Study on Adaptation Modelling

Recommended Approach to Analysis and Modelling

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Table of Contents

Non-technical summary

This report proposes "recommended approaches to analysis and modelling" for better-informed decision-making on adaptation at various levels of governance. It also identifies research advancements to foster "the development and application of the technical, financial, economic and non-monetary analysis and modelling of climate change hazards, risks, impacts, vulnerability and adaptation".

Useful guidance to develop adaptation assessments that are not only informative, but also of easier uptake by decision makers, is provided by the adaptation policy cycle schematised in the Adaptation Support Tool (AST) by Climate-ADAPT. The six AST steps can be easily translated into investigation phases and substantiate well how adaptation analyses should be ideally structured. The phases are: (a) preparing the ground for analysis, (b) assessing risk and vulnerabilities, (c) identifying adaptation options, (d) assessing adaptation options (e) implementing adaptation strategy (f) monitoring and evaluation.

Particularly important in the development of all the steps of adaptation assessment is the proactive involvement of stakeholders, especially those that need to implement the decisions, in order to correctly identify peculiar needs, including those related to the result communication phase. Best practices in co-production, co-design should be encouraged.

The scrutiny of the tools and methodologies currently used in the field of adaptation assessment highlighted the following gaps:

- many models still provide information with a spatial-temporal resolution which is not consistent (too coarse) with that of many adaptation actions. The shortcoming is particularly acute for the analysis and implementation of adaptation measures at the urban, municipal level.
- There is still a "divide" between macro-economic assessment of impacts and adaptation and the local analysis. The empirical foundation of the former is still quite weak with the consequence of producing outputs that could be interpreted more qualitatively than quantitatively. The problem is progressively more severe, moving from the assessment of hazards, exposure, vulnerability and finally adaptation. More information is needed on adaptation costs and effectiveness. Similarly, the possibility to aggregate and transfer local adaption assessments to different contexts is very limited.
- Notwithstanding improvements, models and assessments do not yet address satisfactorily feedbacks and interactions taking place within and between the different dimensions of the climate change adaptation process. The role played by multi hazard, cascading and compounding effects, and interaction between physical and behavioural responses deserve more investigation improving model coupling.

- There is not yet a common and consolidated practice in the communication of uncertainty. In particular, current assessments do not always enable to disentangle different uncertainty sources: that coming from the climate component, the social component, the models used and the parameterization used.
- Climate change impact, vulnerability and adaptation assessments are complex and costly analyses that can exceed funding capacity of smaller administrations. Moreover, the time needed to release such analyses is often too long compared to that of decision making. This points to the need of methods facilitating, when possible "quick and operational" insights from adaptation modelling for policy assessment. Currently, many existing Decision Support Systems do not seem to offer a valid solution.

It finally emerges that adaption options, their concrete implementation and evaluation were hardly ever the main object of the available modelling frameworks, and of the majority of available tools used to study adaptation, at the time such frameworks and tools were first designed. Their original purpose was usually to depict the status and evolution of some natural or economic systems under climatic change. Thus, most of the approaches identified and assessed in the present study cover extensively the first two steps of the adaptation analysis: "preparing the ground for adaptation" and "assessing risk and vulnerability to climate change". A much more limited number of studies relate to "identifying adaptation options", "assessing adaptation options", "implementing adaptation strategy" and "monitoring and evaluation strategies".

In the light of these limitations some actions are suggested.

To improve the support to local adaptation planning it is essential to increase the availability, reliability and accessibility of climate information with the "right" spatial resolution. This can be achieved by the following research initiatives:

- Systematic evaluation of the domain of applicability (strongly dependent on the resolution of observational datasets) of statistical downscaling for the different parameters (temperature, precipitation, wind) over the historical period.
- Systematic comparison of dynamical and statistical downscaling performance in representing the statistics of all the relevant parameters, with special focus on tendencies of extreme events, over the whole EU domain during the historical period.
- Support the development of higher horizontal resolution version of the current models taking part to the current Copernicus Climate Change Services.

And by the following more general actions:

- Support the inclusion of new members in the current Copernicus Climate Change Services.

- Develop a “front office” activity for producers of climate change data, primarily within the Copernicus Climate Change Service, to increase availability, reliability and smooth accessibility (beyond what is already feasible) of climate information (especially on climate extremes and composite indicators) at different spatial resolution and with a focus on enhancing more direct interlinkage of climate with socio economic data.

Similarly, the quantitative empirical basis on cost and effectiveness of climate change adaptation has to be improved and made more accessible to decision making. A particular attention has to be placed on “local” administration that can be less capable to mobilize resources to develop adaptation analyses. In particular, it is suggested to:

- Promote a systematic survey of existing quantitative evidence on cost and effectiveness of adaptation building on the results from many FP7, H2020 projects and research initiatives in this direction. In the longer term, this action can take the form of a model inter-comparison project where different methodologies and results are contrasted on common assumptions and are made publicly available in the form of quantitative databases to the academic and policy community. This action can be supported directly by DG CLIMA or the EC in the form of a CSA if not of a research project and should develop in coordination with the EEA and the JRC.
- Develop systematic guidance tools and case studies for climate change risk and adaptation assessment more tailored to stakeholders needs, in particular to “rapid and light touch” assessments than those currently available. Important is supporting the development of robust decision making under uncertainty. In this action stakeholder engagement is deemed essential.
- Support research in all the gap areas highlighted. With specific reference to adaptation, knowledge is particularly lacking on: cost and effectiveness of adaptation especially in health care, farm-level adaptation, energy supply, in and from biodiversity and ecosystem services, determinants of adaptive capacity and of its effectiveness.

1. Introduction

This report proposes recommended approaches to analysis and modelling for better-informed decision-making on adaptation at various levels of governance. It also identifies research advancements to foster the development and application of the technical, financial, economic and non-monetary analysis and modelling of climate change hazards, risks, impacts, vulnerability and adaptation

More specifically, building on the comprehensive desk review (reported separately), the present report will:

- summarise, substantiate, prioritise, and outline a recommended approach for each of the main cases of technical, financial, economic and non-monetary analysis and modelling of climate change hazards, risks, impacts, vulnerability and adaptation.
- define and outline relevant follow-up actions for the coming five years period with a view to improving the approach for each of the main cases (use cases thereafter) analysed in a separate report.

The present report develops along three main angles. Firstly, it identifies under a more conceptual perspective, key methodological steps enabling the development of an effective analysis of adaptation. Secondly, it analyses how the different models and methods scrutinized match these steps. This will substantiate a gap analysis highlighting what is feasible today, and what is not yet feasible. Thirdly, it suggests options to improve upon identified limits in adaptation assessment. In particular, the report identifies and prioritize the next-term (for the next five years) actions that can further facilitate the application of climate–impact-economic modelling for practical-usable adaptation analyses.

In what follows: section 2 describes the conceptual framework for the development of adaptation analysis, section 3 describes how existing methodologies fit to this framework, section 4 provides recommendations for priority actions in the next five years to bridge the gaps highlighted, section 5, starting from main cases examined in Task 4 derives operational examples on how gaps could be bridged.

2. The conceptual framework for adaptation analysis

A useful conceptual framework for the development of adaptation analysis can be derived by the adaptation policy cycle, schematised in the Adaptation Support Tool (AST) by Climate-ADAPT (see Fig.1). [1]

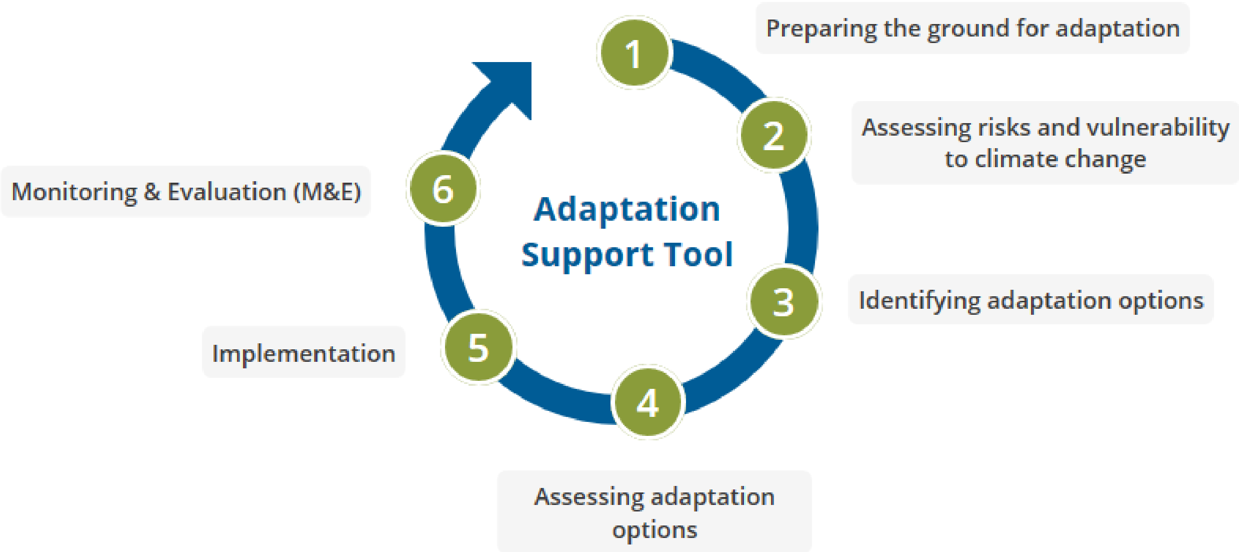

Figure 1 - The Climate-ADAPT 'Adaptation Support Tool'[2]

Although referring to policy action, the six AST steps offer a useful identification of the main phases of the whole adaptation process that can be easily translated into investigation phases. The stages are meant to be consecutive, however, due to the complexity of adaptation analysis, the process can be iterative while the different phases can present multiple interactions and enable multiple pathways (EEA, 2018).

2.1 Preparing the ground for adaptation

Step 1 of the AST introduces key preliminary elements for a successful adaptation process. These include the need to obtain and assure high level support, set up adequate coordination mechanisms, clarify roles and responsibilities, explore funding

[1] The AST is planned to be updated and improved in 2020 by the EEA with the support of its European Topic Centre on Climate Change impacts, vulnerability and Adaptation (ETC/CCA), following up a review and scoping work carried out in 2019. The work took into account the views and opinions of DG CLIMA, the consideration of country needs (and capacities), and the recommendations from the evaluation of Climate-ADAPT and of the EU Adaptation Strategy. https://forum.eionet.europa.eu/etc-cca-consortium/library/etc-cca-2019-2021/etc-cca-2019/project-1.4.3-information-systems-climate-adapt/task-1.4.3.1-climate-adapt/d3-further-development-climate-adapt-web-content/ast_review_20190402/ (Access rights needed)

[2] Climate-ADAPT 'The Adaptation Support Tool' https://climate-adapt.eea.europa.eu/knowledge/tools/adaptation-support-tool, visited on 08.01.2020.

opportunities, identify already available information and increase awareness or understanding of climate change issues.[3]

Translating this in term of adaptation analysis, the initial research phase should aim to take stock of the existing information[4] and identify the different stakeholders that will be engaged in the adaptation process under examination.

The scrutiny of existing information, depending upon the aims and scope of the specific adaptation assessment, could extend beyond the climatic, environmental and social economic data. For instance, the prioritization of adaptation option may require evaluating, among other criteria, the policy viability of a measure or a mix of measures. This on its turn calls for a clear picture of the policy/governance context in which adaptation actions will be implemented.

Strictly connected to this, is the identification of stakeholders a process which is important either for policy makers, which are the potential final users of the analysis results, or for the researchers that produce them. Close communication between policy making and research is naturally essential, either to develop an analysis that is effectively useful to those that have to ultimately implement the policy, or to improve the accessibility to specific information sources or contacts not directly available to scientists. The interaction with policy making could also enable a process of mutual learning, education and training, which can improve transparency and trust across the communities, facilitate the development of adaptation assessment and the uptake of results. Other stakeholders, like interest groups or the general public, are also important for the role that they can play in supporting the identification, prioritization and monitoring phases of adaptation assessment.

Sharing information through a common language and established mechanisms is, among others, an essential pre-condition for a good adaptation[5]. Adaptation analysis might check which are the best means used to communicate and raise awareness on climate adaptation within and outside the responsible authorities (e.g. working groups, web-based communication platforms, mass media and personal consultations) and their effectiveness also in enhancing the acceptance and motivation to taking action.

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[3] Climate-ADAPT, 'Preparing the ground for adaptation' https://climate-adapt.eea.europa.eu/knowledge/tools/adaptation-support-tool/step-1, visited on 09/01/2020.

[4] A variety of evidence and knowledge exist, that can be found through literature review and/or by browsing other sources such as the adaptation knowledge portals, whose landscape is wide-ranging. Most of the web portals, including climate services, offer searchable databases of adaptation knowledge resources, including publications, guidance and technical documents, methods and tools, and case studies. The information can be usually filtered by various features (e.g. type, geographic region, sector or theme, adaptation element, and climate hazard).

[5] Climate-ADAPT, 'Preparing the ground for adaptation - Communicate and raise awareness' https://climate-adapt.eea.europa.eu/knowledge/tools/adaptation-support-tool/step-1/communicate-raise-awareness, visited on 02/03/2020

2.2 Assessing risk and vulnerability to climate change

Decision-making should be informed by the best available evidence. Climate change impacts, vulnerability and/or risks (CCIV) assessments aim to gather and analyse this evidence to support policymaking (EEA, 2018), identifying which regions, sectors, social group or system components are particularly affected by climate change and where there is an urgent need to adapt. This is the most crucial step to inform adaptation planning, prioritization and implementation.[6]

Quantitative analysis needs thus to develop the most comprehensive picture of current and future climate change risks. [7]

This includes:

- identification of main climate variables drivers of the hazards;
- translation of climate stressors into hazards;
- identification of how these interact with the socio-economic and environmental dimensions. This specific investigation phase pertains to the characterization of "exposure" and "vulnerability". In this last respect, it would be essential to provide information on social vulnerability accounting for characteristics, like, for instance, gender, demographic structure, income, that can identify vulnerable groups. Particularly important for the assessment of vulnerability is defining and measuring adaptive capacity that can play a paramount role in determining the final risk. Against this background, although not directly related to a quantitative evaluation, the EC in the Commission Staff Working Document evaluating the EU Strategy on adaptation to climate change (EC, 2018b) suggests to verify specifically if: systems are in place to monitor and assess current and projected climate change; impacts and vulnerability; knowledge transfer processes are in place to build adaptive capacity across sectors; knowledge gaps on climate change and climate change adaptation are tackled.
- identification of opportunities arising from climate change
- development of a transparent and informative treatment of uncertainty.[8] Uncertainty is intrinsically originated by the incomplete knowledge of the phenomena investigated. In adaptation assessment, it takes the typical "cascading" form amplifying along the assessment chain going from climate pressures, to environmental reaction and eventually to social economic

[6] Climate-ADAPT, 'Impacts, risks and vulnerabilities' https://climate-adapt.eea.europa.eu/knowledge/adaptation-information/vulnerabilities-and-risks, visited on 11/12/2019.

[7] Climate-ADAPT, 'Assessing risks and vulnerability to climate change' https://climate-adapt.eea.europa.eu/knowledge/tools/adaptation-support-tool/step-2, visited on 09/01/2020.

[8] Climate-ADAPT, 'Assessing risks and vulnerability to climate change' https://climate-adapt.eea.europa.eu/knowledge/tools/adaptation-support-tool/step-2, visited on 09/01/2020.

responses. The uncertainty space can be spanned using different models, model parameterizations, and climate and socio-economic scenarios. CCIV assessments should transparently inform on the impact of each different uncertainty source on the final results.

In all of these phases, particular care should be placed in harmonizing the investigation scope with that of policy action. This issue has at least three dimensions:

- The "spatial" one: adaptation strategies are decided and implemented at different levels. For instance, national adaptation actions require a completely different detail and type of CCIV assessment with respect to municipal level adaptation. Climate data, environmental data and social economic data in support of adaptation decision have thus to match the appropriate "spatial" resolution.
- The "temporal" one: CCIV should be timely. Decision making and planning have their specific timing. The majority of administrative decisions are taken on a yearly or shorter basis. This aspect should not be underestimated when CCIV are developed. Matching the time of science with the time of policy decision process is fundamental for the former to be useful and used by the latter.
- Accessibility and replicability. This aspect is also connected to the broader transparency of scientific research and outcomes. Methodologies should be transparent and replicable. Ideally also databases and tools used for CCIV assessment should be accessible and usable by policy makers. In fact, this requisite is hardly achievable. Nonetheless, full accessibility of data and the possibility to develop "back of the envelope" or simplified analyses starting from the more complex CCIV assessments for policy makers or their technical staff, would be an important feature granting their wider diffusion and a better uptake of results. At the same time, it is important to state clearly when these reduced form analyses are reasonable and how to correctly interpret their results.

2.3 Identifying adaptation options

After the CCIV assessments, a first scrutiny of adaptation options can be performed. This phase consists of the preliminary identification of actions that can address the previously identified concerns, bring negative impacts at an acceptable level or take advantage of any positive opportunity that arise from climate change. The identification should take into account good practices and existing experience (EC, 2018b). This phase can thus benefit from the interaction with all the actors involved in the adaptation process: researchers, practitioners and decision makers.

Adaptation options can be the most diverse and their appropriateness can be only defined according to the context of the analysis. They can range from actions that build adaptive capacity (for instance producing/sharing information, creating supportive institutional frameworks) to concrete adaptation measures (for instance technical solutions, insurance mechanism, green and grey infrastructure). Accordingly, in this initial scrutiny, a categorization of options along different typologies can be useful.

An illustrative example of classification of adaptation measures has been proposed by the Italian National Adaptation Plan and is reported in Table 1 below.

Table 1: An example taxonomy of adaptation measure

Type of adaption action	Macro Category	Category
Soft adaptation actions	Informational adaptation processes (including early warning systems)	Research
		Data and models
		Awareness raising
	Organizational and participatory adaptation processes	Institutional
		Management
		Partnership
	Governance adaptation processes	Legal and regulatory actions
		Adaptation plans and strategies
		Financial actions
Hard adaptation actions (green and grey)	Adapting plants and infrastructures	Improving plants, material, technologies
		Protection systems
	Nature based adaptation solutions	Forestry and agro-forestry ecosystems
		Riverine, coastal and marine ecosystems
		Integrated solutions
		Restoration recovery

Source: Authors' adaptation from the Italian National Adaptation Plan[9].

The classification facilitates the exploration of potential adaptation options and helps identify relevant actions and their potential co-benefits.[10]

[9] Supporto tecnico-scientifico per il Ministero dell'Ambiente e della Tutela del Territorio e del Mare (MATTM) ai fini dell'Elaborazione del Piano Nazionale di Adattamento ai Cambiamenti Climatici (PNACC) https://www.minambiente.it/sites/default/files/archivio_immagini/adattamenti_climatici/documento_pnacc_luglio_2017.pdf

[10] Climate-ADAPT, "Identifying adaptation options" https://climate-adapt.eea.europa.eu/knowledge/tools/adaptation-support-tool/step-3, visited on 09/01/2020.

2.4 Assessing adaptation options

When adaptation options have been identified, the next step consists of their evaluation according to a set of chosen criteria. The selection of criteria should be done in collaboration with the actors involved in the adaptation process, especially those who have eventually to decide and implement them or are affected by them.[11]

The criteria for assessing adaptation options can be many.

The typical ones, recurrent in many different processes of policy appraisal are:

- effectiveness of the adaptation option/measure. Options are ranked according to their ability to "reduce a particular vulnerability or number of vulnerabilities to a desired level". In practice, this implies the need to return to the results of the CCIV assessment and propose adaptation actions that address identified risks and vulnerabilities (EEA, 2018).[12] Effectiveness substantiates the benefit of the option and can be expressed with multiple metrics, including economic evaluations.
- cost of the policy. This can be interpreted in financial, economic and social terms (see chapter 5 of the comprehensive desk review).

Effectiveness and costs can then be evaluated jointly, developing both cost-effectiveness and cost-benefit analyses (see sections 5.1. and 5.2 of the comprehensive desk review). Particularly important is the concept of efficiency of the measure that pertains to its ability to achieve the desired goal at the minimum possible cost.

Further criteria (Florke et al., 2011) consider:

- Higher order effects. This criterion evaluates all the effects that derive from the implementation of adaptation actions but are not their main aim. Higher order effects can be either positive (also called "ancillary benefits") or negative. The presence of ancillary benefits could then originate adaptation actions of the "no-regret" and of the "win-win" type*.* Although the distinction is not always clear in the literature, the former concept denotes actions producing benefits in different climate scenarios, not conflicting with other policy goals, and characterized by a high benefit-cost ratio. The latter concept defines actions that originate benefits beyond, and in addition to, damage reduction. Finally, negative higher order effects define "maladaptation".
- Performance in the presence of uncertainty. This criterion evaluates the suitability of a given adaptation action to be applicable in a multiplicity of

[11] Climate-ADAPT, "Assessing adaptation options" https://climate-adapt.eea.europa.eu/knowledge/tools/adaptation-support-tool/step-4, visited on 09/01/2020.

[12] Criteria can change according to the nature of different adaptation options. Climate-ADAPT provides tools and guidance documents to help selecting assessment procedures for

climate and social economic scenarios or, more extensively, under different impact scenarios. This criterion can be further specified in the concepts of robustness and flexibility. The first pertains to the ability of the measure to be effective in different contexts; the second to its ability to "adapt" to different contexts at a relatively "low cost". Flexibility may imply transformation of the adaptation action, its integration with supplementary action or, in extreme cases, its abandonment.

- Policy viability. Any policy action should account for the societal, economic, institutional and normative contexts in which it has to be implemented. A policy viability analysis should evaluate the existence of institutional, legal and social acceptability barriers for the implementation of the measure. It should also evaluate the measure interactions with other pre-existing measures or policies that can strengthen or weaken its effectiveness or deployment. Finally, an important attribute of viability is "urgency". Urgent measures are those that address the impacts more dangerous and that thus should be addressed first and more incisively.

In order to achieve the most robust outcomes, the assessment of adaptation options should be developed combining different methods: modelling, the use of multi-criteria analysis[13], the literature and expert elicitation (EC, 2018b).[14]

The assessment of adaptation options enables "prioritization" that is key for the efficient and effective use of limited adaptation resources.

2.5 Implementing adaptation strategies

The phase that follows the prioritization of adaptation measures is their implementation. This requires an action plan which sets out the steps to convert adaptation options into action. It should specify: by whom, when and with what resources. These plans should be harmonized within the broader context of adaptation strategies at different levels (e.g. national or higher)[15] and „mainstreamed" into national, regional, local legal frameworks, like for instance urban, spatial and coastal planning (EC, 2018 a).

adaptation options: 'Assessing adaptation options' https://climate-adapt.eea.europa.eu/knowledge/tools/adaptation-support-tool/step-4, visited on 09/01/2020.

[13] MCA is an analytical approach that allows for quantitative and qualitative criteria to be analysed within the same single framework. It can be combined with weightings to produce rankings and/or scoring of the options being assessed to support decision making (EC, 2018 b).

[14] SWD/2018/461 (EC, 2018 b) presents some selected examples of such combined approaches adopted by Countries.

[15] Climate-ADAPT, 'Implementation' https://climate-adapt.eea.europa.eu/knowledge/tools/adaptation-support-tool/step-5, visited on 09/01/2020.

Adaptation analysis could thus support the implementation phase helping the identification of funding resources and suggesting how to mainstream adaptation measures into priority for national and sectoral policymaking (EC, 2018 b).

2.6 Monitoring and evaluation

As governments, regional and local administrations increasingly invest in adaptation it becomes essential to ensure the effectiveness, efficiency and equity of adaptation interventions. Monitoring is thus necessary to learn what works and not, in which circumstances and why. Indeed, the assessment of the progress in achieving the adaptation policy objectives and the periodic review of adaptation strategies should be integral parts of the adaptation cycle (EC, 2018b). Monitoring (M) is strictly linked to reporting (R) and retrospective evaluation (E) of adaptation performances. These phases are usually grouped together (MRE) and constitute the last step of adaptation analysis. An MRE system may have different aims and also different scopes, be it related to a continental strategy (like the EU Adaptation strategy), a national or regional adaptation strategy, or a national, regional, local adaptation plan. This has a direct impact on the methods used, the actors who should be involved in the process, and how the results are used in policies and practices. The Climate-ADAPT AST offers some guidance on this subject.[16]

MRE should identify specific indicators to measure the performance of the adaptation process. Indicators need to address all the main phases, thus not only of the evaluation, but also of the implementation steps.[17]

[16] Climate-ADAPT, 'Monitoring and evaluation' https://climate-adapt.eea.europa.eu/knowledge/tools/adaptation-support-tool/step-6 , visited on 09/01/2020.

[17] A 2020 forthcoming EEA report provides an overview of country developments in terms of climate change adaptation strategies and plans and their implementation, and analyses lessons learned, future directions and opportunities on MRE based on available national adaptation indicator sets. Actually, only a few European countries have in place an operational set of adaptation indicators, while several countries are working on them (EC, 2018 b).

3. Existing methodologies: gap analysis

This section is conceived as a "gap analysis" that will be conducted for the adaptation assessment methodologies (but not at the single model level) encompassed by the comprehensive desk review. Gaps are grouped into four main categories:

- gaps in data availability, accessibility, analysis and processing,
- gaps in addressing dynamics and feedbacks,
- gaps in model coupling,
- gaps in decision support.

3.1 Gaps in data availability, accessibility, analysis and processing

Resolution and completeness of data from climate models and scenarios: The spatial and temporal resolution of Global Climate Models (GCMs) has increased the confidence of climatic projections, providing greater accuracy in simulations of extreme events (Giorgi et al., 2014). Nevertheless, the resolution of GCMs and even Regional Climate Models (RCMs) (10-30 km) is generally too coarse to usefully support several adaptation assessments. An example is their inability to capture sub-daily extreme events that is needed for a large number of "local" adaptation assessments (Reder et al., 2020; Ban et al., 2015; Chan et al., 2014). This issue is addressed by applying downscaling techniques and bias corrections, but uncertainty remains large in these methods. In the specific field of the prediction of spatially and temporally localized (sub daily scale) intense precipitations, some advancements are expected from a new generation of Convection Permitting (CP) RCMs. These are being currently investigated by different projects such as the H2020 EUCP project[18] and initiatives including FPS CORDEX CP[19] (Coppola et al., 2018; Fita et al., 2018; Güttler and Srnec, 2018).

Usability of online services: Online services to analyse climate data have become increasingly popular in research over the last five years. A topical example is the Climate Explorer from the Royal Netherland Meteorological Institute (KNMI). It allows users to select a specific indicator such as 'monthly mean temperature' for a user-defined area, and then generates time series for that area. However, due to the significant volume of data that needs to be downloaded for the calculation of the indicators, these services are mostly addressed to scientists and of difficult usability for end-users in the policy domain. Other services, such as data from the Expert Team on Climate Change Detection and Indices (ETCCDI), lack some specific variables such

[18] European Climate Prediction System project: https://www.eucp-project.eu/

[19] https://cordex.org/experiment-guidelines/flagship-pilot-studies/endorsed-cordex-flagship-pilote-studies/

as wind, snow and humidity[20]. There are thus some actions to improve the accessibility and diffusion of these tools: (1) the current systems needs to be upgraded to enable the handling of large amounts of data, (2) the websites with the software need to be developed such that they become more attractive for policy makers and enable access to rapid assessment tools, (3) future applications of services should constantly expand the variables considered.

Resolution and completeness of data for hazard assessments: Despite the enormous growth in hazard data from, for example, remote sensing, data quality and time series lengths are not always sufficient. This, for instance, applies to hydrologic models that require a large enough dataset of observations for adequate calibration and validation. The same issue is reported in heatwave research, where it appears that the assessment of heatwave events and their trends lack long-term data records with, in particular, many European regions having no or sparse in-situ data.

A similar problem affects the spatial resolution and accuracy of input data, with most advanced and detailed modelling approaches requiring high resolution DEM and land cover in order to realistically simulate hazard features. Traditionally, two main streams for flood modelling exist, namely empirical methods and hydrodynamic models. Empirical methods consist in processes such as measurements, surveys, remote sensing and statistical models derived from data analysis (e.g. Schumann et al., 2009; Smith, 1997). Hydrodynamic models, instead, simulate water movement by solving fluid motion equations derived from physical laws with varying degrees of complexity, including one-dimensional (1D) (e.g. Brunner, 2010), two-dimensional (2D) (e.g. Roberts et al., 2015), and three-dimensional (3D) (e.g. Umgiesser, 2014) methodologies. Recently, due to the increasing accessibility to ever high quality and high-resolution remote sensing data such as LiDAR (Light Detection And Ranging) a new flood hazard modelling approach has emerged in the literature, known as digital elevation model (DEM)-based flood models (e.g. see Samela et al., 2016; and Persiano et al., 2020). In any case, event-based data characterising the magnitude of the hazard event is required to validate such models, but those are rarely available. Vegetation models need more empirical data on species and on the factors, which influence species niche requirements (Isaac et al., 2019), although one of the most limiting factor and challenge over the last years has been digitization and mobilization of existing data rather than acquisition of new data Meyer et al., 2015;). This not only pertains to climate, but also to non-climate factors such as pollution, land degradation and habitat fragmentation (Bellard et al., 2012; Williams et al., 2020), which risk turning into neglected environmental challenges (Scherer et al., 2020).

[20] In addition to those proposed by the ETCCDI, other indices are on line available, such as those calculated for the E-OBS daily maps https://surfobs.climate.copernicus.eu/maps/eobsdailymaps.php or https://eca.knmi.nl//indicesextremes/index.php

The problem is that managing the huge amount of data required can rapidly become unfeasible. A solution could be to develop the utilisation of flexible grids, in order to use high resolution data only in those areas where it is needed. In this way, computation time remains manageable. Further development of remote sensing can complement observational measurements when missing. This avenue is particularly promising for local hydrological models, which require local precipitation data, as demonstrated by the RADKLIM dataset provided by the German Weather Service.

Resolution and completeness of data for exposure assessments: The exposure analysis requires the availability of future social economic data and it is thus strictly linked to the development of social economic scenarios. The Shared Socio-economic Pathways (SSPs) relating to GDP and population growth, are among those most used in the study of climate change. They are, however, specified at the "country level", which makes them less applicable for impact and adaptation analyses at regional to local levels. An increasing number of initiatives provide "downscaled" or gridded specification of SSPs (for instance Murakami and Yamagata 2016) but these are not yet of widespread use. Similarly, high resolution exposure data, especially on assets, is required. Although some databases, like PAGER[21] developed by the USGS for rapid estimates of earthquake impacts, offer some information about building assets, these data are far from complete to enable local to regional assessments. New development such as OpenStreetMap (OSM) and Google Environmental Insights Explorer (GEIE) could offer new opportunities to map the built environment including critical infrastructure providing the advantage of active continuous updating of information (e.g. van Ginkel et al. 2020). OSM has been extensively used in the literature to support the identification of assets exposed to natural hazards (e.g. Eckle et al., 2016; Schelhorn et al., 2014), while GEIE is a new tool developed by Google that aims to bridge the gaps between data analysis and new technologies so to accelerate actions required to enable the transition to a low-carbon future, but that could potentially be used for mapping natural hazards in space and time.

Furthermore, the implementation and quantification of the role of climate change adaptation in different scenario-building exercises is still less developed and consolidated than that of climate change mitigation. These are all areas of research that deserve more effort and that can benefit the socio-economic modelling community.

Resolution and completeness of data for vulnerability assessments: Most socio-economic vulnerability data required for adaptation studies (i.e. related to sensitivity and adaptive capacity), including demographics, income and gender, are needed at the regional scales (regional, provincial or municipal administrative levels). A sample set of sensitivity/susceptibility and adaptive capacity indicators can be found in Table 2.

[21] USGS Earthquake Hazard Program: https://earthquake.usgs.gov/data/pager/

Table 2: sample set of sensitivity/susceptibility and adaptive capacity indicator can be used in socioeconomic vulnerability assessment

Sensitivity		Adaptive Capacity	
Dimension	Indicator	Dimension	Indicator
Manufactured Capital	Urban areas	Economic resources	Gross Domestic Product (GDP)
	Industrial areas		Distribution of the household income (GINI)
	Impervious surfaces		At-risk-of-poverty rate
Natural Capital	Forest areas	Infrastructures	Extension of the infrastructure (road and railways)
	Natural Protected Areas		Irrigated and Irrigable land
	Soil erodibility		Share of the protected lands
Social Capital	Population density	Knowledge and Technology	Total expenditure for R&D
	Structural dependency index		Patent applications to European patent office (EPO)
	Age dependency		Electricity consumption of agricultural enterprises
	Gender inequality		
Economic Capital	Gross added value - agriculture	Institutions	Institutional Quality Index
	Gross added value - industry		Corruption Perceptions Index
	Gross added value - services		Perceived independence of the justice system

Source: Authors' adaptation from: Heintze et al. (2018), Marzi, Mysiak and Santato (2018), and Mysiak et al.(2018).

Most of the social-economic indicators typically used to measure sensitivity and partly adaptive capacity in Europe are available either at NUTS2[22] or sometimes at NUTS3[23] administrative levels. This is already a great improvement compared to country aggregated data, however to perform analysis on finer resolutions, such as at municipal or local scales, developers have to either use the countries' census data, as demonstrated in Marzi et al., (2019), perform statistical downscaling based on proxies, as in Amadio et al. (2018), or peruse stakeholder-driven approaches (Linkov and Trump, 2019). More empirical data are needed to validate vulnerability models. As an example, Bakkensen *et al.* (2017) made an attempt to empirically validate five of

[22] For instance the EUROSTAT provides information on

[23] For instance the EUROSTAT provides information on population density ant NUTS3 (http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_r_d3dens&lang=en)

the top U.S. disaster indices, including three resilience indices and two vulnerability indices using independent proxy data, such as observed disaster losses, fatalities, and disaster declarations. To perform such analysis, disaggregated loss and damage data at finer scales shall be provided. In addition, as highlighted in Marzi, Mysiak and Santato (2018), multiple scale vulnerability assessments could be more informative and useful for policy makers than scale-specific ones. There are few studies investigating socioeconomic vulnerability at several collective and community levels paying attention to scale-dependency issues.

Resolution and completeness of data for adaptation assessments: More information is definitely needed on the cost and benefit/effectiveness of adaptation. One of the main criticalities in this area is represented by the local nature of adaptation. Accordingly, while information can be available and gathered for specific actions and contexts, the extension of adaptation analyses that require aggregation at the wider scale, such as the regional, national or larger, becomes challenging. There is a gap that still needs to be convincingly bridged between the huge aggregation in adaptation cost estimates, performed by Integrated Assessment Models or other macroeconomic models, and the more precise, but not generalizable, local analyses. Areas where knowledge gaps are particularly wide are: many insurance applications, which limits the study of insurance as an adaptation option. More specifically, there are limited data available for calibrating insurance pricing rules as well as for consumer decisions with regards to insurance purchases and whether to implement risk reduction measures. With a few exceptions (Hudson et al., 2019), models often only focus on the impacts of climate change on the insurance sector. Instead, there is a need for a comprehensive integrated modelling framework of risk, insurance supply and demand, and risk reduction behaviour. Assessment of the cost and effectiveness of ecosystem-based adaptation, and nature base solutions emerging field are also lacking and supported by scarce evidence (see also section 3.3). While adaptation effectiveness in agriculture is rather well understood, the cost of adaptation action, especially at the farm level is not. Only tentative estimates of the cost and effectiveness of private adaptation are available. Moreover, better understanding of the evolution in adaptive capacity and developing of “scenarios-with-adaptation” is needed for a more realistic representation of climate change risk.

3.2 Gaps in addressing dynamics and feedbacks

Impact interaction, extremes and temporal dynamics in hazard assessment: Hazard and adaptation assessments should consider the effect of multiple hazards. Just as examples: landslides are more easily triggered after a forest fire and during a flash flood event. However, the current hazard-impact models do not account for compound or consecutive multi-hazards (De Ruiter et al., 2020). This is an issue, for instance, for desertification models, where the effect of different vegetation structures and species composition should be better integrated with models for erosion processes and land degradation/conservation. Another knowledge gap, quite generalised across many different impact areas, is the modelling and quantification of impacts from extreme events. This is the case, for example, of crop-modelling that still feature a limited understanding of the interactions among climate extremes, such as frost and heat, with changes in quality of crop production. Similarly, pests and diseases, phosphorus, nutrition, and ozone effects, need to be further explored and implemented in such models (Antle et al., 2017). Another example is provided by the assessment of extreme events impacts on forest productivity. This is particularly challenging due to the difficulty to identify the threshold effects on forest ecosystem resilience. Furthermore, hazard processes and their driving factors change over time. The current simulation approaches account for an increasing degree of complexity, but, in general, they oversimplify reality especially when the analysis develops in the longer term. This is, for instance, an issue in forestry models where more research is needed to investigate how certain forest dynamics may change in response to long term changes in CO_2 fertilization. Similarly, the interaction of wildland fire with climate and vegetation has major effects on vegetation dynamics, ecosystem carbon budgets and patterns of biodiversity over longer timespans. The same applies to coupled hazard and adaptation models, which mostly lack the functionality to simulate changes over longer time periods, both historically and in future scenarios. The latter aspect is particularly important for addressing the effects from climate change in decision-making and adaptation.

Human-physical interactions in hazard assessment: Research shows that human and physical systems are largely connected. Human activities influence physical processes. In the short term, human impacts on the terrestrial hydrological cycle or on the availability of important natural resources (for instance fisheries) can be larger than those of climate change. Conversely, physical factors can influence human adaptive behaviour. For instance, after an extreme flood, risk perception is higher and can result in a higher uptake of adaptation measures. These interactions are largely missing in current hazard, vulnerability and adaptation models. The usual approach is to conduct a scenario-based analysis where hazard and vulnerability are calculated separately and adaptation measures are assumed for a discrete point in time. Some advances in this direction can be observed, for instance, in the development of "socio-hydrology" and in the use of agent-based models (ABMs) which put the decision makers at the core of the adaptation analysis. Nonetheless these coupled models, especially involving ABMs, require a huge amount of data that are often not available.

Macro-economics of impacts and adaptation assessment: Much work is still required regarding the development of models that assess the wider indirect economic impacts of climate change and adaptation. This includes, for instance, cascading network effects using empirical data instead of stylized or reduced-form approaches in damage and adaptation modelling like in Integrated Assessment Models. Although useful to provide qualitative insights, the quantitative support, especially for adaptation analysis is weak. Computable General Equilibrium models (CGEs) that are used as an alternative methodology to partly address the criticism against reduced form climate change damage and adaptation functions, lack anyway the ability to capture discontinuity, irreversibility and non-market consequences typical of climate change impacts. Both typologies of model are then applied mostly to the study of mitigation and much less of adaptation. These considerations apply also to econometric approaches. A recently emerging literature is addressing the relation between climate change and economic performance, but a debate is still ongoing on the extent these methods are able to account for adaptation processes (Aufhammer, 2018). One of the main barrier is that macroeconomic assessments are developed at a level of aggregation which is larger than that of the majority of adaptation measures. This, coupled with the lack of reliable information on adaptation costs and effectiveness (see section 3.1 above) prevents a wider application of these approaches.

3.3 Gaps in model coupling

As a direct consequence of gaps highlighted in section 3.2, there is also a difficulty in developing the full model coupling requested by climate change impact and policy assessment. Ideally, model-based analysis of adaptation should be conducted integrating the whole causal chain from climate stressors to adaptive responses into one unifying modelling framework. This is indeed the final aspirational goal of integrated assessment models. However, hard link integrated assessment models proposing this integration developing a unifying mathematical system are too coarse to support the implementation of adaptation measures. They can, at best, provide broad indications on trends and dynamics triggered by the implementation of adaptation strategies on other macroeconomic variables or policies. The alternative is to couple different models dealing each with a specific dimension of the chain with the desired level of detail. This "soft link" procedure is, however, burdensome under the computational point of view and requires a high level of multidisciplinarity. As a consequence, it is not pursued to the extent needed. Examples where coupled models are required is in the energy sector, particularly for niche technologies such as wave and tidal power, but also on emerging ones such as solar power. The climate-water-energy-food nexus is another field of investigation where integrated assessment should be explored further. Studies coupling energy water impacts at the basin level should be replicated and enriched systematically as few studies review the whole of the EU. Furthermore, coupled impact modelling is also required for the tourism sector to assess issues such as snow reliability for skiing, and the climate change impacts on biodiversity losses and forest fires on tourism. Many hazard models are still stand-alone models without having an impact module. There is also the need to foster a better coordination of adaptation and disaster risk reduction for a coherent response to climate and disaster risk (EC, 2018 b). Opportunities for that are described in EEA (2017). Additionally, links, synergies, combination and coherence of climate change adaptation and mitigation solutions at all levels and sectors should be further pursued, prioritizing efforts in the sectors that are key for greenhouse gas emission reduction, e.g. land use, agriculture, energy or transport (EC, 2018a). Finally, more consideration should be given to the advantages provided by ecosystem-based adaptation, nature-based solutions and green infrastructures, whose multi-functional feature brings various environmental and social benefits (EC, 2018a).

3.4 Gaps in decision support

Chapter 5 of the comprehensive desk review, reports the main tools and techniques supporting the evaluation and prioritization of adaptation options. This phase of the adaptation analysis, taking place "end of pipe", suffers from the shortcomings affecting the steps that precede in the adaptation investigation cycle. Eventually, no cost effectiveness, cost benefit, multi-criteria analysis, can be better than the input information processed. In this respect, more information is definitely needed on the cost and effectiveness of adaptation especially in the long term (section 3.1).

A particularly thorny issue is then the handling of uncertainty. Policy action on adaptation is not yet supported by fully transparent information on different uncertainty sources. This can prove to be particularly difficult though. Indeed, in addition to the uncertainty related to CCIV assessment (see section 2.2) also that related to the effectiveness of adaptation options operates. Under situations of deep uncertainty or ambiguity that typically arise, choices based upon optimization criteria like Cost Benefit Analysis (CBA) and Cost Effectiveness Analysis (CEA) may not correctly reflect risks and tend to underestimate damages. Decision support should then propose, in addition to these criteria, techniques applying robust decision making under uncertainty, such as Real Option Analysis, or dynamic adaptive policy pathways that can support a more precautionary perspective in the presence of potential irreversibility.

Another issue pertains to timing. CCIV and adaptation assessment are complex and require time and resources that may conflict with the needs and availability of decision making, especially at the more local level.

In principle, Decision Support Systems (DSS) should help in that. They are conceived as user friendly, user orientated guides to adaptation analyses to non-experts. In practice, the majority of DSS does not evolve beyond the pilot, demonstration phase and is hardly replicable outside its original context; it often offers a sectoral perspective on physical or environmental issues and does not examine the overall picture of multi-hazard risk. Most importantly, although developed for decision makers, it remains mostly confined to the research environment and is not perceived as user friendly for the broader public. The lack of diffusion and uptake surely depends on the complexity of adaptation decision. The more a DSS aspires to capture "real world" dynamics, the more it requires training and learning to be used. A common misunderstanding on DSS is that they are "simple" either in terms of data or learning effort requirements. In fact, they can facilitate the application of complex analyses and increase transparency, but they cannot eliminate complexities. At the same time, best practices in co-designing with the final users are not always followed, because they are costly in terms of time and resources. As a consequence, often potential final users are not engaged frequently enough during the development of the DSS, they are not involved as co-developers of the DSS, and they are not assisted after the release of the DSS. This customization and post-delivery support is indeed more typical of a commercial product than of a research output. Some of these problems are also common to climate services and have been extensively addressed by the H2020 projects EUMACS[24], CLARA[25], MARCO[26].

3.5 Gaps in Policy Support

The gap categories 3.1 to 3.4 highlight the research gaps from the literature reviewed in this comprehensive desk review, and predominately focus on informing decision and policy making. Yet, it is also noted that there is a distinct gap within the academic literature pertaining to the implementation of adaptation measures. Therefore, greater emphasis is also required to follow through research to include the final stages of climate adaptation strategies: in addition to conducting risk and impact assessments and decision support tools, research and guidance should also be developed to support decision makers with implementation and monitoring and evaluation stages of the policy cycle.

[24] EU-MACS project: http://eu-macs.eu/
[25] CLARA project: http://clara-project.eu/
[26] MARCO project: http://marco-h2020.eu/

4. Recommendations to bridging the gaps

In the light of previous findings, this section identifies next-term (for the next five years) actions that can further facilitate the application of climate–impact-economic modelling for practical-usable adaptation analyses.

Actions suggested will be either (a) additional lines of research and innovation; or (b) cross fertilization opportunities across sectors, levels of governances, or innovation platforms.

Improving climate information for adaptation

To improve the support to local adaptation planning it is essential to increase the availability, reliability and accessibility of climate information with the "right" spatial resolution.

In the case of long-term projections, this directly relates to improving the downscaling processes applied to climate data, which is particularly relevant for the investigation of extreme events and necessary to address adaptation at the urban level.

Two downscaling methodologies are usually applied: dynamic downscaling, with a huge computational cost, and the much cheaper statistical downscaling, used to improve spatial and/or temporal distributions from climate models (Gutmann et al. 2019, Salehnia et al. 2019). The two approaches are not equivalent though. Dynamical downscaling refers to the use of an RCM driven by a GCM to simulate regional climate. Its computational complexity that may require further downscaling and bias correction for specific impact applications is compensated by the representation of the different atmospheric parameters, consistent with physical mechanism and thanks to the program, such CORDEX, by the possibility to perform a detailed analysis of the uncertainty in the different geographical areas. Statistical downscaling is simpler, but requires the establishment of empirical relationships between historical large-scale atmospheric and local climate characteristics which are not always available. Accordingly, statistical downscaling seems not superior to dynamic downscaling to describe many meteorological parameters, and sometimes it is not applicable. Therefore, depending on the specific context of application and on the data availability, each of them has its merits and limits.

Against this background, useful and "urgent" research initiatives should aim to systematically test the performances of statistical versus dynamic downscaling techniques over the whole EU domain to understand when/where the former can be a good substitute for the latter. Investigation should prioritize that parameters already identified as major triggers for climate risk and of particular relevance to local adaptation planning in the coming three decades. Among these, heat waves which are projected to be nearly twice as frequent in comparison to the modelled historical period, and severe heath waves for which the expected increase is even larger (Lhotka et al. 2018). A significant increase in single extreme hot perceived temperature is also expected, with a more than doubled extension of the huge discomfort domain over Europe under extreme conditions (Scoccimarro et al. 2017) on the same time horizon. Another well-established fact is that the intensity of extreme precipitation increases more strongly with global mean surface temperature than mean precipitation (Berg et al. 2013). Since the most intense precipitation events observed today are likely to almost double in occurrence for each degree of further global warming, this will also interest the short time horizon to the middle of the current century (Myhre et al 2019).

Operational steps to reach this objective are suggested below:

- Systematic evaluation of the domain of applicability (strongly dependent on the resolution of observational datasets) of statistical downscaling for the different parameters (temperature, precipitation, wind) over the historical period. The goal is the definition of the maximum horizontal resolution achievable, through statistical downscaling, for each parameter over EU subdomains: it is not obvious that the subdomain decomposition corresponds to the different EU States borders.
- Systematic comparison of dynamical and statistical downscaling performance in representing the statistics of all the aforementioned parameters, with special focus on tendencies of extreme events, over the whole EU domain during the historical period. The goal is to identify systematically regions and parameters for which statistical downscaling can be used instead of dynamical downscaling.

Turning to seasonal and decadal forecasts, the performance of dynamical and statistical downscaling over Europe has been evaluated by the projects SPECS,[27] EUPORIAS[28] MEDSCOPE[29]. Results suggest that both methods lead to similar predictive capacity with about the same overall performance as the global model used to force them without added value in model skill improvement (Manzana et al. 2018). Against this background, to improve the forecast ability, rather than focusing on downscaling techniques, it would be more productive to improve the current numerical prediction systems based on General Circulation Models such as the ones taking part to the Copernicus Climate Change Service (C3S), implemented by the European Centre for Medium-Range Weather Forecasts (ECMWF) on behalf of the European Union.

Operational steps to reach this objective are suggested below:

- Support the development of higher horizontal resolution version of the current models taking part to the current C3S for next generation systems: research centres involved in C3S activities must be supported in the development of

[27] SPECS project: http://www.specs-fp7.eu
[28] EUPORIAS project http://www.euporias.eu
[29] MEDSCOPE project http://www.euporias.eu

their future higher resolution models in parallel with the provision of the ongoing services based on the current version of their model.

- Support the inclusion of new members in the current C3S. This is important because each model simulates the Earth system processes that influence weather patterns in different ways, leading to different kinds of model error. Some errors are shared by the different models but others are not, thus combining the output from an increasing number of models enables a more realistic representation of the uncertainties due to model errors. Multi-model ensembles emphasize the uncertainty in climate predictions resulting from structural differences in the global climate models as well as uncertainty due to variations in initial conditions or model parameterisations, in fact, when compared against gridded data, ensemble results have come closest to replicating historical climate projections (Semenov et al. 2010).

Improving information on adaptation costs and effectiveness

As highlighted by several sources (see recently UNEP 2018), there is still patchy and non-systematic knowledge on adaptation costs and effectiveness. Areas where research is particularly lacking are: cost and effectiveness of private adaptation in different domains, but in particular health care; cost of farm-level adaptation, cost of adaptation in energy supply, adaptation cost and effectiveness estimates for biodiversity and ecosystem services, estimation of determinants of adaptive capacity and its effectiveness. Also when research on adaptation cost is more developed, as for instance in the case of adaptation to sea-level rise or to flood risk, a systematic comparison of results across countries, regions and studies is still missing. Moreover, existing aggregate estimates of adaptation costs are not well connected to local level data. Nonetheless, there is also an increasing production of information in this direction supported by many recent and ongoing research projects and data collection initiatives, one above all the EEA adaptation portal Climate-ADAPT.

In the light of this it seems particularly useful either for researchers or policy makers at the EU and national level to promote a systematic survey of existing quantitative evidence on adaptation costs.

The survey should aim to:

- highlight ranges for adaptation costs at different scales: across countries and, when possible, regions within countries, sectors and “families” of measures within sectors;
- understand and motivate differences across studies and ranges of estimates
- project adaptation cost trends under different climate change scenarios to highlight (a) “hot spots” of adaptation costs and (b) potential insurgence of

limits to adaptation or adaptation thresholds in different sectors, geographical areas.

It should be clear that this exercise is not meant to provide a direct support to adaptation plans at the local level, but aims to identify order of magnitudes for adaptation costs and investments, ranges for adaptation cost/effectiveness ratios at a more aggregated level that can guide strategic considerations and suggest where additional research is needed. Albeit remaining "not measure specific" it will also provide richer and more consolidated data to improve the parameterization of adaptation functions in integrated assessment models.

Albeit being based on existing knowledge, this action should go beyond a simple survey of the literature. It should pro-actively involve the research networks of relevant projects and scholars working in the field, to support the sharing of information and possibly revisit original studies, re-run models and assessment in order to build a usable, comparable and tested adaptation database reporting on sources and ranges of uncertainty. This initiative could take the form of an "Adaptation Modelling/Method Inter-comparison Project" AD M^2IP.

More sector-specific research initiatives are suggested below:

Tourism: The priority in terms of impact modelling and adaptation for tourism is the inclusion into IAMs/economic models of more accurate and up-to-date metrics. Projected tourist flows and expenditures, possibly at a high geographical resolution and distinguishing domestic and international flows and expenditures, would be ideal in order to capture international dynamics. When the differences across the typical activities of tourist areas matter (e.g. mountain vs. beach tourism), a more accurate and consistent characterization of future suitability for such activities through specific comfort indexes would be needed, although populating a comprehensive global database underpinned by empirically grounded weighting may be a daunting task.

A concrete action to respond to this priority would be promoting a research to refine and update statistic-based models of tourism flows and climate change (an example is provided by the HTM approach (Bigano et al. 2008)) and their inclusion into CGE models (see the report of the comprehensive desk review). This would include a) collecting and harmonizing tourist flows and expenditure data for national and domestic tourists, at the subnational (NUTS3) level b) include a richer representation of climate at origin and destination, using tourist comfort indexes projections based on the most up-to-date climate scenarios and c) update macroeconomic models in order to include these new tourist flows and expenditure projections.

Energy To correctly address adaptation needs in the energy sector, it is particularly important to map systematically across the EU, the present and future cooling needs of thermal electricity plants and the impact of hydropower production on water availability in European river basins. This research should be developed in a water-energy-food-climate nexus perspective, under present and future climate and social economic development scenarios. This is essential to identify limits or bottlenecks to energy supply posed by cross-sectoral and competing uses of the water scarce resource, devise integrated adaptation actions and reduce the risk of maladaptation.

Ecosystem based adaptation. Within the broader context of "soft" or "green" adaptation measures, generally considered more flexible, more environmentally sustainable, more community centred than "grey" or "hard" adaptation measures, ecosystem-based adaptation is an emerging area. More scientific data and evidence from the field are however needed to validate its cost and effectiveness and to improve/standardize methodologies to understand about whether, when and how it is effective. Evidence is still lacking on ecological, social and economic effectiveness of ecosystem-based adaptation which, among other, prevent comparison with alternative adaptation actions. What is particularly challenging is to determine the temporal scale according to which the natural environment buffers human communities against the effects of climate change, and the limits of, interaction, potential trade off across adaptation and other services from ecosystems.

Uncertainty

It would be particularly important to establish a "protocol", or best practices, for the definition, treatment and communication of uncertainty. Some suggestions are the following:

- Climate-change hazards should be defined according to different climate change scenarios and using ensembles of climate models. Past research highlighted that model uncertainty is more relevant in the medium term, while scenario uncertainty in the long term. Accordingly, to help a better use of limited investigation resources , if adaptation action has to be defined before mid-century, multi model use should be prioritized respect to multi scenario use. There could be then different approaches to span the uncertainty range. Central estimates can be offered by the multi-model mean. Upward and lower bound for estimates can be determined either by the maximum and minimum of the observations across the model ensemble, or by choosing in advance the models with the highest and lowest temperature signal. Model agreement can be also sought in order to discard those observations that are at odd with the majority of the ensemble.
- Ample variability of results is also originated by the use of different impact models. For instance, different crop models, perturbed with the same climate forcing factors, can give rather different yield results. Although in principle, the use of different impact models and their comparison can be useful, we recognize that the procedure could be out of scope and of the feasibility of adaptation assessment. Nonetheless, also when results can rely just on one modelling tool, sensitivity tests on major model behavioural parameters should be performed and reported.

- This reasoning applies also to the quantification of cost and effectiveness of adaptation. Sometimes impact models incorporate this information (an example is the DIVA sea-level rise model that can represent cost and effectiveness of coastal protection). Sometimes models provide the starting point for adaptation assessment that has to be performed with different methodologies or tools. Anyway, ranges for the effectiveness and costs of adaptation have to be considered.
- Exposure and sensitivity are relevant determinants of climate change impact and therefore of adaptation needs. At the same time, their evolution, especially in the long term, is highly uncertain. Therefore, while suggesting to include different exposure and sensitivity scenarios in the analysis to span the uncertainty range, we also recommend to consider, as a benchmark "current conditions".
- Adaptive capacity is perhaps the most uncertain component of climate change risk, and, accordingly, of the cost effectiveness assessment of adaptation. As such, including adaptive capacity in adaptation assessment should be regarded more as an "explorative" exercise. With scarce financial and time resources, priority should be given to exposure and sensitivity assessment. Improving the assessment of adaptive capacity is anyway an action that can be pursued in the longer term even though it seems more relevant academically than operationally.
- Finally, if correctly conducted, the analysis should enable to report and highlight which among the abovementioned uncertainty sources is the most relevant in determining the final outcomes of the assessment.

5. Recommendations from/for use cases examination

This section will use the selected use cases presented in Task 4 as operational examples on how the indications from sections 2 to 4 can/should be put in practice.

5.1. Rapid analysis for CLIMA to support rapid policy response (Use Case A1) and policy development support for the EC (Use Case A2)

Use Cases A1 and A2 are treated jointly here because they tackle the same issue from different yet related angles: they both respond to the need of supporting policy response by DG CLIMA in adaptation-related matters. A1 deals with rapid analysis for policy response while A2 deals with the support to policy development based on extensive studies. Thus they mostly differ in terms of the timing and depth of the analysis, but not in terms of the field of investigation, and both consist in providing relevant information to help DG CLIMA in dealing with the mitigation-adaptation nexus, the streamlining of adaptation into EU policy, liaising with DG ECHO in disaster risk reduction matters, and in adaptation-related climate diplomacy (e.g. UNFCCC COP negotiations). These use cases are naturally linked to the need of closing the gaps related to decision support, discussed in section 3.4 above.

Recommended approach (practical suggestions)

For Use Case A1, rapid analysis, it is firstly important to stress when it is appropriate and what can be extracted from it. These analyses can be realistically done only with the purpose to get preliminary/generic order of magnitudes for climate risk and the cost and effectiveness of "broad" adaptation types (for instance "coastal protection") on rather extended geographical/spatial scales. On the contrary, the possibility to identify and rank adaptation actions in regional or local specific contexts is neither feasible nor credible. Furthermore, they are more suitable to identify hazards, exposures, and vulnerability, which affect the preparatory phases of adaptation action, than adaptation identification and assessment. In other words, these assessments can be useful to indicate where (adaptation) policy may be needed, but not which kind of policy or measure to implement.

This said, there are two main, rapidly implementable, recommended approaches to enable a preliminary screening of climate change risks and adaptation to then support policy action: develop semi-quantitative indicator-based assessment using existing databases or, alternatively, rely on tools designed for non-expert users in order to access and understand the results of fully integrated quantitative climate change assessments. In both cases, user-friendly interfaces if not provided, need to, could be developed, also in the form of simple scripts (using programming languages such as R or Python) to harvest and organize the required quantitative information. Note that relying on full assessment exercises through these interpretative tools is regarded as ideally preferable to the use of indicators. This however implies a direct interaction with model developers. The development of an indicator based assessment involves a relatively quick process implementable "in house" that, however, entails a number of steps such as: defining the sub-indicators capturing physical hazard, exposure, sensitivity and adaptive capacity indicators; choosing the approach to normalize, weight and aggregate sub-indicators; collect the data needed to compute the indicators; and finally compute the indicators and provide them in an user-friendly format (e.g. maps) (see for further detail the separate report on rapid assessment): the translation of the raw data at the local scale and in an easily interpretable format could favour the process of making global warming and its impact a more "concrete" and therefore raising the awareness of citizens and non-scientific societal groups.

Specific actions to put in place in the next 5 years

In order to develop an increasingly informative, rapid and extensive analysis of adaptation it is essential to grant quick and operational access to full quantitative assessment results. The following indicative actions are proposed (See Task 4 for more detail):

- Promote a systematic survey of existing quantitative evidence on adaptation costs, engaging the relevant research networks in order to build a usable, comparable and tested adaptation database. The survey should highlight ranges for adaptation costs at different scales; explain differences across studies and ranges of estimates; and project adaptation cost trends under a range of climate change scenarios.
- Develop a "front office" activity for producers of climate change data, primarily within the Copernicus Climate Change Service, to increase availability, reliability and smooth accessibility (beyond what is already feasible) of climate information (especially on climate extremes and composite indicators) at different spatial resolution and with a focus on enhancing more direct interlinkage of climate with socio economic data.
- In the longer term: Building upon the aforementioned survey, develop an "Adaptation Modelling/Method Intercomparison Project" to set up and maintain public databases on adaptation costs and effectiveness. Note that this course of action is envisaged for use case A2: given its more extensive and thorough analysis it requires, it naturally calls for a longer time horizon and quick-and-dirty solutions simply cannot be put forward for immediate action in such case. As

explained in detail in Task 4, The AGMIP or ISIMIP initiative can provide an example of the main project vision, and one can draw on the FP7 ECONADAPT structure and on its web tool (https://econadapt-toolbox.eu/) for practical implementation. Full integration with the Climate-ADAPT portal is also advisable.

- Again for Use Case 2, beside costs, easily accessible databases should be built and maintained on attribution of impacts next to hazards, and on context based preferred adaptation options and on good practice case studies.
- Improved support to both rapid and extensive analysis could benefit from (partially) steering the follow-up to the PESETA JRC stream of research towards adaptation assessment, integrating DG CLIMA's views and needs within a systematic co-design approach. This interaction with JRC could eventually allow building technical capacity within DG CLIMA (possibly supported by EEA, besides JRC).

5.2 Climate change risk and adaptation assessment for EU investments (Use Cases B4 and B5)

The relevance for climate proofing of EU investments and of EU adaptation investments stems from the long lifetime of infrastructural investments, that exposes them to potentially major impacts from climate change; from the risk of locking-in of inadequate technologies or land use patterns; and from the recognition of physical climate risk as a financial risk in its own right by the Task Force on Climate-related Financial Disclosure (TCFD, 2017), and the Network for Greening the Financial System (NGFS, 2019).

Use Cases B4 and B5 focus in particular on the assessment of the climate resilience (climate proofing) for investment projects. Use Case B4 deals with the extensive analysis, while Use Case B5 deals with rapid analysis. Both are linked to the need of closing the knowledge gaps related to understanding macro-economics of impacts and adaptation assessment, discussed in Section 3.2, and to the need to improve information on adaptation costs and effectiveness, discussed in Section 4.

Extensive analysis (use case B4) originates from the need by organisations – that fund, appraise, or are the recipients of European investments – of thorough knowledge of climate-related risks and adaptation options, and of the degree of uncertainty implied, for major infrastructural investments mobilizing substantial financial resources.

The scope for rapid analysis (use case B5) is originated by the interest of e.g. international institutions to simplifying the screening process and reduce the use of resources and time with preliminary identification and prioritization of adaptation options. Rapid analysis can also be applied to small-scale, simple projects for which the climate risk situation is not complex, the financial exposure of said institutions is kept within reasonable limits and thus a major assessment effort cannot be justified.

Recommended approach (practical suggestions)

Each assessment must be fine-tuned to the characteristics and requirements of the funding institutions, and of the projects to be financed. However, a general ideal approach can be the following:

- At the beginning of the concept development for an investment project, projects that necessitate an in-depth analysis and those suitable to rapid analysis have to be identified. Therefore, guidance, tools or checklists that can help this screening should be developed and available. Useful and operational examples are provided by institutional approaches followed for instance by the Asian Development Bank or the World Bank (see the separate report on rapid assessment for more detail). These methodologies can be improved/enriched building around open source and freely available information.
- When rapid analysis is appropriate, during the project preparation phase, lighter-touch approach for climate risk assessment could be used. These focus on the major risks, and undertake rapid assessment using simple tools, or existing information, such as: the use of climate change factors for sensitivity testing in the main project models; the use of simple rules-of-thumb (also known as ready reckoners) that can provide a sense of the scale of the risk involved, the transfer of risk information from previous studies.
- The idealized rapid analysis would then develop simple way to identify potential adaptation options. This could be tables and suggestions of adaptation by sector/investment project type. There could also be decision trees to help support the identification of good projects and case study examples and "how to" guides.
- Rapid adaptation assessment should be finally undertaken following rapid assessment tools and guidance. These are, however, far from being consolidated. These could include cost look-up tables of options including costs (and relative benchmarking), simplified tools for addressing benefits, inventories of benefit to cost ratios for options, good practice case studies, etc. This would be most useful if this was available at the sector or project level (i.e. rapid assessment for road investment projects, etc.). Training courses and a network of practice can also be useful. Important aspect is the development of rapid tools for applying decision making under uncertainty. These should use simplified concepts while capturing principal conceptual aspects and maintaining a degree of rigour. This would allow a wider application in qualitative or semi-quantitative analysis.

For an in depth description of the development of extensive analysis we refer to the separate report on rapid assessment. Here we just stress that a major climate risk screening and adaptation assessment, especially one that considers uncertainty, can easily take 6 months to 1 year, and has high resources costs (>100kEuro). This may be justified where the size and the climate sensitivity of the investment are "high" and there are "high" adaptation costs.

Specific actions to put in place in the next 5 years

In order to maximize the implementation of the idealized framework for the assessment sketched above, a number of indicative actions can be identified. Some of them are readily implementable, whereas other can start immediately but will require a few years to yield results; others yet, are ongoing processes which may start immediately but need to be continued consistently in order to deliver their expected outcomes.

Actions readily implementable are the following:

- Consulting and engaging with the relevant EU institutions for the development of rapid assessment tools and information (Horizon, Copernicus, JRC, RTD, EEA and the Climate-ADAPT initiative).
- Conducting workshops and training.

Actions in the next 5 years (that should be fine-tuned at the sector level or, if possible, at the project level) are the following:

- Developing open source climate risk screening tools and information.
- Developing guidance tools and case studies for rapid climate change risk assessment for investment projects (including sector specific for common projects, and for small projects) and identification of adaptation options.
- Developing guidance, tools and case studies for rapid adaptation assessment for investment projects (including sector specific for common projects, and for small projects).
- Developing guidance, tools and case studies for rapid economic analysis of adaptation in investment projects (costs and benefits).
- Developing guidance, tools and case studies for rapid decision making under uncertainty.
- Developing tools to better integrate environmental-societal impact indicators (e.g. linked to Sustainable Development Goals) next to Indicators of Risk Reduction (IRR).
- Consulting with relevant stakeholders. This is a recurring action and its reiteration here signifies the need to keep stakeholders up to date on the developments in this field and at the same time, update the providers of these

information services, on the relevant developments in the policy and financial communities.

- Conducting workshops and training. This is a recurring action and its reiteration here signifies the need to keep users up to date on the developments in this field.

5.3 Development of City Adaptation Plans: tools supporting adaptation planning (Use Case C8) and Climate resilient regional planning and management (Use Case C10)

The Use Case C8 focusing on tools supporting city adaptation planning and the Use Case C10 concerning climate resilient regional planning and management (in three areas: river basin, agriculture and coastal zone) pertain to how adaptation modelling can and should support climate resilient planning and decision-making and guide public investment at local to regional level.

These Use Cases are linked to the need of closing the gaps in decision support, discussed in Section 3.4, and to the need of improving climate information for adaptation and of improving information on adaptation costs and effectiveness, discussed in Section 4. Both of them point to the need for adaptation modelling to resolve climate hazards, impacts and vulnerability on a detailed scale and to foster stakeholder engagement in the planning and decision making processes.

Regional, and especially urban adaptation plans, interact with many other societal, institutional, governance and natural aspects. Even though with different extent, both have to take into account how climate change affects the availability of natural assets, such as water, soil, ecosystems services, physical assets, human activities and the landscape where these take place.

In both cases governments have to set up processes to engage, collaborate with and coordinate many stakeholders. This is essential to ensure that all the relevant knowledge, needs and interests are taken into account avoiding negative side effects and maladaptation, exploiting synergies, building ownership and increasing uptake of the adaptation plan, and granting continuous support during the implementation phase.

Available climate, hazard and integrated assessment models however, do not provide the level of detail required for local decisions. Nonetheless, some rapid analyses at coarser resolution are possible. They cannot substitute a detailed analysis of climate risks and adaptation options, but they can support an initial scan of likely risks and impacts to be considered (flooding, water quality and drought) as well as of suitable adaptation options, providing a first overview and rough guidance where to invest in more detailed assessment. Rapid analysis can also support stakeholder engagement enabling the development of storylines and/or serious gaming to let stakeholders act out their response within such scenarios.

Recommended approach (practical suggestions)

Hazard and impact models are quite specialized in nature, while an adaptation plan is very integrative. This thus implies that models should provide just one piece of information. Furthermore, given also the importance of stakeholders engagement, models that are more suitable for, or appropriately tailored to use in participatory environments should be favoured. This may entail to enabling quick scans of potential impacts to raise awareness and/or developing decision support tools acting as interfaces with fully fledged hazard or adaptation models. Both methods should aim to bringing together stakeholders to develop and agree upon a shared adaptation plan. Rapid response analyses facilitating smart aggregation of specialized results into digestible and useful blocks of information can be extremely useful. As illustrated in the Use Case C8, this could be implemented ideally with a tool/interface allowing the users (in a workshop setting aimed at developing an adaptation plan) input their choices and subsequently see the impact of those choices on various indicators related to the hazards and well-being of their city and citizens. This approach has the ancillary benefit of enriching the actors' (mutual) understanding and mind-set.

The starting point should anyway be solid quantitative evidence based on highest-resolution available data and locally validated models. Existing modelling systems for real-time early warning could be also used and modified to assist in scenario analysis. More specific actions are recommended below:

1. Preparatory phase

    1.1. Identify system boundaries - Identify the relevant geographical system boundaries at the start of the assessment (e.g. water sheds for river-basin management and agricultural plans and coastal segments for coastal zone management).

    1.2. Define hazards - Define the physical hazards that are relevant in the ecosystem (such as drought, flood and erosion).

    1.3. Define thresholds and return periods - Define for the defined hazards thresholds and acceptable return periods.

    1.4. Choose tools/methods - Review and select the appropriate tools/methods to quantify hazards and translate them to impacts.

    1.5. Collect data - Collect necessary data, that is ideally open, quality assured and available from climate change databases (such as Copernicus and similar).

2. Assessing risks and vulnerabilities

   2.1. Calculate the risk - Use the tools to calculate the hazard with associated return periods.

   2.2. Map vulnerability - Based on locally available data, map vulnerability using index-based vulnerability assessment methods

3. Identification of adaptation options - Use existing libraries to identify adaptation options that can reduce the risk below the defined thresholds and return periods. The adaptation options should suit the local bio-physical and socio-economic context and fulfil the desired lifetime of the measure.

Specific actions to put in place in the next 5 years

- Local assessments of hazard, exposure vulnerability and adaptation options have to be improved. It is thus recommended to spur research and innovation on downscaling tools and methods in all these dimensions.
- Setting common standards for local data collection and archiving as well on costing adaptation options is particularly useful. These actions could be included in the new EU Adaptation Strategy, research and innovation questions could be addressed in the framework of Horizon Europe, with the support of the EEA and JRC, and with a possible role of sectors and national governments.

5.4 Analysis of climate risks for business and finance (Use Case D12)

There is an increasing recognition that failure to account for climate risks in investment decisions could lead to large economic and financial impacts.

Climate change can bring about physical risks, resulting from climate change induced (acute) events or longer-term (chronic) shifts in climate patterns, leading to direct damage to assets and indirect impacts from supply chain disruption, transition risks, i.e. those originated by the policy, legal, technology, and market transition to a lower-carbon economy and reputational risk.

These risks are relevant either for financial or non-financial sectors.

Initiatives like the G20 Task Force on Climate-related Financial Disclosure, the Network for Greening the Financial System, the development of the work of the Technical Expert Group (TEG) on sustainable finance, are promoting actions toward a transparent climate risk disclosure and risk mitigating measures for companies.

While some companies may have already incorporated climate change considerations into their own risk analysis, many companies may not necessarily have the needed expertise. This can apply also to consultancies that need to develop these new skills and to regulators/ auditors that may want to undertake audits of company risk assessments.

Against this background, support to adaptation assessment appears to be needed in all the phases of the adaptation cycle and especially: to understand and report the climate physical risks; provide insight on the actual and future climate induced financial risks and opportunities for the company's assets, activities and supply chains; to identify potential adaptation options

Recommended approach (practical suggestions)

Climate change risks and adaptation assessment for climate related financial disclosure and risk management, and especially for risk and adaptation assessment at the physical asset level, requires detailed analysis. However, a light touch analysis could be useful to an early scoping, to allow a subsequent more focused inspection. It can also support those companies with potential low risks and/or time or resource constraints.

The recommendation from the Task Force on Climate-related Financial Disclosure[30] for reporting offers a starting frame for the development of the assessment. This has to be further expanded including an analysis of adaptation options.

Ideally the investigation should develop according the following steps quite similar to what proposed for Use Cases B4, B5:

- Identification of relevant business constituent (for instance assets/activities, supply chain and portfolios) and scale of the assessment.
- Identification of impact indicators to quantify the most critical expected impacts from climate change on the business. Direct impacts are most suitable to be assessed in a rapid analysis and may include probability of default, expected annual damages and expected losses due to extreme events if an increasing likelihood of such events can be attributed to climate change. Impacts on businesses can also arise form shifting consumer behavior or regulatory changes (transitional risk).
- Identification of hazards
- Choice of tools/methods to quantify hazards and translate them to impacts.
- Data collection.
- Assessing risks, vulnerabilities and impacts: outputs may include amongst others: map of hotspots of climate change risk, which can inform decisions on the distribution of production sites, sourcing of materials etc;
- Identification of adaptation options

[30] https://assets.bbhub.io/company/sites/60/2020/10/FINAL-2017-TCFD-Report-11052018.pdf

Based on the outputs of the rapid analysis of impacts, more detailed studies can be dedicated to risk hotspots or key risk sectors to identify broad adaptation options. Some can be investigated in greater detail. A rapid analysis may provide general indications on adaptation and in particular to the subsequent phases of adaptation analysis starting from the assessment of adaptation options

Specific actions to put in place in the next 5 years

The recommendations for actions draw from what already suggested for Use Cases A1, A2, B4 and B5. In particular:

- Develop a "front office" activity for producers of climate change data, primarily within the Copernicus Climate Change Service, to increase availability, reliability and smooth accessibility (beyond what is already feasible) of climate information (especially on climate extremes and composite indicators) at different spatial resolution
- Build and maintain easily accessible databases on attribution of impacts next to hazards, and on context based preferred adaptation options and on good practice case studies.
- Developing general and sector specific guidance tools and case studies for rapid climate change risk assessment, including for climate change financial risk assessment.
- Developing guidance, tools and case studies for rapid adaptation identification and assessment.
- Developing guidance, tools and case studies for rapid decision making under uncertainty.

5.5 Analysis of insurance for wider group of users (Use Case D14)

Insurance is an effective adaptation tool that provides a sure amount of financial compensation in case the events specified in the insurance policy do occur. Events covered by insurance include weather-related disasters occurring in the EU, such as floods and droughts, and rely on the varying expected occurrence of the insured events across time and space (over a large area) in order to diversify risks and keep the insurance business viable. Exceptionally dire and/or widespread events may put a strain on the financial capacity of the insurance sector to compensate damages and may call for governmental intervention. The limits of a national insurance system may be reached when natural disaster occur in areas where they are usually rare, such as droughts in Northern Europe, a situation made increasingly likely by climate change. Governmental intervention may also become necessary as a consequence of socioeconomic and behavioural factors, as discussed below.

While there is some pressure from EU national governments towards improving national insurance systems to reduce the likelihood of governmental intervention, and some sectoral actions at the EU level for specific risks related to draught impacts on crops, there is much less coordination for flood risks, whose insurance covered is organized and regulated at the national level, as described in the report on rapid analysis. This resulted in different national approaches for the regulation of the insurance sector for flood risk, ranging from mandatory uptake with regulated premia in France to market-driven voluntary uptake in Germany. This variation in the regulatory approach across countries has important consequences for policy, because stricter price regulation with mandatory uptake simplify considerably the determination of the uncovered damages, and hence of the burden for public finances for the reasons, besides having important implications in terms of effectiveness and equity, as discussed in the report on rapid analysis. In the perspective of the present section, it also determines to a considerable extent which actions are amenable to rapid analysis and which ones will require more extensive studies.

In this field, modelling can assist European and national policy makers in three main respects, all related to the key steps in the chain linking physical impacts, insurers' business models, consumers' response and the burden, public financial support and the consequent burden for public finances.

- Risk modelling techniques able to capture climate-induced changes, need to be developed and included into existing models and climate services, in order to ensure the continued operativity of flood insurance systems under a changing climate .
- Insurers should incorporate climate change in their premium-setting models in order to avoid becoming insolvent due to unanticipated larger insured damages in the future, a situation that would leave insured individuals financially exposed.
- Finally, consumers' responses to changing flood insurance premiums needs to be modelled, in order to assess the likely occurrence of insufficient insurance uptake (that may slow down recovery after a flood, as households have to rely on alternative, possibly insufficient funding), and to assess the consequent need for quick deployment of governmental damage relief.

Actions in these areas may help towards closing the knowledge gaps related to adaptation costs and effectiveness discussed in the previous section, and can contribute to the development of flood insurance systems that are robust to increasing flood risk brought about by climate change.

Recommended approach (practical suggestions)

A rapid analysis for the impacts of climate - and socio-economic change on insurance premiums can be performed applying premium-setting rules used in the national and EU-wide models, as described in detail in the report on rapid analysis. Therefore, the following actions are easily implementable in the short run:

- Use existing climate services, such as the global flood risk model GLOFRIS or LISFLOOD for riverine floods, to obtain projections of annual risk based on scenarios of climate- and socio-economic change. Relevant data can for instance be readily retrieved online from the open data source AQUEDUCT (https://www.wri.org/aqueduct/)
- Based on premium setting rules used in the insurance industry, back-of-the-envelope insurance premiums estimates can be computed for specific insurance systems.

Specific actions to put in place in the next 5 years

The estimation of other relevant parameters will require the implementation of statistical and econometric studies involving considerable time for the derivation of useful results. Studies of this kind will involve the following actions:

- Building on the modelling results and on user interface tools provided by climate services projects mentioned under item 1 above, create detailed maps of flood risk and how this is likely to develop in the future due to climate change.
- For insurance systems having a broadly fixed insurance uptake due to regulations in place mandating insurance purchase requirements, when the coverage of insurance is limited, the uncovered risk can be estimated. Drawing on the existing climate services mentioned above to identify risks, the uncovered risk provides thus computed a rough quantification of the amount of ad hoc government compensation needed to cover damage exceeding insurance coverage. This is in principle quite a rapid exercise, but some time is needed to link correctly the expected risks in the specific areas under scrutiny and the estimates of uninsured risks.
- Estimating of the impact of premiums on household budgets, by applying household income data and projections. The finer the geographical and socioeconomic resolution of the households, the longer and more complex the study. However, since the impact of weather-related disasters varies considerably across the territory of the EU and of its Member states (and so do the socioeconomic characteristics of households) a fine resolution is advisable for the policy relevance of the information. Accommodating the households'

adaptation response to flood risk calls for an even deeper and more time-consuming analysis of the households 'decisions in view of the subjective perception of risk and of the varying economic incentives they face.

- In the longer run, the underpinning of a more extensive analysis can be put in place. The role of behavior and attitudes towards flood insurance, which are key factors determining demand for coverage, can be assessed by calibrating models to empirical observations of insurance penetration rates, a more time-consuming analysis. This implies that for the insurance systems where disaster insurance is not mandatory, the assessment of uncovered risk will require extensive studies, and so will the assessment of the impacts of flood risk on government budgets, when they are tapped for ad hoc financial support after flood events.

5.6 Analysis supporting national adaptation plans in accordance with EU requirements: risk assessment and options analysis (Use Case E16)

Much of the responsibility and mandate for adaptation lies at the national level (subsidiarity). For this reason, the European Commission with the 2013 EU Adaptation Strategy (EC, 2013a) encouraged Member States to adopt comprehensive National Adaptation Strategies and provided funding to help them build up their adaptation capacities and take action.

While the number of National Adaptation Plans (NAPs) adopted by Member States (MS) increased considerably since 2013, the quality of these plans varies significantly across MS (EC, 2018a, b). Taking in due consideration the countries' heterogeneity, the following points and room for improvement of MS capacity can be highlighted.

- The potential risks to be considered are many, and not all of them are easily addressed by current models and/or rapid assessment methodologies. In particular, some of the MS would benefit from additional climate risk information and models.
- There is definitely potential for improved inventories of adaptation options, and supporting information on lessons learned from their application and success.
- Support is needed to appraise and prioritise adaptation options, and to develop them into plans and policies, including financing of adaptation. "Costing" adaptation seems particularly challenging. Furthermore, there is often an emphasis on technical measures and much less focus on the range of accompanying and supporting background actions.

- For most of the MS, there has been little progress on adaption monitoring and evaluation, including through indicators, therefore support is needed to improve country action in this respect.

Recommended approach (practical suggestions)

Some general guidelines for rapid assessment supporting the formulation of NAPs can be given, though it is stressed that the exact approach will vary with the Member State. Such suggestions are presented below following the relevant steps of the adaptation policy cycle. (For further information, see Task 4.)

- Assessment of risks and vulnerabilities - The idealized analysis would use initially information sources with a broad scope, to be then complemented by more specific risk information on individual risk or sector. It is likely that in five years' time, and probably before, more open source information on a wide range of key risks for the whole Europe, with downscaled data and free access portals will be available.
- Identification of adaptation options - Adaptation options can be identified through inventories or databases broken down by sector and/or risks. The information here included could encompass the practical applications of these options and related case study information. Useful examples in this area already exist, including on Climate-ADAPT, where the adaptation options are cross-linked with the case studies that implemented them in practice (and vice-versa).
- Adaptation assessment – This is the phase of the adaptation policy cycle where less support for rapid assessment is available from modelling. Possibly, in 5 years' time, a set of rapid assessment tools and guidance supporting adaptation assessment might be ready. There would be also related training courses and network of practice. For major risks, however, detailed assessment will still be necessary in national adaptation planning.
- Addressing uncertainty - Moreover it is advisable to enhance the introduction of adaptive management (and pathway) perspectives in NAPS to help addressing climate uncertainty. It is possible that in 5 years' time there are tools and guidance on developing iterative NAPs, including case study material. These might have a broad national scope, but also specific (e.g. sectoral) focus.
- Enhancing adaptation mainstreaming - All this could be complemented with guidance and tools to enhance mainstreaming of climate change adaptation in all the several relevant areas and sectors of national planning and policy.

Specific actions to put in place in the next 5 years

Undertaking the following actions in the near future would help MS conducting rapid climate risk assessments and rapid climate adaptation assessments, including the costs and benefits of adaptation options, for input into NAPs and, ultimately, developing comprehensive NAPs (for further information see Task 4).

- Consulting and engaging with the relevant EU institutions (Horizon, Copernicus, JRC, EEA) for the development or support to improvement of rapid assessment tools and information for national climate risk assessment.
- Developing open source climate risk tools and information, ideally at risk or sector level, to inform national climate risk assessments.
- Developing guidance, tools and case studies supporting:
    - rapid adaptation assessment at the national level, ideally at risk or sector level.
    - rapid economic analysis of adaptation costs and benefits.
    - adaptive management in national adaptation planning.

In particular, it is desirable for the near future to have inventories and support tools helping countries to undertake a first appraisal of adaptation options, and to cost their adaptation plans at least as a first approximation. Such instruments could include, for example, look up tables of options including costs, simplified tools for addressing benefits, inventories of benefit to cost ratios for options.

- Conducting workshops and training.

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