightforward sequence of steps and tasks. Tompkins et al. (2008) present a case study regarding the integration of Adaptive Management into the disaster risk management of the Cayman Islands, where the adaptive governance of the National Hurricane Committee (NHC) dramatically reduced the economic and social impacts of hurricanes. The approach has also been used in the development of the Thames Estuary 2100 project (TE2100), which is one of the first major infrastructure projects to explicitly recognise and address the issue of the deeply entrenched uncertainty in climate projections throughout the planning process. The method is defined as "dynamic robustness" (Ranger et al., 2013), a process based on flexible strategies that can change according to the new information learnt and the modifications of the climatic conditions.

7. Considering the effects of climate change over the whole economic life of the measures

Regardless of the mitigation efforts by the international community, climatic changes will inevitably persist in the coming decades, and the magnitude of these changes will depend upon the countries' mitigation commitments. Emission scenarios by the IPCC (IPCC, 2021) shows the effects of different mitigation policy pathways over climate dynamics and the possible related impacts on natural resources. If the short-term differences between the expected climate change impacts of the different scenarios may sometimes be narrow, the discrepancies and related uncertainties between these scenarios on a longer temporal scale (the mid or the end of the XXI Century) may well be massive. According to IPCC (2021) the near-term increase of temperature would be +1.5°C in the best case and +1.6°C in the worst scenario, whereas, at the end of this century, the distance between the scenarios is wider, +1.4 in the best future, but a dramatic +4.4°C in the worst scenario. Therefore, where short-term decisions may be indifferent towards the alternative scenarios, long-term policies or high-sunk costs investments (dam, sewage network, transport infrastructure, perennial crops) might be radically compromised by completely changed climate conditions (e.g. horticultural investments might be modified in the short-term, whereas grapevines or olive trees cannot be moved easily to other locations).

There are different ways to consider these long-term effects in the decision-making processes. Clearly, decision trees are an interesting strategy to tackle this point, in order to reflect in advance upon the possible future performances of the available policies. Moreover, climate projections should be considered in the economic analysis of long-term policies and investments affected by climate components, assessing the performances across different climate scenarios. When dealing with distant future costs and benefits in Cost Benefit Analysis (CBA), the social discount rate (SDR) issue becomes crucial. The value of SDR is influenced by the expected increase of the population’s wealth and their pure time preference (or impatience), i.e. the measure of the propensity to prefer income today rather than tomorrow. Fundamentally, high values of SDR are used to evaluate investments in developing countries, whereas in developed nations lower values are applied. For example, the African Development Bank used a 12% SDR for the evaluation of a Road Rehabilitation Project (2016) in Kenya, whereas in Rwanda, the SDR published by MINECOFIN is 13% (Rwanda Ministry of Finance and Economic Planning, 2018). These high SDR values assign a higher value to short-term costs and benefits, underestimating the effects of climatic changes over the long-term sustainability of the policy. Since there is a high level of uncertainty relating to the welfare of future generations and the possibility, even remote, to incur catastrophic events due to climate change, during recent years an increasing part of the scientific literature has proposed a Declining Social Discount Rate (DSDR) for those policies holding long-term effects (usually projects that have an economic life longer than 40/50 years), affecting the life of the future generations (Arrow et al., 2014). French and UK administrations use a DSDR in the evaluation of their investment projects. In its ‘Green Book for the Appraisal and Evaluation of Public Interventions’ (2022), the UK HM Treasury suggests a declining SDR of 3.5% for the first 30 years, thereafter, decreasing to 3.0% from the 31st to the 75th and 2.5% from the 76th to the 125th year. Thus, in case of CBA of climate sensitive and long-lasting measures, different climate scenarios might be considered and a sensitivity analysis of the SDR, even reflecting on possible declining SDRs, could increase the robustness of the economic assessment.

8. Conclusion

The implementation of adaptation policies is particularly challenging, due to the ambiguity of the theoretical framework and the presence of various barriers. Citizens and government can be reluctant to assign economic resources and effort to choices with distant benefits, to face problems that they have never experimented with before, especially in the face of economic constraints due to a crisis, or in the presence of more urgent priorities (e.g. Covid-19 response)

A thorough analytical phase (assessing climate impacts, specific local vulnerabilities and climate risks) can be helpful to greatly clarify the pressures and the responses needed for the community, making it more evident with what can be considered adaptation. Such analysis should take into consideration the most relevant local climate information or acknowledge the gaps in knowledge and the uncertainty factor to operate with. A healthy balance between scientific knowledge and technical recommendations on the one hand and traditional knowledge and local coping strategies on the other should be struck, establishing inclusive procedures to engage those most marginalised and vulnerable communities.

Even with such a high level of uncertainty, adaptation can be designed and implemented as a safe and precautionary way to move forward. Uncertainty may be managed through robustness and flexibility in the planning of measures; by taking into account by design, the rather lengthy lifespan of most adaptation measures; and therefore, to set up iterative processes of policy verification and adjustment, continuously updating knowledge and data about ongoing climate tendencies and expected climate scenarios.

Clear ownership makes for even clearer policies: well-structured (multilevel) governance of adaptation measures under development may allow such to align more easily to the same level of efficacy and efficiency as ordinary policies, established in the institutional structure. Furthermore, responsibilities need to be coherently and effectively shared between the different levels of government and cooperative processes need to be fostered, especially when the impacts of climate change on natural resources (e.g., rivers, lakes, or coastal areas) are complex and require ongoing collaboration among various public institutions.

However, few analyses have been produced on the monitoring and assessment of adaptation policies and the existing studies mainly rely on self-reported communications coming from national or local authorities. Therefore, further in-depth research is needed to assess the effectiveness of these approaches for the development of adaptation solutions and strategies.

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Climate change is a crucial challenge to sustainable development. Climate greatly contributes to setting development conditions and constraints, considerably affecting the availability and quality of natural resources and local environment. Besides mitigation efforts, adaptation strategies and measures are needed in the attempt to reduce the expected negative impacts of global warming, to increase the resilience of the communities and to take advantage of the positive effects. However, despite the urgency of adaptation policies, the multitude of national and sub-national adaptation strategies and plans have not been implemented evenly. We argue that this may well be connected to the fragmented and often puzzling theoretical framework of adaptation, along with the high level of uncertainty that characterises the ratio between the costs of climate change impacts and the benefits of adaptation measures, while there are also issues concerning accountability problems and ownership of the adaptation process. In this paper, we discuss some of the most relevant tasks for the identification of effective, sustainable, and integrated adaptation strategies. The aim is to help public decision-makers in the definition and implementation of measures, considering the peculiar vulnerabilities and development objectives of local communities.

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