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Understanding high-end climate change: From impacts to co-creating integrated and transformative solutions

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Abstract

The world is not yet on track to meet the Paris Agreement climate change target of keeping global average temperature rise within 2°C above pre-industrial levels. Current greenhouse gas emission trends point to much more substantial warming, with possible increases of 4°C or more in the long-term. This Special Issue describes findings from the IMPRESSIONS project which advanced the understanding of impacts of high-end climate change (defined as global mean temperatures > 2°C above pre-industrial levels) and potential solutions for reducing these impacts through adaptation, mitigation and transformative actions. With stakeholders, the project developed a set of integrated climate and socio-economic scenarios and applied these to multi-sectoral impact models in five case studies: Hungary, Scotland, Iberia, Europe as a whole and Central Asia. This showed that benefits in some regions and sectors, such as increasing forest productivity in northern Europe, are offset by detrimental effects in others, such as severe water scarcity, heat stress and loss of productivity in southern Europe and parts of central and eastern Europe, and widespread flood damage. Adaptation and mitigation pathways were generated with stakeholders to address these impacts and identify integrated and transformative solutions. These highlighted the importance of shifting to sustainable lifestyles, good governance for sustainability and climate resilience, and new forms of integrated and sustainable resource management. The stakeholder-led approach of IMPRESSIONS ensured that the research was driven by the priorities of decision-makers, enabling significant co-learning and the identification of robust, innovative and effective solutions for addressing high-end climate change.

1. Introduction

The UNFCCC Conference of the Parties meeting in Paris in December 2015 agreed "to holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels" (UNFCCC 2016). However, projections based on current greenhouse gas emissions trends point to much more substantial warming, with possible increases of 4°C or more in the long-term (Friedlingstein et al. 2014; Fuss et al. 2014). Furthermore, it has been shown that achieving the 2°C target will require greater emissions reductions than currently pledged (Rogelj et al. 2016).

Despite the increasing plausibility of these high-end scenarios (which we define as global mean temperatures > 2°C above pre-industrial levels, i.e. overshooting the Paris Agreement targets), there are few studies that simultaneously assess their potential impacts, the ability of adaptation options to reduce vulnerabilities, and their possible synergies and trade-offs with mitigation. Furthermore, existing methods and modelling tools fail to account for the need to cope with radical rather than gradual change, the amplified interdependencies between sectors, and the need for transformative

strategies that address potential synergies and trade-offs between adaptation, mitigation and sustainable development. It is vital that decision-makers have access to reliable scientific information on these uncertain, but potentially high-risk, scenarios of the future, so that they can make effective climate governance plans that deal with adaptation and mitigation in a synergistic way.

This Special Issue consists of a set of 14 papers from the IMPRESSIONS (IMPacts and Risks from higher-End Scenarios: Strategies for Innovative solutiONS) project that quantify and explain the consequences of high-end climate change under different socio-economic scenarios, and identify and evaluate pathways and transformative solutions for moving society towards a sustainable future.

2. What is IMPRESSIONS?

IMPRESSIONS was a research project funded by the European Union from 2013 to 2018. It was a large multi-institution endeavour involving 26 European and international partners from 16 countries, including research institutions and small and medium-size enterprises. The project aimed to provide a scientifically robust and policy-relevant understanding of the nature and scale of more extreme and long-term consequences of climate change, and support the use of this knowledge by decision-makers working on adaptation, mitigation and sustainability. It was guided by the following objectives:

- To establish decision-maker needs for enhancing current approaches to climate change policies and actions through maximising their active participation in the research;
- To develop a novel stakeholder-driven methodology for the creation of an integrated set of high-end climate and socio-economic scenarios;
- To apply these scenarios to a wide range of models of impacts and adaptation within an integrated assessment approach which advances the analysis of multi-scale and cross-sectoral synergies and trade-offs;
- To co-create a suite of harmonised adaptation and mitigation pathways with a broad community of stakeholders, which are tested with the models, and assess the adequacy of adaptive capacity for implementation of the pathways;
- To develop recommendations on robust new policy strategies and pathways, including the risks and opportunities of different policy options, in order to provide integrated and potentially transformative solutions that help society plan for the long-term in the context of high levels of climate change.

To achieve these objectives five case studies were carried out: (i) in two municipalities in Hungary (Szekszárd and Veszprém); (ii) at the national scale in Scotland; (iii) for a transboundary river basin in Iberia (the Tagus); (iv) at the continental scale for Europe; and (v) in an international case study focused on Central Asia that explored interactions with Russia, China and Europe under high-end climate change.

3. The IMPRESSIONS approach

The IMPRESSIONS approach was implemented in the five case studies in a number of steps (as illustrated schematically in Figure 1):

(i) In-depth interviews were undertaken with stakeholders to understand what tools and knowledge decision-makers need in order to make robust and effective decisions on adaptation and mitigation in the face of highly uncertain scientific information.
(ii) Participatory workshops, complemented by online engagement with stakeholders, were organised to describe potential future changes in socio-economic drivers (e.g. economic, demographic, technological, social and political). These were matched with climate change

scenarios according to the magnitude of greenhouse gas emissions in the socio-economic assumptions. The socio-economic and climate scenarios were based on the IPCC scenario framework of Shared Socio-economic Pathways (covering SSPs 1, 3, 4 and 5) and Representative Concentration Pathways (covering RCPs 4.5 and 8.5) (Moss et al. 2010) to enable consistency and comparability across the different scales and contexts of the case studies. This led to a set of integrated scenarios about what the future might look like under high-end climate change.

(iii) The scenarios were used to drive models to project future changes in impacts for different sectors of the economy, society and environment. A common multi-scale modelling framework was developed to analyse the complex interactions, synergies and trade-offs between different sectors such as agriculture, forestry, urban development and tourism as they compete for land, water and energy, and the resulting impacts on health and biodiversity. The models results were used to indicate whether the system as a whole was becoming more or less sustainable under each integrated scenario.

(iv) Stakeholders were involved in co-creating a vision of a sustainable future for the case study for the year 2100. The visions describe people's aspirations for governance, energy, social equity, living and lifestyles, the environment and other factors essential to human well-being.

(v) Stakeholders worked with the project team to co-create a suite of harmonised adaptation, mitigation and transformation pathways that attempt to move society from the projected future impacts (from step iii) and towards the sustainability visions (from step iv). The pathways consist of several strategies (focused on people, nature, markets or technology), which describe bundles of actions that are specific activities carried out by one or multiple actors at a specific point in time.

(vi) The effectiveness of the pathways was evaluated using the models and qualitative analyses to assess the extent to which the actions in the pathways moved selected vision indicators closer to the vision of a sustainable future. The results of this evaluation were fed back into the stakeholder engagement process to highlight where the pathways could be strengthened.

(vii) This resulted in a set of pathways that work in all scenarios, with different emphases for each case study, to achieve the vision of a sustainable future. In each case study, combinations of transformative solutions accelerate progress towards the vision.

4. Overview of IMPRESSIONS findings

The papers in the Special Issue map onto the IMPRESSIONS approach as illustrated in Figure 2.

4.1 Decision-maker needs assessment and stakeholder engagement process

Stakeholders were central to the IMPRESSIONS approach and particularly to the case studies. A structured methodology for engagement and participation was applied that started with identifying and selecting stakeholders, in order to ensure representativeness across different categories, including societal, geographic, topic/sector, gender and age (Gramberger et al. 2015). Each case study undertook three stakeholder workshops and in between online engagement activities to co-develop socio-economic scenarios, visions, pathways and transformative solutions (Kok et al. 2019, this issue; Frantzeskaki et al. 2019, this issue; Hölscher et al. 2019, this issue; Tàbara et al. 2019, this issue). A final workshop brought together representatives from across the case studies in order to further explore robust pathways and solutions. The final workshop also allowed the exchange and reflection of the learning experience of the stakeholders from their engagement in IMPRESSIONS research.

More detailed interviews were undertaken with a sub-set of stakeholders, selected according to the individual's involvement in decision-making processes, their organisational affiliation and level of operation and function within that organisation. The interviews focused on the needs of decision-makers for information on high-end climate change in four case studies (EU, Hungary, Portugal and

Scotland) (Capela Lourenço et al. 2019, this issue). They found that information from high-end scenarios is not normally included in decision-making processes, due to its nature and lack of availability, as well as institutional settings and adaptation decision timeframes. Furthermore, stakeholders perceived a conflict between the climate change projected by high-end scenarios and the Paris Agreement target, although current decision-making processes were more concerned with climate impacts than degrees of temperature change. This was also reflected in concerns about uncertainty, which generally was not seen as a major barrier to adaptation-related decision-making processes. Finally, adaptation-related decision-making was seen as a multi-faceted process, with socio-economic factors at least as important as climate ones, if not more so.

4.2 High-end climate and socio-economic scenarios

IMPRESSIONS has advanced the development of integrated climate and socio-economic scenarios. A set of five SSPs×RCPs was selected, with SSP1 and SSP4 linked to RCP4.5; and SSP3 and SSP5 linked to RCP8.5. Additionally SSP3 was linked to RCP4.5 to enable a comparison of model outputs with varying climate change and the same socio-economic change. For each RCP, three combinations of global climate model (GCM) and regional climate model (RCM) were selected from available climate models to represent uncertainty over future climate change in Europe. Madsen et al. (2017) showed that uncertainty may be overestimated at the global scale when sub-ensembles of climate models are selected based on regional criteria and they argued that any sub-selection should be done based on well-argued and transparent choices. In IMPRESSIONS climate model sensitivity and the availability of regional model data were used as the main selection criteria (see Kok et al. 2015 and Madsen et al. 2016 for further information).

Kok et al. (2019, this issue) showed how, using a novel approach, the global SSPs can be downscaled to Europe, whilst ensuring that the qualitative narratives are consistent (as far as possible) with an existing set of European scenarios. They found a number of challenges and risks in developing equivalence for these scenarios, including loss of detail, specific uncertainties and degree of subjectivity and recommended further work on scenario archetypes to aid scenario comparison. Pedde et al. (2019, this issue) demonstrated the value of applying a fuzzy set approach in the context of the development of stakeholder-led socio-economic scenarios for bridging the gap between epistemic and linguistic uncertainty, thus enabling the potential linking of qualitative and quantitative scenarios. By linking the SSPs with the pattern and structure of the population at sub-national scales for input into a regional urban growth (RUG) model for Europe, Terama et al. (2019, this issue) have shown how patterns of population growth and socio-economic preferences affect urbanisation patterns across Europe, as well as how population structure and dynamics are important drivers of other land uses.

4.3 Climate change impact and adaptation modelling

A wide range of climate change impact models were developed, expanded and used in IMPRESSIONS. As mentioned in the previous section, Terama et al. (2019, this issue) projected impacts on urbanisation finding that artificial surfaces in Europe could remain similar to today under the sustainable SSP1 scenario or double by 2100 under the SSP5 fossil fuel driven scenario where urban sprawl is not controlled and population significantly increases. Harrison et al. (2019, this issue) used an integrated assessment model to assess impact differences across land and water sectors under high-end and low-end (Paris Agreement) climate change. They found that impacts are considerably greater under high-end than low-end climate change in the 2050s and 2080s, and that socio-economic factors much more strongly drive changes in land use and food production than changes in climate, sometimes overriding the differences due to low-end and high-end climate change. Fronzek et al. (2019, this issue) conducted a sensitivity analysis using a suite of impact models using the Impact

Response Surface approach. This revealed increases in north-eastern Europe and decreases in central and eastern Europe for yields of all crops and productivity of all tree species, and decreases of river discharge and forest productivity in southern Europe. Similar to Harrison et al. (2019, this issue), the authors also found that responses were more sensitive to socio-economic than to climate drivers for some impact indicators, such as heat-related mortality, coastal flooding and land use. Dunn et al. (2019, this issue) applied a climate analogues approach to explore the extent to which Scotland may become suitable for wine production under high-end climate change. The authors found temperature analogues that matched with several current wine grape growing regions of Europe, however, when precipitation and/or lithology and topography are also taken into account, no matches were found.

Holman et al. (2019, this issue) reviewed the ways in which adaptation is represented in impact models finding that a minority of models take account of the human decisions underpinning the choice of adaptation measures, the triggers that motivate actions or the time-lags and constraints that may limit their uptake and effectiveness. These issues are further explored by Holzhauer et al. (2019, this issue) and Lamperti et al. (2019, this issue) who discuss the use of agent-based modelling for improved representation of adaptation and climate policy in the integrated assessment of high-end climate change. Lamperti et al. (2019, this issue) focus on integrated agent-based models of climate change and economic dynamics, whilst Holzhauer et al. (2019, this issue) focus on agent-based models of multi-scale institutions and land use change.

4.4 Adaptation and mitigation pathways

The IMPRESSIONS project developed and implemented a novel methodology for developing transition pathways to move towards a more sustainable future. This methodology and the results of applying it in the European case study are described by Frantzeskaki et al. (2019, this issue). The pathways, co-created with stakeholders, include adaptation to and mitigation of climate change as well as transformational actions and solutions for climate change within the context of different socio-economic and climate scenarios. Three pathways were found to be robust in the face of climate and socio-economic uncertainty: (i) shift towards sustainable lifestyles; (ii) support and strengthen good governance for sustainability; and (iii) promote integrated and adaptive resource management for water, agriculture and energy. The authors conclude, however, that it is unlikely that these future actions alone are sufficient to fully enable Europe to achieve its vision of a sustainable future. This arises due to a combination of the significant residual impacts of high-end climate change, systemic time lags and/or the more pervasive negative aspects of some of the socio-economic scenarios.

It is very important, however, to recognise that Europe will not only be affected by climatic and socio-economic changes within its borders. Changes in other parts of the world can also have an (indirect) impact and thus potentially require adaptation measures. As Benzie et al. (2019, this issue) emphasise, Europe is increasingly connected to the rest of the world via flows of people, capital, goods and resources and these flows are exposed to changes occurring outside its borders. Benzie et al. (2019, this issue) describe how the EU could be affected by such changes and identify some of the potential key issues for EU adaptation. The results show that many EU countries are more exposed than the global average to climate-related risks with regard to transboundary water dependency, trade openness, openness to asylum and globalisation. These results have implications for future iterations of the EU Adaptation Strategy, which needs to take cross-border impacts into account. Furthermore, the authors points out that any adaptation at national and EU level that introduces resilience and stability into global systems will make a positive contribution to global sustainable development, while adaptation that reduces risks in the EU whilst redistributing or worsening vulnerability in other countries will ultimately undermine global resilience, which is likely to affect the EU, given its interdependences with the rest of the world.

4.5 Integrated and transformative solutions

Overall the results of the IMPRESSIONS project underline the fact that high-end climate change together with socio-economic changes that could occur will require transformative solutions. That is, solutions are needed that change economic and social systems and tackle the underlying causes of unsustainability. Conventional strategies and solutions will not be enough to avoid major disruptions in social-ecological systems due to the complex and non-linear changes associated with high-end scenarios. However, as Tàbara et al. (2019, this issue) point out, conventional climate assessment approaches and methods demonstrate many limitations with respect to providing robust knowledge and support to the design and implementation of transformative solutions in practice. Conventional approaches cannot deal well with the complexity and non-linearity of projected changes and they tend to focus much more on describing the problem than on finding solutions. Therefore, Tàbara et al. (2019, this issue) introduce the concept of Transformative Climate Science as the open-ended process of producing, structuring and applying solutions-oriented knowledge to fast-link integrated adaptation and mitigation strategies to sustainable development. The main characteristics of this approach are outlined in order to provide guidance for other scientists and practitioners.

One aim of Transformative Climate Science (Tàbara et al. 2019, this issue) is to understand and support agents' transformative capacities. Hölscher et al. (2019, this issue) provide a conceptual framework of capacities for transformative climate governance. Transformative climate governance enables climate mitigation and adaptation while purposefully steering societies towards low-carbon, resilient and sustainable objectives. The framework distinguishes between different types of capacities needed to address transformation dynamics: responding to disturbances (stewarding capacity), phasing-out drivers of path-dependency (unlocking capacity), creating and embedding novelties (transformative capacity) and coordinating multi-actor processes (orchestrating capacity).

Conclusions

The IMPRESSIONS project aimed to improve scientific understanding of the consequences of high-end climate change and support the use of this knowledge by decision-makers working on adaptation and mitigation. Combining model-led climate trends with stakeholder-led socio-economic trends has provided a unique set of comparable yet stakeholder-relevant multi-scale scenarios. Three common cross-scale pathways for climate action are identified: shifting to sustainable lifestyles; new governance for sustainability and climate resilience; and new forms of integrated resource management. Analysis of the adaptation and mitigation pathways shows that beyond the 2^{o}C threshold, conventional solutions to adaptation and mitigation may prove not to be enough. Transformative solutions aimed at implementing radically different institutional arrangements, searching for synergies between adaptation and mitigation and linking them to sustainable development become increasingly important.

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Figures

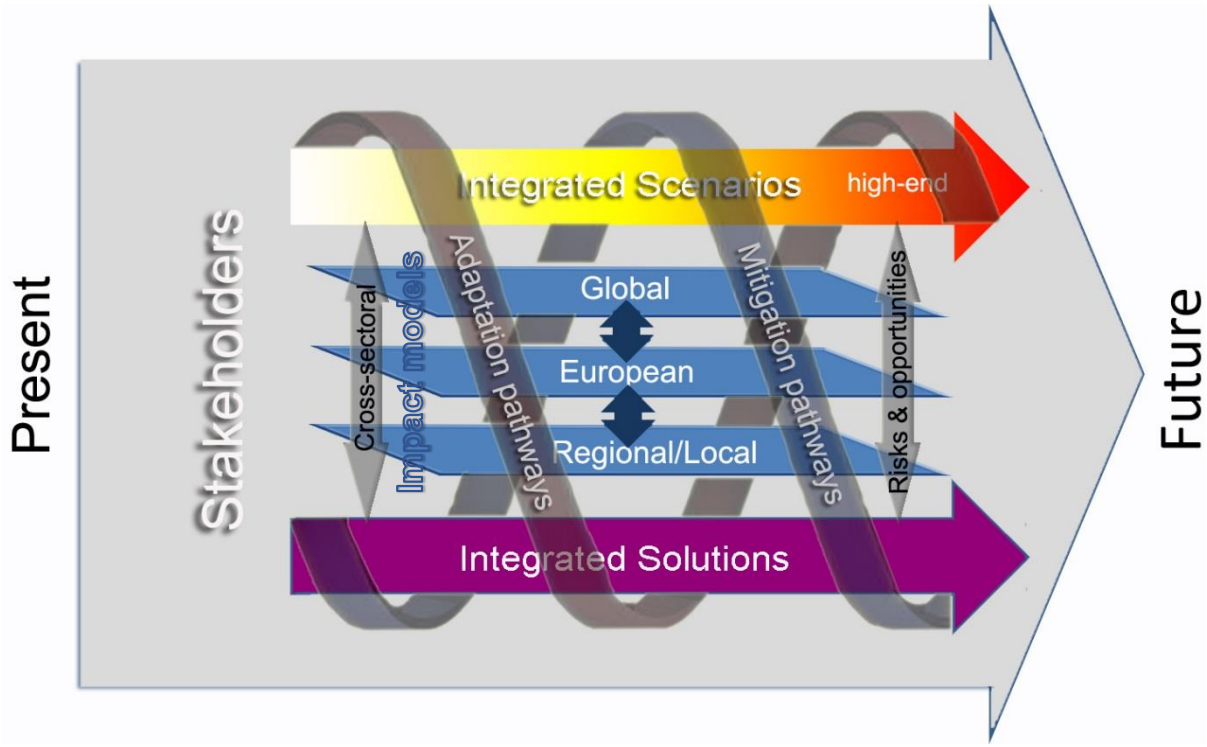

Figure 1: Schematic of the overall IMPRESSIONS approach to co-creating integrated solutions to high-end climate change with stakeholders.

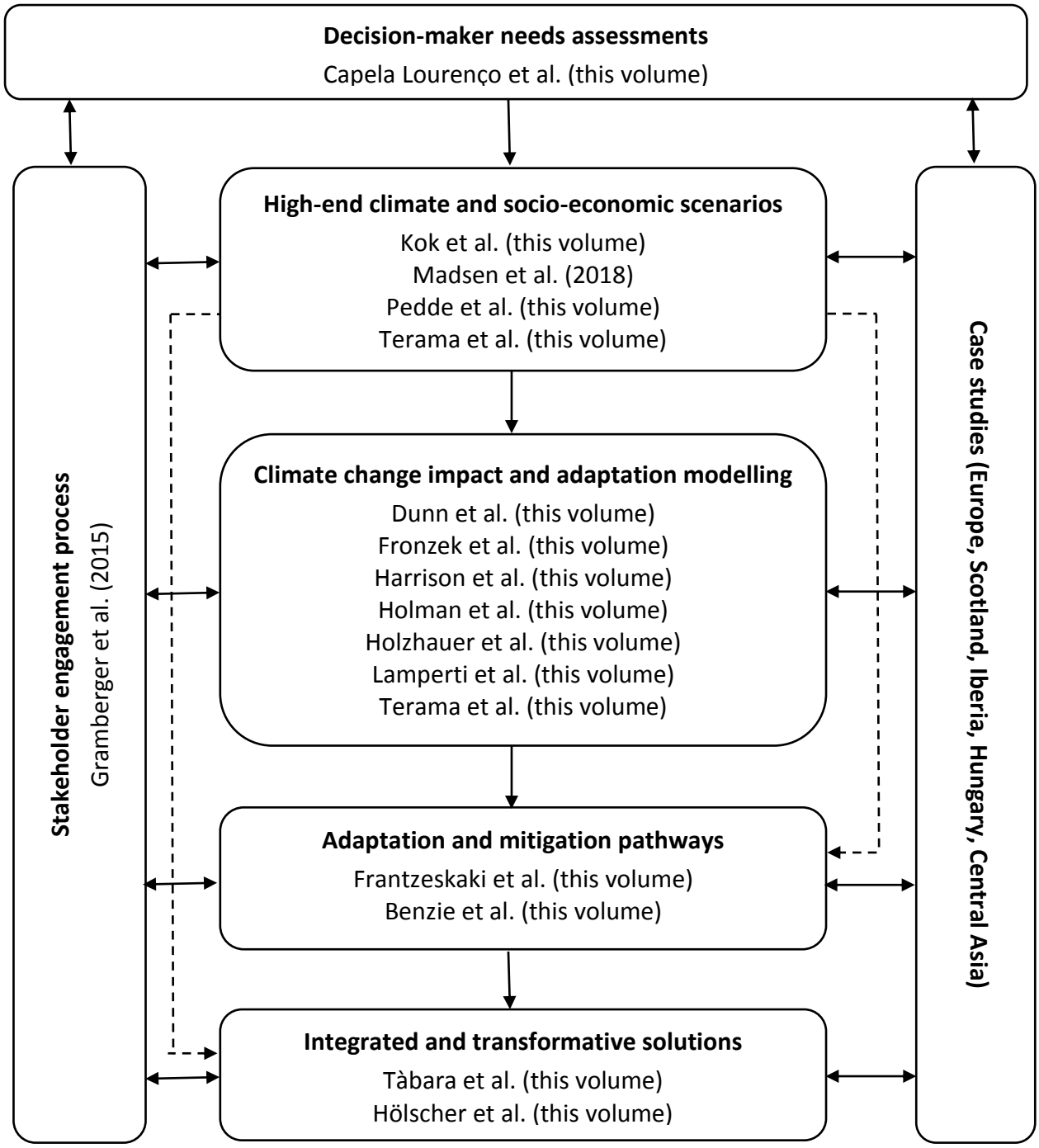

Figure 2: The methodological components of the IMPRESSIONS project and references to publications.