Assessment of current policies and strategies using stress-testing methods

Deliverable D5.3

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Preface

This Deliverable Report has been written for the project "Impacts and Risks from High-end Scenarios: Strategies for Innovative Solutions" (IMPRESSIONS) and reports on the results of Task 5.3: Stress-testing of existing policies and strategies. The first part of the stress-testing was embedded within a process of stakeholder engagement in a series of workshops, which has been described in more detail in Deliverables D6A.2 ('Report on second set of stakeholder workshops') and D6A.3 ('Report on third set of stakeholder workshops'). It is important to point to the strong link in the IMPRESSIONS project between this deliverable and Deliverable D5.1 ('Evaluation of economic approaches under high-end scenarios'), which provides two conclusions of importance for stress-testing:

- Presenting policy appraisal in simple numerical terms risks giving a spurious, ultimately unhelpful, and even dangerous illusion of confidence or certainty;
- Finding 'optimal' policy solutions is unlikely under high-end scenarios. Hence, IMPRESSIONS focuses more on aiding the process of reflection about the possible consequences of climate and socio-economic change and possible robust adaptation options for dealing with them.

The two overarching purposes of the stress-testing in Task 5.3 are:

- To illustrate and highlight some of society's vulnerability to high-end climate change with regard to current policies; and
- To use the results of the stress-testing as a basis for identification of new, more robust, actions and strategies (elements of pathways).

These two purposes were operationalised via stakeholder assessments of a selection of current policies in the European, Scottish, Hungarian and Iberian case studies. Furthermore, for the European case study the stakeholder assessment was complemented with a modelling-based analysis using the Integrated Assessment Platform (IAP) developed within the CLIMSAVE project and further developed in IMPRESSIONS (IAP2). This report describes both strands of the stress-testing activities in IMPRESSIONS.

Summary

A qualitative stress-testing was carried out in the EU, Scotland, Hungary and Iberian case study workshops in 2016 (Zellmer et al. 2016). The stakeholders were asked to assess whether a set of current policies would be effective within the context of a scenario. The European case study assessed whether policy measures were effective in achieving the objectives of current policies within the different scenario contexts. The Scottish, Hungarian and Iberian case studies assessed whether the current policy measures would be effective in achieving the vision for the world in 2100 developed in each case study.

The European case study assessed policy measures from the Common Agricultural Policy (CAP), the Habitats Directive and the Floods Directive. For the CAP measures, none of the policy measures were found to be effective over all scenarios. For the Habitats Directive, one policy measure ('Control invasive species') was assessed positively in the two scenarios (SSP1 and SSP5) that considered this measure. For the Floods Directive, three policy measures ('Building codes and legislation', 'Floodplains and flood control', and 'Reforestation of river banks') were assessed positively in the two scenarios (SSP3 and SSP4) that considered these measures.

The Scottish case study assessed policy measures from the Land Use Strategy, the Biodiversity Strategy, Water Management and Flood Management in Scotland. For the Land Use Strategy policy measures, only one of the measures ('Develop models and Geographic Information System (GIS) tools to enable assessments of land use/management change') was assessed positively in all scenarios. The Biodiversity Strategy measures were assessed in the SSP1 and SSP3 scenarios and, while they were all assessed positively in SSP1 (Mactopia), it was felt that the measures would not help to achieve the vision, or only partially help, in SSP3 (Mad Max). For Water Management measures, two of the measures had a positive assessment in all scenarios except SSP3 ('Improve our understanding of water flows in key zones by integrating climate models into water resource plans' and 'Invest in further monitoring of wastewater catchments to understand climate impacts').

In the Hungarian case study the stress-testing exercise focused on one of the two communities that are engaged in the case study (Szekszárd) and two policy areas (water management and health). Policy measures on water management were assessed positively in all scenarios. The policy measures on health issues were also generally assessed positively within two scenarios (SSP1 and SSP3) emphasising the importance of dealing with heat stress, and one scenario (SSP4) pointing to the impact of a division of the society in this scenario (rich vs. poor), meaning that the rich would have resources to deal with health issues, while the poor would not.

The Iberian case study assessed policy measures from the EU Water Framework Directive (WFD) and the CAP. Overall, the results of this qualitative assessment show that for CAP, the measures are deemed to work in the SSP1 and SSP4 scenarios, but only partially in SSP3 and SSP5, where the stakeholders noted that the measures would only work until 2040. For the WFD measures, the measure that works in most scenarios is 'Joint planning and management of international river basins between Portugal and Spain', which cannot work in SSP3 due to the fragmentation of a world of regional rivalry.

Stakeholder evaluations at the end of each case study workshop showed that while this session on stress-testing of current policies against the objectives of the policy or against the case study vision was difficult, it was highly valued by the stakeholders. Discussing how current policies would fare in the different socio-economic settings and with different levels of climate change stimulated a lot of thinking about how current policies might have to be changed in the face of high-end scenarios.

For the quantitative stress-testing using the Integrated Adaptation Platform (IAP2), the overarching idea was to select a few EU-level policies, identify associated policy measures, stress-test them against the vision of EU case study and finally assess different measures of robustness. A simplified 'portfolio analysis' was also carried out. A selection of measures from three policies at the EU level was analysed: the CAP, WFD and EU Adaptation Strategy (EAS). Results were compiled for the baseline (before implementation of the measures) and for the time-slices 2041–2070 and 2071–2100.

For the CAP, four policy measures and two combinations ('portfolios') of measures were tested using the IAP2. None of the measures or combinations gave positive (i.e. supporting the achievement of the EU vision for 2100) results for all time-slices and all scenarios. For the WFD, four policy measures and four combinations were tested. The policy measure of water pricing (modelled by increasing water savings due to behavioural change and increasing water savings due to technological change) was essentially robust across all time-slices and scenarios, since it reduced or did not change vulnerability to water exploitation in all IAP2 runs. Interestingly, the WFD policy measures work particularly well for the scenarios associated with more extreme climate change (RCP8.5), suggesting that these measures are particularly useful in the face of high-end climate change. For the EAS, five policy measures were tested. One measure – building capacity – which was modelled in the IAP2 by increasing social and human capital was essentially robust across all scenarios.

The quantitative analyses also contained a test of different ways of defining robustness. This was performed on the policy measures for the WFD and the EAS. The results show that the preferred set of policy measures is highly dependent on what is meant by 'robustness'. A risk-avert definition of robustness led to very different conclusions compared to, for example, a more optimistic perspective. This part of the analysis highlights the necessity of being explicit about what is meant by robustness.

Overall, the stress-testing with the IAP demonstrated the complexity of policy implementation, with cross-sectoral impacts often leading to increasing vulnerability to climate and socio-economic change when single or combined policy measures are applied.

1. Introduction

The overall objective of IMPRESSIONS' WP5 is: "…to synthesise results from WPs 1-4 and use the concept of Integrated Climate Governance to develop integrated strategies and map out key synergies and trade-offs between adaptation and mitigation pathways in terms of the level and distribution of societal and economic risks, vulnerabilities, opportunities, costs and benefits within the context of high-end scenarios."

To contribute to the overall aims of WP5, Task 5.3 is described as follows:

"This task will conduct a stress-test of key policies and strategies from the case studies (for example, regional water management strategies in Iberia, land use policies in Scotland, adaptation related municipal strategic plans in Hungary, key elements of the EU Adaptation Strategy 2013 and key EU external policies such as the European Common Foreign and Security Policy and EU negotiating strategy for the UNFCCC, etc.) in order to assess their social-ecological robustness to high-end scenarios. The task will apply a 'wind-tunnelling' method to examine elements of a policy or strategy against possible futures. Key policies and/or strategies from each case study will be selected in consultation with the case study coordinators. These policies and strategies will be 'wind-tunnelled' within a set of representative scenarios drawn from WP2, including, for example, the +2 or 3°C scenario and the high-end RCP-based scenarios, with the aim of identifying the robustness of policies to both moderate and extreme levels of climate change, as well as different socio-economic futures. The strengths and weaknesses of each policy within each scenario will be assessed. A specific focus will be on assessing the implications of potential thresholds, beyond which current policies and strategies will become unfit for purpose or impossible to implement within certain conditions present in the scenarios. The task will be framed by a theoretical understanding of policy implementation, and the consideration of multiple social and ecological systems' feedbacks which will also enable a preliminary review of gaps, potential new policy approaches and policy transformation for adaptation to high-end scenarios to inform Task 5.4. The results of the stress-test will also be used as inputs to stakeholder discussions in the case studies and as an input to the analysis of adaptation pathways (Task 5.4)."

This deliverable reports on the results of Task 5.3. Based on the Description of Work we defined the following two overarching purposes of the stress-testing:

(i) Illustrate and highlight some of society's vulnerability to high-end climate change with regard to current policies;
(ii) Use the results of the stress-testing as a basis for identification of new, more robust, actions and strategies (elements of pathways)[1].

These two purposes were operationalised via stakeholder assessments of a selection of current policies in the European, Scottish, Hungarian and Iberian IMPRESSIONS case studies. The European-scale case study is quantifying cross-sectoral climate change impacts and vulnerability and developing adaptation and mitigation pathways for addressing them under high-end climate and socio-economic scenarios within the EU27. The sectors being analysed include agriculture, forestry, water, urban development, human health, coastal areas and biodiversity.

The regional-scale case study for Scotland is exploring multi-sectoral interactions in a north-western European environment. The sectors being assessed include agriculture, forestry, water and tourism along with the multi-scale issue of supply chains for food and beverages. The case study for Hungary explores multi-sectoral interactions and responses to high-end climate change in two medium-size towns, Veszprém and Szekszárd, in Western Hungary. The sectors studied include water, agriculture and human health (heat stress), with the multi-scale issues of water management and local/regional food supply and related land use issues also under consideration. The Iberian case study is concerned with one of the areas in Europe most likely to be negatively affected by high-end climate change. It focuses on sectors that directly depend on precipitation and temperature, such as agriculture and water supply. The focus of this case study is on exploring innovative options for the integrated resource management of the Tagus transboundary river basin under 'high-end' climate and socio-economic scenarios.

Furthermore, for the European case study the stakeholder assessment was complemented with a modelling-based analysis using the Integrated Assessment Platform (IAP) developed within the CLIMSAVE project and further developed in IMPRESSIONS (IAP2). This report describes both strands of the stress-testing activities in IMPRESSIONS.

Section 2 introduces the concept of stress-testing and describes the methodology used for stress testing in the IMPRESSIONS project. We then present, in section 3, the results of a qualitative stress-testing carried out in stakeholder workshops in 2016. Section 4 presents the results of quantitative stress-testing using the Integrated Assessment Platform (IAP2). The overall results of the stress-testing are discussed in Section 5 which presents our conclusions and some directions for further work.

[1] Strategies are a bundle of actions linked to a vision-based objective; they can be sectoral or cross-sectoral and require collaboration or coordination of multiple actors. Pathways are bundles of short-term, medium-term and long-term strategies (See IMPRESSIONS Deliverable D4.1).

2. Methods

2.1. Stress-testing in context

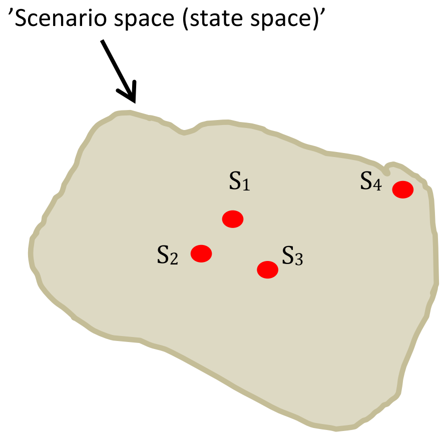
When scenarios are used to guide policy analysis and decision-making, the aim is typically robustness in the sense of supporting the search for strategies that work reasonably well for a wide range of external conditions. There are several approaches for doing scenario-based stress-testing to assess robustness. The first distinction to consider is the different ways scenarios are used in the stress-testing. One class of approaches starts with the policies and identifies 'critical scenarios' or scenarios that illuminate vulnerabilities of the set of policies ('RDM – Robust Decision Making'; Groves and Lempert 2007; Bryant and Lempert 2010). In such a process, computer simulations that project the performance of one or more policies are used, with one or more outputs of interest, contingent on various uncertainties in the model structure and input parameters. In general, given the huge number of possible combinations when building scenarios, a large database of simulation results is generated. Each case tracks the performance of a policy in one scenario. Finally, some criterion (e.g. critical thresholds) applied to the model outputs distinguishes those scenarios where the policy meets its goal from those where it does not and, hence, scenarios that illuminate vulnerabilities are identified. In this approach, all combinations of scenario variables (sometimes called 'drivers' or 'driving forces' or 'descriptors') are considered. Hence, all possible scenarios (for a given set of variables and associated states, e.g. the variable *Education* with states 'High', 'Medium' and 'Low') are considered in the identification of scenarios that illuminate vulnerabilities. This is in contrast to the socio-economic scenario set utilised by the climate change research community (the Shared Socioeconomic Pathways – SSPs) where (only) five scenarios are developed (see further below).[2]

In other approaches a fixed set of scenarios is used for the stress-testing (e.g. van der Heijden 2005). This is the approach used in IMPRESSIONS where the SSPs in combination with climate projections are used. Here the scenarios must be constructed before the stress-testing, and are not based on the stress-testing. The scenario selection methodology, therefore, becomes *policy-independent*, and not *policy-dependent* as above. There are several ways of doing the policy independent scenario selection, both quantitatively and qualitatively. Perhaps the most used quantitative approach is to select scenarios with strong *self-consistency* (Weimer-Jehle 2006). Self-consistency refers to focusing on scenarios with qualitative elements depicting circumstances that reinforce each other. It is important to note that self-consistency is a property of individual scenarios; selecting a set of self-consistent scenarios does not provide the analysts with any clue on how the set of scenarios performs. Hence this method has shortcomings for robustness analysis across a set of scenarios.

When testing the robustness of policies across a set of scenarios it is important that the scenarios, as a set, cover as many future possibilities as possible. When applying a single consistency measure across all scenarios the resulting selection runs the risk of being too narrow, which could imply a too restrictive robustness test. This is illustrated in Figure 1 below. First the policies P_1 and P_2 are stress-

[2] In the process of developing the SSPs (O'Neill et al. 2017), potential variables considered to be important determinants of challenges to mitigation or adaptation were generated through expert discussions and expert elicitations. In total 31 variables were identified in six broad categories: demographics, human development, economy and lifestyle, policies and institutions (excluding climate policies), technology, and environment and natural resources. However, no *systematic* process for generating the scenarios from this set of variables was utilised.

tested against the scenario set[3] {S_1, S_2, S_3}. The performance of the policies are assessed using a simple metric (-3, -2, …, 3). The range of the performance over the set {S_1, S_2, S_3} is relatively narrow which is due to the fact that the three scenarios are close in the scenario space. When the policies are tested against a fourth scenario, a scenario at a large distance from the original set, a wider span of performance is revealed.



	S_1	S_2	S_3	S_4
P_1	-1	1	0	-3
P_2	0	1	1	3

Figure 1: Conceptual illustration of the scenario space, scenarios and a simple matrix approach to stress-testing. Each policy (P_i) is assessed in each of the scenarios (S_i). This illustrates the necessity of having a broad span of scenarios for the stress-testing.

From this simple reasoning we conclude that the scenarios in a set for stress-testing need to be widely separated in order to expose the full range of possible performance of policies. One option for capturing this broad span of scenario space is to employ very large scenario sets, as discussed above. For communication purposes it is, however, often useful to limit their number. A methodology for generating scenario sets where the scenarios are, in a quantifiable sense, maximally different and therefore best span the whole set of feasible scenarios is described in Carlsen et al. (2015; 'Scenario Diversity Analysis'). RDM and Scenario Diversity Analysis have recently been combined and tested for a real case involving climate-resilient infrastructure for three African river basins (Carlsen et al. 2016). The idea of combining the self-consistency and diversity approaches has earlier been proposed by Kemp-Benedict (2012) but this has, however, yet to be done.

Of the qualitative approaches for developing scenarios, *Intuitive Logics* has become the dominating paradigm (Amer et al. 2013). In this approach no mathematical or system theoretical tools are used. Instead the method builds on expert opinion, intuition and/or brainstorming techniques. This approach is also the dominating paradigm in environmental and climate change research (Rounsevell and Metzger 2010), as exemplified by the SRES[4] storylines (Nakicenovic et al. 2000). This is also the method used in the storyline development in IMPRESSIONS where the qualitative part used *Intuitive Logics* which was complemented by quantitative input from modelling ('Story and Simulation' approach, Alcamo 2008 and Deliverable D2.2, Kok and Pedde 2016). In order to achieve the necessary

[3] In decision theory often called 'state space'. A scenario is called 'state of nature'.

[4] SRES – Special Report on Emissions Scenarios, a special report by the Intergovernmental Panel on Climate Change (Nakicenovic et al. 2000).

broad span discussed, this combination of approaches relies on using two 'key uncertainties' and associated polarities, usually identified with a combination of back-office analysis and stakeholder input.

The inset table in Figure 1 shows the basic structure for the stress-testing used in IMPRESSIONS. Since we are stress-testing existing policies against a range of scenarios covering the time period up until 2100 with three time-slices (present–2040, 2040–2070 and 2070–2100), we are naturally led into another central distinction, that between static and adaptive robustness (Walker et al. 2013). Here, static robustness stands for single-point decisions deploying policy measures well before the threats materialise. Adaptive robustness implies opting for a sequential decision strategy involving investment in preparatory measures and learning intended to deliver the capability of handling future uncertainty as it unfolds. One example where sequential decision-making has been employed in the context of climate change is the Thames Estuary 2100 Project (Ranger et al. 2013). It should be emphasised that the transition pathways (see Deliverable D4.2, Hölscher et al. 2017) needed for coping with high-end climate change will include elements of both static and adaptive robustness (see purpose B of the stress-testing above).

The chapter on "Foundations for Decision-Making" of Working Group 2 of IPCC's fifth assessment report (Jones et al. 2014) acknowledges robustness as an appropriate criterion for managing large uncertainties, but the chapter gives surprisingly little information on *how* a robustness test could be performed or how robustness could be operationalised in decision-making. The three chapters dedicated to adaptation (chapters 14-16, Jones et al. 2014) also provide no guidance on this. More details on robustness in the context of adaptation-related decision-making is provided by Hallegatte et al. (2012). Furthermore, we should point out that a decision-maker rarely considers *one* policy against a range of possible future outcomes. In almost all real situations, decisions are bundled together in "portfolios". This will be further elaborated upon in Section 4.

Finally, it is important to point to the strong link in the IMPRESSIONS project between this deliverable and Deliverable D5.1 'Evaluation of economic approaches under high-end scenarios' (Tinch et al. 2015). Task 5.1 considered the specific challenges related to appraising policy options in the context of high-end scenarios (HES). It showed that conventional methods of policy appraisal, such as cost-benefit analysis, were not suited to policy assessment in the context of HES because of the large uncertainties and non-linearities. Deliverable D5.1 concluded that there is a need to develop ways in which the impacts of near-term policies and decisions can be assessed, in terms of their long-term consequences. It also suggested that it is necessary to provide a structure that will help stakeholders and researchers compare radically different future scenarios and assess opinions regarding desirable and undesirable futures. These purposes are closely linked through the search for robust policy options – adaptation and mitigation choices that perform well under all scenarios.

This led to two conclusions of importance for stress-testing in the IMPRESSIONS project:

- Presenting policy appraisal in simple numerical terms risks giving a spurious, ultimately unhelpful, and even dangerous illusion of confidence or certainty;
- Finding 'optimal' policy solutions is unlikely under high-end scenarios. Hence, we focus more on aiding the process of reflection about the possible consequences of climate and socio-economic change and possible robust adaptation options for dealing with them.

Thus, in this deliverable we focus more on qualitative, than specific quantitative, results and we use them not to find 'optimal' solutions (the most robust[5] solution of all), but to engage in a discussion with stakeholders about the possible robust options.

2.2. Operationalisation in IMPRESSIONS

Two recent papers that are methodologically close to the method proposed here are Brown et al. (2015) and Jäger et al. (2015). The first paper (see also Brown et al. 2014) develops a stress-testing methodology for assessing the efficiency and robustness of different options for sustaining ecosystem services in the UK. The state space used was combined climate and socio-economic scenarios. The options were assessed (using a scale from -2 to +2) against different ecosystem service categories and in many case trade-offs were identified. The authors, furthermore, found that individual responses in isolation are unlikely to be robust across the scenarios and hence forming 'bundles' (*cf.* portfolios above) of options enhance their individual strengths (in some scenarios) and compensate for weaknesses (in other scenarios).

Jäger et al. (2015) also assessed policy robustness across sets of scenarios, with a focus on investigating whether the policies reduce vulnerability to climate and socio-economic changes. Ecosystem services were also assessed here. Adaptation policy options were first clustered (e.g. ecosystem-based adaptation and technology-based adaptation; *cf.* the discussion on portfolios above) and then these clusters were tested by calculating (with the CLIMSAVE IAP) the number of vulnerable people. Hence, in contrast to Brown et al. (2015), which was based on expert opinion, this is a model-based robustness assessment.

2.2.1. Qualitative assessment with stakeholders

The first part of the stress-testing was embedded within a process of stakeholder engagement, described in more detail in the reports from the stakeholder workshops (Deliverables D6A.2, Zellmer et al. 2016, and D6A.3, Faradsch et al. 2017). A qualitative stress-testing was carried out in the EU, Scotland, Hungary and Iberian case study workshops in 2016 (see also Deliverable D6A.3). The stakeholders were asked to assess whether a set of current policies would be effective within the context of a scenario. To provide an end-point for the assessment of policies, each case study produced a vision of "what they want the world to look like in 2100". The methodology for developing this vision is described in Deliverable D4.1 and the actual visions developed in each case study are described in Deliverable D4.2.

The qualitative stress-testing consists of four parts: (i) the set of existing policies; (ii) the vision for 2100; (iii) the set of scenarios; and (iv) a scoring method.

Existing policies: The overall purpose was to test *today's* policies (and/or strategies) against *future* changes in terms of climate and socio-economic changes, the (implicit) hypothesis being that today's set of policies are not adequate for dealing with the challenges associated with high-end scenarios. At the same time, another hypothesis is that these policies, in some cases, have elements (actions/strategies) that could be included in pathways to support the achievement of the vision.

[5] In Section 4 *different* robustness metrics are discussed.

The policies to be tested were identified in each of the case studies. The policies should be related to the focus areas of each case study, so, for example, the Scottish policies that were tested related to land use (agriculture and forestry), water resources and biodiversity.

Vision: As mentioned above, the vision provides an end-point for the stress-testing. The visions created by each case study consist of a narrative and a visual representation. Figure 2 shows an example of a case study vision developed before the workshop in 2016. It shows the main elements of the vision of "the world we want in 2100". Some of the sub-elements of the vision can be related to current policies and thus used as an endpoint for assessing the effectiveness of policies in each scenario.

'Integrated' socio-economic and climate scenarios: The scenarios used for stress-testing were developed within the IMPRESSIONS project (Deliverables D2.2, Kok and Pedde 2016, and D2.3, Sloth Madsen et al. 2016). At each case study workshop in 2016 there were four groups, each working within the context of a combination of a climate scenario (based on RCP4.5 or RCP8.5; Sloth Madsen et al. 2016) and a socio-economic scenario (based on SSP1, SSP3, SSP4 or SSP5; Kok et al. 2016) as shown below:

- Group A: SSP1 and RCP4.5
- Group B: SSP3 and RCP8.5
- Group C: SSP4 and RCP4.5
- Group D: SSP5 and RCP8.5

Scoring method: There exists a myriad of methods for valuing cost and benefits of decisions, or policies under certain state of nature (see the comprehensive review by IMPRESSIONS Deliverable D5.1; Tinch et al. 2015). At one end of the spectrum we have fully qualitative assessments and on the other end we find rather sophisticated mathematical tools relying on precise estimates of, for example, monetary expressions of all cost and benefits and probabilities for each state of nature as well as discounting rates. In the review in D5.1 methods are divided into economic tools and non-probabilistic approaches.

The complexity of valuation methods was one aspect to take into account when deciding on a scoring system for the IMPRESSIONS stress-testing, with another being the degree of comparability between the case studies. It was first suggested that all case studies should follow a very simple cardinal scale from very negative (-2), negative (-1), neutral (0) to very positive (+2) (cf. Brown et al. 2015 and Brown et al. 2014), where the terms ('very negative', 'negative' etc.) need to be related to some objectives; all valuations are about achieving some objectives and two objectives were considered:

(i) Its (the policy's) own objectives;
(ii) Its contribution to achieving the vision.

The first objective (i) can be identified from the policies themselves, or from some other higher level objectives in the case study context. The second objective is related to the vision developed for each of the case studies (Figure 2).

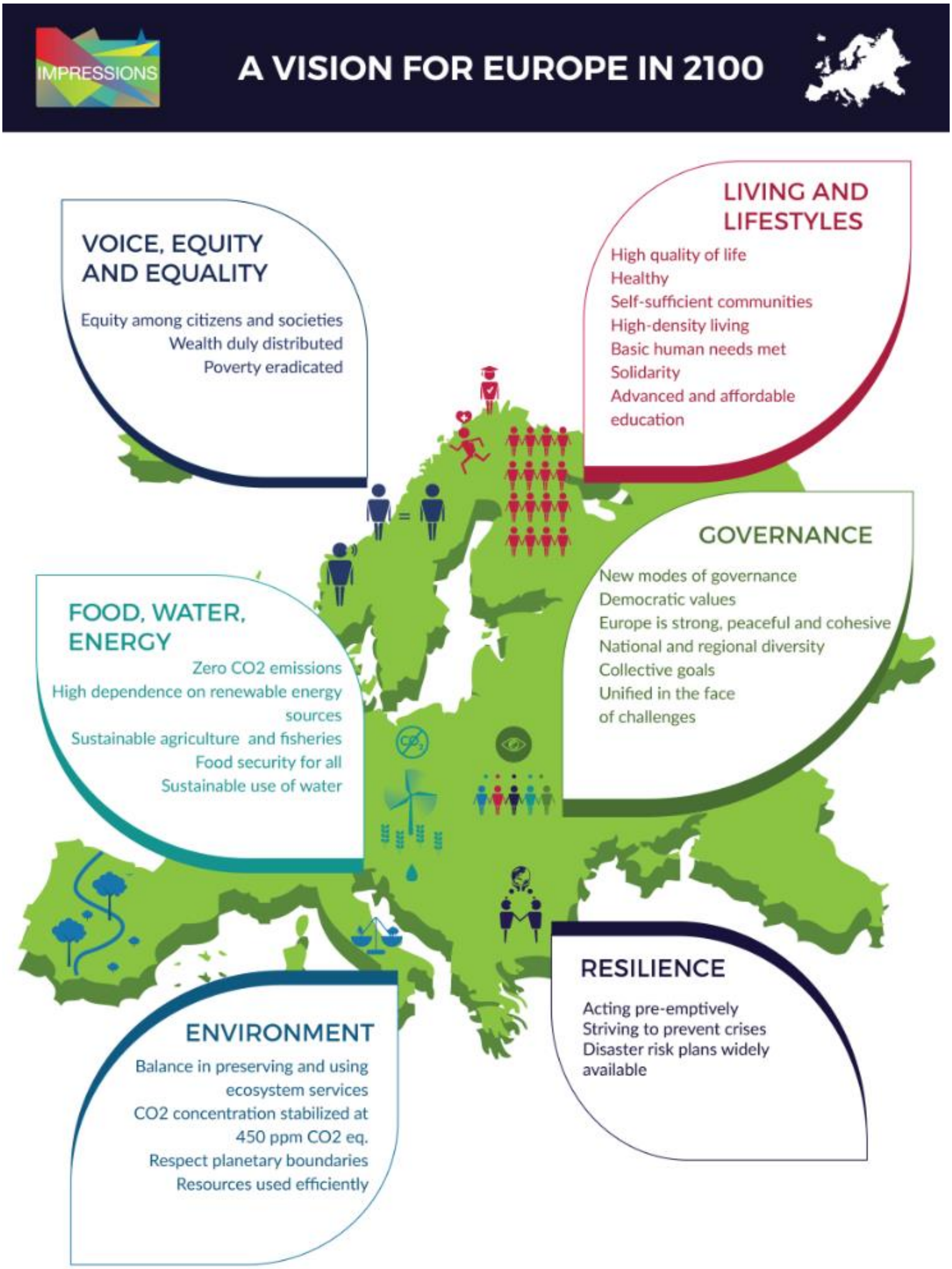


Figure 2: The vision for the EU developed by stakeholders before the Workshop in 2016.

The quantitative scoring method against the objectives of the policy was tested in the EU case study, whose stakeholder workshop was held first out of all the case studies. Based on the evaluation of this approach by the stakeholders and the project team, the three subsequent regional case study stakeholder workshops used a qualitative assessment method where the policies were tested against the vision (see section 3).

2.2.2. Quantitative assessment using the Integrated Assessment Platform (IAP2)

For the EU case study, it was possible to carry out a quantitative assessment using the IAP2. The IAP2 is a further development of the IAP developed in the EU-funded CLIMSAVE project (www.climsave.eu). The further development has included extending the time coverage to 2100, including the new climate and socio-economic scenarios and updating meta-models that are used. The IAP2 is an interactive, web-based modelling platform that can be used to investigate climate change impacts, vulnerability and adaptation across multiple sectors. It includes a series of meta-models for the urban, agriculture, forestry, water, coastal and biodiversity sectors, which are interlinked to capture cross-sectoral interactions (Harrison et al. 2015; 2016). For the EU case study in the IMPRESSIONS project, we have used the version that operates at a 10 arcmin x 10 arcmin resolution for the European Union (plus Norway and Switzerland). Figure 3 shows a screen shot of the IAP2 highlighting the scenario selection process for IAP2 runs.

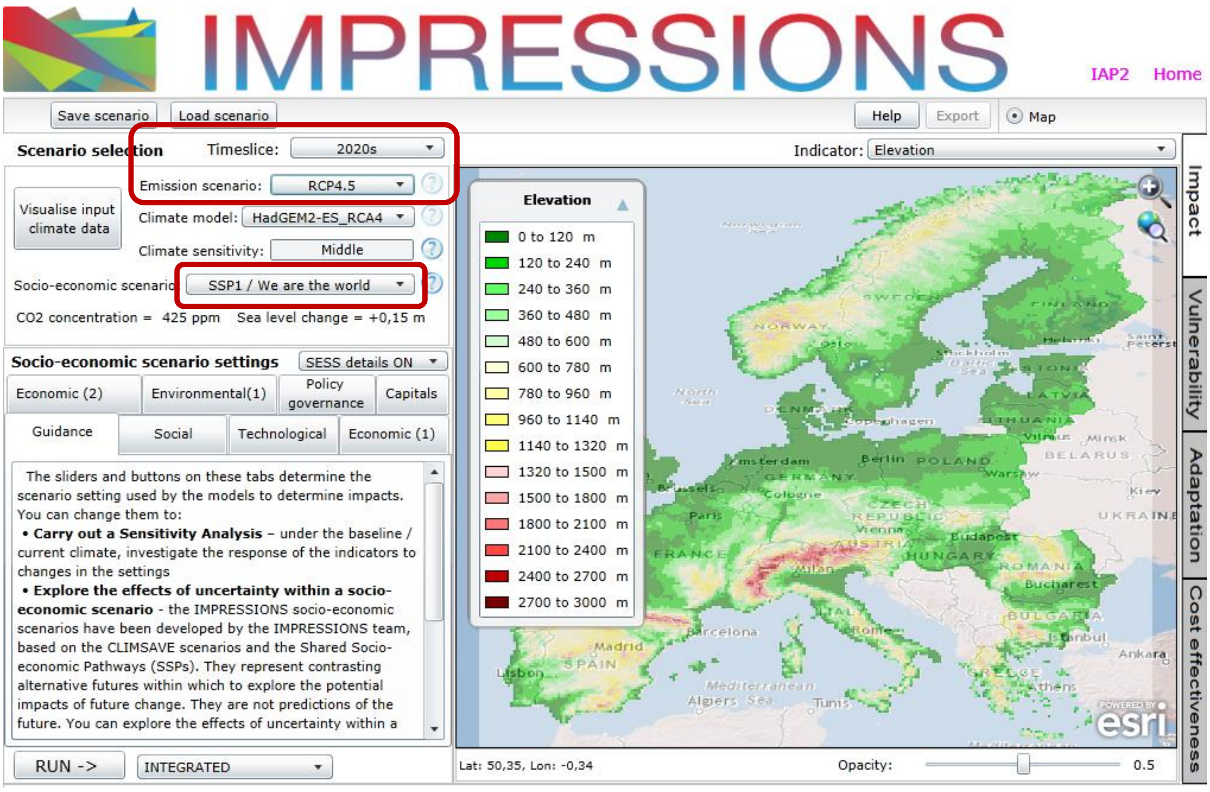


Figure 3: The IAP2 interface ("Impacts" screen) used in the IMPRESSIONS stress-testing exercise for the EU case study. The user can select the time-slice (2020s, 2050s, 2080s), the emission scenario (RCP4.5, RCP8.5) and the socio-economic scenario (SSP1, SSP3, SSP4, SSP5) and then run the IAP2. Climate model and climate sensitivity were held constant during all the runs (Climate model = HadGEM2-ES_RCA4; Climate sensitivity = Middle).

The IAP2 calculates the vulnerability to climate and socio-economic change for selected scenarios with and without adaptation measures, so that the effect of policy measures can be quantified. Figure 4 shows the vulnerability screen for one scenario and one time-slice, illustrating the results that are used in this deliverable for quantitative stress-testing. The results were presented to stakeholders at the EU case study meeting in May 2017.

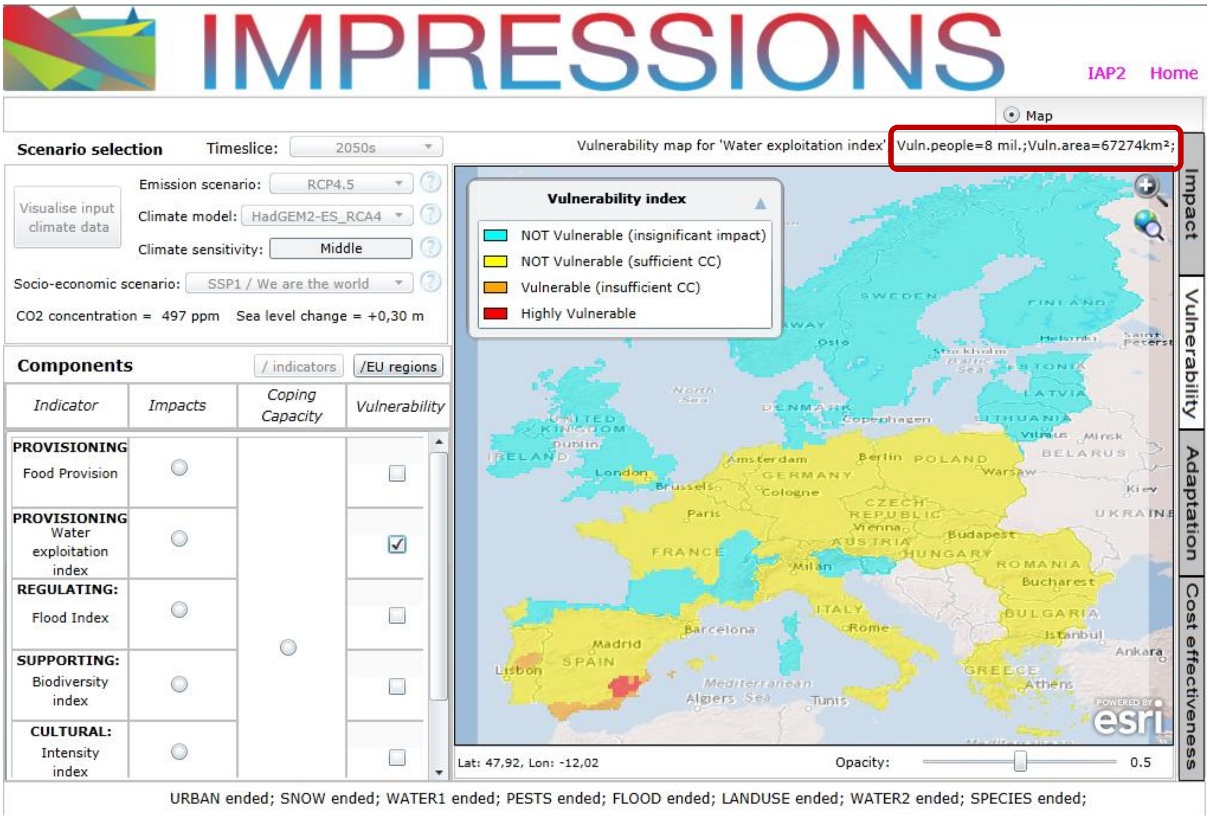


Figure 4: Screen-shot from IAP2 showing the vulnerability screen for SSP1, RCP4.5 and the 2050s time-slice. In this case the map shows the vulnerability of the water exploitation index. The number of vulnerable people and the vulnerable area are shown on the right-hand side above the map; these results are used in the stress-testing.

3. Stress-testing with stakeholders

The first stage of the work included stress-testing in four of the IMPRESSIONS case studies with stakeholders in workshops. The European case study used a slightly more complicated set-up compared to the other three later workshops. Evaluations from the EU session indicated that the session was experienced as somewhat complicated and time-constrained. These experiences from the first workshop were used to simplify the process for the three regional workshops. The process was substantially modified and the most important change was that the stakeholders did not test against the objectives of the policies, but instead the effectiveness in achieving the vision developed for each case study was tested within the context of each input scenario. These changes resulted in a better process according to stakeholder evaluations.

3.1 European case study

Three European-level policies were used in the stress-testing:

- **The Common Agriculture Policy** (**CAP**) (using scenarios SSP1, SSP3, SSP4 and SSP5)
- **Habitat Directive** (using scenarios SSP1 and SSP5)
- **Floods Directive** (using scenarios SSP3 and SSP4)

For each of the policies a set of policy measures were identified prior to the workshop. When making the final selection of policy measures the following criteria were used as a guiding principle for selection: (i) relevance to adaptation; (ii) relevance to the case studies' thematic focus; (iii) cross-sectoral measures included in the choices if available; and (iv) ability to measure the success of the policy measure.

CAP comprises two "pillars". The first pillar is support to farmers' incomes. This support is provided in the form of direct payments and market measures and is entirely financed from the European Agricultural Guarantee Fund. The second pillar is the support provided for the development of rural areas. This support takes the form of Rural Development Programmes and is co-financed from the European Agricultural Fund for Rural Development.

The objectives for CAP have been the same since the 1960s[6]. The first objective was to increase productivity, by promoting technical progress and ensuring the optimum use of the factors of production, in particular labour. The second objective was to ensure a fair standard of living for the agricultural community. The third was to stabilise markets and the fourth was to secure the availability of supplies and to provide consumers with food at reasonable prices. After a reform in 2013 CAP is now focused on three long-term objectives[7]: viable food production, sustainable management of natural resources, and climate action and balanced territorial development.

To achieve the long-term objectives for the CAP, the reform focused on the competitiveness and sustainability of the agricultural sector by improving the targeting and efficiency of policy instruments. The objective of past reforms to enhance the market orientation of EU agriculture is continued by adapting the policy instruments to further encourage farmers to base their production decisions on market signals. Given the pressure on natural resources, the EU argues that agriculture has to improve its environmental performance through more sustainable production methods and farmers also have to adapt to challenges stemming from changes to the climate by pursuing climate change mitigation and adaption actions (e.g. by developing greater resilience to disasters such as flooding, drought and fire).

The following six policy measures were identified prior to the EU workshop:

- CAP1: Maintaining permanent grassland (not rotational grassland, usually less intensive/productive for sheep, tends to have more biodiversity and soil carbon);

[6] Article #39 of the "Consolidated Version of the Treaty of the Functioning of the European Union".

[7] EU COM (2010) 672 FINAL: The CAP towards 2020: Meeting the food, natural resources and territorial challenges of the future.

- CAP2: Crop diversification (farmers cannot completely economically optimise their crop choice, more rotations, better for soil/biodiversity, small effect on farm incomes);
- CAP3: Increase in ecological focus area (small areas meant to improve biodiversity, e.g. buffer strips, hedgerows);
- CAP4: Integrated farm management and organic agriculture (more holistic);
- CAP5: Preservation of landscape (income support to maintain cultural landscapes; to stop abandonment);
- CAP6: Conservation of high-value habitats.

The **Habitat Directive**[8] (together with the Birds Directive) forms the cornerstone of Europe's nature conservation policy. It is built around two pillars: the Natura 2000 network of protected sites and the strict system of species protection. The directive protects over 1000 animal and plant species and over 200 so called "habitat types" (e.g. special types of forests, meadows, wetlands), which are of European importance. The objectives for the directives are: (i) good conservation status for species; and (ii) good conservation status for habitats.

The policy measures tested in the EU workshop were:

- Habitat 1: Reintroduction of native flora and fauna species;
- Habitat 2: Control invasive species;
- Habitat 3: Expansion of Natura 2000 areas;
- Habitat 4: Restoration of degraded land.

The **Floods Directive**[9] on the assessment and management of flood risks entered into force in 2007. This directive requires Member States to map the flood extent, assess if all water courses and coastlines are at risk from flooding in these areas, and evaluate the assets and humans at risk from flooding. It further requires EU Member States to take adequate and coordinated measures to reduce these risks. The directive also reinforces the rights of the public to access this information and to have a say in the planning process.

The purpose of the directive is to establish a framework for the assessment and management of flood risks, aiming at the reduction of the adverse consequences of floods, especially with regards to human health, the environment, cultural heritage, economic activity and infrastructure.

The policy measures for the Floods Directive tested in the EU workshop were:

- Floods 1: Relocation from flood-prone areas;
- Floods 2: Building codes and legislation;
- Floods 3: Floodplains and flood control;
- Floods 4: Restoration of wetlands;
- Floods 5: Limitation of urbanisation;
- Floods 6: Reducing river flow into artificial or natural drainage systems;

[8] COUNCIL DIRECTIVE 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora.

[9] Directive 2007/60/EC on the assessment and management of flood risks in all available languages (OJ L288, 6.11.2007, p.27)

- Floods 7: Reforestation of river banks;
- Floods 8: Modification or removal of water retaining structures.

In each scenario group, the complete list of policy measures for the three policies was considered and an evaluation was made of the effect of measure *n* on the respective objectives of the policy using the scoring system *Very negative* (-2), *Negative* (-1), *Neutral* (0), *Positive* (+1) and *Very positive* (+2). The results are shown in Table 1. For the CAP measures, none were positive over all scenarios. For the Habitats Directive, measure 2 (Control invasive species) was assessed positively in the two scenarios (SSP1 and SSP5) that considered this measure. For the Floods Directive, measures 2 (Building codes and legislation), 3 (Floodplains and flood control) and 7 (Reforestation of river banks) were assessed positively in the two scenarios (SSP3 and SSP4) that considered these measures.

Table 1: Results of quantitative assessment of selected policy measures for the three chosen policies. The scale goes from -2 (*Very negative*), via 0 (*Neutral*) to +2 (*Very positive*). Not all policy measures were assessed in all scenarios.

POLICY MEASURE	SSP1	SSP3	SSP4	SSP5
CAP 1	+2	0	0	+1
CAP 2	-	+1	+1/+2	0
CAP 3	+2	0	0/+1	0
CAP 4	+2	+1/+2	0/-1	+2
CAP 5	-1	0	+1	+1
CAP 6	-	0/+1	+1/+2	0
Habitat 1	-			0
Habitat 2	+2			+1
Habitat 3	0			-1
Habitat 4	+2			-1
Floods 1		+2/-2	+1/+2	
Floods 2		+1	+2	
Floods 3		+2	+2	
Floods 4		-1/+1	0/+1	
Floods 5		0	-	
Floods 6		+2	-	
Floods 7		+2	+1	
Floods 8		+2/-2	+1/+2	

In addition to the quantitative results in Table 1, the workshop also generated qualitative comments and responses.

For **SSP1** (which is coupled with the RCP4.5 climate scenario), the CAP is very relevant and this leads to high scores for four of the measures (CAP1, 3 and 4; see Table 1). For the policy measure '*Preservation of the landscape*' (CAP5), the stakeholders commented that this is more about stopping intensification than abandonment, so they thought the policy measure would be less effective. For the Habitats Directive, two of the measures scored high (Habitat 2 and 4) but for the '*Expansion of Natura 2000 areas*', the stakeholders noted that while this would be an interesting objective, there would be a need to redefine the areas due to climate change.

In **SSP3** (which is coupled with the RCP8.5 climate scenario), the CAP measure that was judged to be most effective was '*Integrated farm management and organic agriculture*' (CAP4) because it is a financial incentive ("if you do these things you receive money"). For the Floods Directive, '*Restoration of wetlands*' (Floods 4) received mixed scoring because the stakeholders noted that there would be strong regional differences with "negative impacts in southern regions and positive in northern". Similarly, for the measure Floods 8 regional differences were noted: "For some areas it is a good thing to remove it, for others not, e.g. flood risk". The measure on '*Limitation of urbanisation*' (Floods 5) was deemed to be ineffective because "Population is going down in this scenario, so the pressure on urbanisation would be less".

For **SSP4** (which is coupled with the RCP4.5 climate scenario), the stakeholders felt that there is no incentive to maintain grassland (CAP1), thus giving that measure a score of 0. Crop diversification (CAP2) is "extremely effective" in this scenario, while '*Increase of ecological focus area'* (CAP3) is "not yet a major interest". It was felt that '*Integrated farm management and organic agriculture'* (CAP4) are incompatible with this scenario "which is more about technology, more accepting of pesticides". Overall for the CAP, the stakeholders noted that for most of the measures the effectiveness will depend on the interest of the elite in buying and managing the land. The Floods Directive measures are all effective in SSP4, but the stakeholders noted that some of them would only be effective in the longer term.

In **SSP5** (which is coupled with the RCP8.5 climate scenario), the stakeholders thought that the CAP is valuable "to counter-act the damage done in this scenario". For '*Crop diversification'* (CAP2) they felt that "this measure is effective under specific conditions only, but there is no certainty on the availability of these conditions", so the score was 0. For '*Conservation of high-value habitats'* (CAP6) it was pointed out that "people do not care about the environment" in this scenario and the economic drivers behind this measure are small. For the Habitats Directive, only the measure on '*Control of invasive species'* (Habitat 2) was felt to be effective. The other measures were deemed ineffective because they are not tackling the root causes of the problem or because they might work in some areas but not in others.

3.2 Scottish case study

Four policies areas were tested with stakeholders at the case study workshop in Stirling in 2016:

- **Land Use Strategy** (using scenarios SSP1, SSP3, SSP4 and SSP5)
- **Biodiversity strategy** (using scenarios SSP1 and SSP3)
- **Water management** (using scenarios SSP1, SSP3, SSP4 and SSP5)
- **Flood management** (using scenarios SSP1 and SSP4).

The Scottish Government's **Land Use Strategy (v2)**[10] has three objectives: (i) to encourage land-based businesses to work 'with nature' to contribute more to Scotland's prosperity; (ii) to promote the responsible stewardship of Scotland's natural resources to deliver more benefits to Scotland's people; and (iii) to enhance urban and rural communities to better connect to the land, with more people enjoying the land and positively influencing land use.

[10]https://consult.scotland.gov.uk/land-use-and-biodiversity/land-use-strategy-for scotland/supporting_documents/Land%20Use%20Strategy%202016%20%202021%20consultation%20FINAL%202.pdf

The following policy measures were selected for the Land Use Strategy:

- Land use 1: promote an ecosystem approach to managing our natural capital;
- Land use 2: Develop models and Geographic Information System (GIS) tools to enable assessments of land use/management change;
- Land use 3: Develop regional land use frameworks for rural areas;
- Land use 4: Facilitate the step change to climate friendly farming and crofting;
- Land use 5: Promote increasingly integrated land use;
- Land use 6: Utilise more localised map-based ecosystems assessments to inform funding decisions.

The Scottish Government has published two strategy documents: '2020 Challenge for Scotland's Biodiversity' and 'Scotland's Biodiversity: It's in Your Hands'. Together these comprise the **Scottish Biodiversity Strategy**. The Nature Conservation (Scotland) Act 2004 requires the government to report on progress with the strategy every three years. The Scottish Biodiversity Strategy has three objectives[11]: (i) to protect and restore biodiversity on land and in our seas, and to support healthier ecosystems; (ii) To connect people with the natural world, for their health and wellbeing and to involve them more in decisions about their environment; and (iii) to maximise the benefits for Scotland of a diverse natural environment and the services it provides, contributing to sustainable economic growth.

The following policy measures were selected for the Biodiversity Strategy:

- Biodiversity 1: Multi-agency collaboration at the catchment-scale across Scotland;
- Biodiversity 2: Full account of land use impacts on ecosystems services;
- Biodiversity 3: Management of protected places for nature that also provides wider public benefits;
- Biodiversity 4: Ecosystem approach to land management;
- Biodiversity 5: ‘High Nature Value’ farming and forestry;
- Biodiversity 6: Restore and extend natural habitats as a means of building reserves of carbon.

For **water management** and **flood management**, the main objectives considered were taken from the Scottish Climate Change Adaptation Programme (SCCAP). This is the overarching programme in Scotland that covers adaptation. It requires adherence by both government and non-government bodies to the actions set out in the programme. The aim of the SCCAP is to increase the resilience of Scotland’s people, environment and economy to the impacts of a changing climate. The SCCAP has seven objectives that relate to water and flood management and for which various organisations are responsible, including the Scottish Environment Protection Agency (SEPA), Scottish Water, Local Authorities, Ordnance Survey, public and private sector bodies and land managers. These are listed below and are also addressed in SEPA’s Flood Risk Management Strategies and also in the climate change and carbon management appendix to Scottish Water’s Business Plan 2015-2021, which set out some of the policy objectives and actions that are being taken by SEPA and Scottish Water to address climate change.

[11]http://www.gov.scot/Topics/Environment/Wildlife-abitats/biodiversity/BiodiversityStrategy

The relevant objectives are: (i) to understand the effects resulting from climate change and their impacts on the natural environment; (ii) to understand the risks associated with coastal flooding through development and implementation of local flood risk plans; (iii) to develop datasets to support flood risk, river and coastal management; (iv) to support a healthy and diverse natural environment with the capacity to adapt; (v) to implement River Basin Management Plans, (vi) to support the development of Local Flood Risk Management Plans; and (vii) to improve the condition of Special Areas of Conservation as part of River Basin Management Plans.

The following policy measures were selected for Water management and Flood management:

- Water 1: Improve our understanding of water flows in key zones by integrating climate models into water resource plans;
- Water 2: Improve our monitoring of raw water to understand quality impacts;
- Water 3: Invest in further monitoring of wastewater catchments to understand climate impacts;
- Water 4: Update our assessments of risk from climate change and contribute to Scotland's Climate Risk Assessment;
- Flood 1: Undertake catchment-wide Strategic Flood Risk Assessments to inform development plan allocations;
- Flood 2: Undertake an annual assessment of planning advice and its contribution to flood risk;
- Flood 3: Progress exemplar projects that demonstrate the potential for land use planning to mitigate surface water flooding and contribute to wider environmental benefits;
- Flood 4: Maintain flood protection schemes.

In each scenario group at the workshop, the above lists of policy measures were considered (six for land use; six for biodiversity; four for water management and four for flood management). The key question was whether these policy measures would help to achieve the Scottish case study vision for 2100. As can be seen in the example flip chart for SSP3 (Figure 5), this gave answers "Yes", "No" and "Partially" and stimulated discussion on the extent to which today's policies need to be modified for possible futures.

The results of the qualitative assessment are presented in Table 2. For the land use policy measures, only one of the measures (Land use 2: Develop models and Geographic Information System (GIS) tools to enable assessments of land use/management change) was assessed positively in all scenarios. The biodiversity measures were assessed in the SSP1 and SSP3 groups and while they were all assessed positively in SSP1 (Mactopia), it was felt that the measures would not help to achieve the vision, or only partially help, in SSP3 (Mad Max). For water measures, two of the measures had a positive assessment in all scenarios, except SSP3 (Water 1: Improve our understanding of water flows in key zones by integrating climate models into water resource plans and Water 3: Invest in further monitoring of wastewater catchments to understand climate impacts).

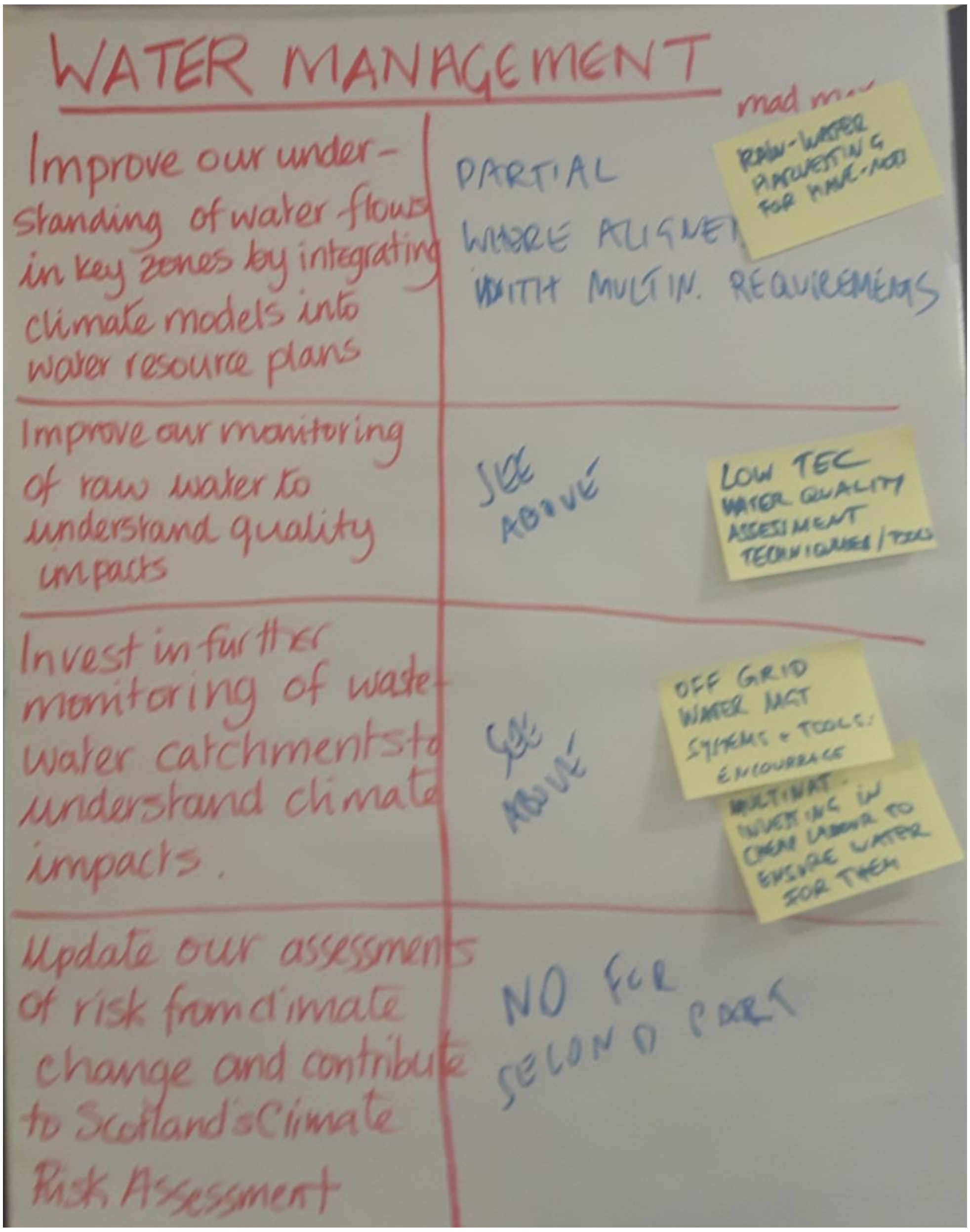


Figure 5: An example from the discussions of SSP3 at the Scottish Workshop. The left-hand side shows the measures tested. The right-hand side shows the assessment made by the stakeholders of whether the measure would achieve the vision. The yellow 'post-its' indicate new measures that were proposed as a result of the discussions, to be included in the SSP3 Pathways.

The group working on SSP1 noted that all of the measures were compatible with the scenario, since they are government-led initiatives that fit well with the storyline. In the other scenarios, some of the policy measures were assessed to be "partially" effective in achieving the vision. This is generally because only some of the actors would implement the measures or because only particular time-slices would be relevant. For example, for the measure "Promote an ecosystem approach to managing our natural capital", SSP4 noted that in the scenario storyline, there is a gradual decline in the government's commitment. In the first time-slice, there is a sustainable approach, respecting the natural environment, but towards the end of the century this might not be in the interest of the rich elite. In SSP3, for the measure "Undertake catchment-wide strategic flood risk assessments to inform development plan allocations", the participants agreed that this would only be relevant for companies as part of the business practice.

For SSP1 (which is coupled with the RCP4.5 climate scenario), in addition to noting that all measures are relevant, the focus of the discussion was on the implications of the measures. For example, in the case of "Use localised land use assessment tool to inform funding", the participants discussed where the funding would come from in this scenario and concluded that it would not necessarily be government funding. For the measure "Undertake catchment wide strategic flood risk assessment to inform development plans", the participants noted that cross-boundary agreements would need national facilitation between cross-boundary organisations, which is feasible in SSP1 (Mactopia) because of strong government regulation.

For **SSP3** (which is coupled with the RCP8.5 climate scenario), many of the comments pointed to the overriding role of the multinationals in this scenario. The multinationals could be interested in implementing some of the measures, but only if they support the ultimate goal of making more money. For example, the multinationals could use GIS heavily to manage land but they won't necessarily be using it for benefit for society. In this scenario, nobody will pay for research unless the multinationals are paying for it for their own gains. Full accounting of land use on ecosystem services would be taken up by multinationals, if it were focussed on their needs. Similarly, ecosystem services would be considered inasmuch as they contribute to corporate benefit not for social or environmental reasons. The management of protected places would be implemented to take care of the "playgrounds" of the 'haves', where they go for shooting or looking at nature, but not to provide wider public benefits. Lastly, manpower is cheap in this scenario, so monitoring could be reduced in cost, but again any monitoring would be focussed on what the 'haves' need to know.

For **SSP4** (which is coupled with the RCP4.5 climate scenario), the participants noted that for the measure "Develop models and GIS to assess land use and management change", the GIS tools would help the development of other measures and the use of such tools fits with the high-tech nature of this scenario, but it is not clear what would be done with the data unless individual millionaires had an incentive to use them. For the water management measures they pointed out that because water is rapidly privatised in this scenario, the policy measures would not contribute much to achieving the vision; responsible water management would only happen where water is a commodity. Similar to the discussion of some other measures, for the measure "Undertake an annual assessment of planning advice and its contribution to flood risk", it was questioned whether there would be any incentive for the elite (rich) to undertake this.

For **SSP5** (which is coupled with the RCP8.5 climate scenario), many of the environmental protection measures would not be taken up because in this scenario natural capital is exploited and environmental protection is not a priority. Resources are extracted and used to make a profit. The government would map where the resources are, but not in order to protect them. Along the same lines, this scenario is not interested in "climate friendly" measures. Water management is undertaken, but not because of a vision of "responsible water use", the aim is to have good water quality for people but not necessarily for the environment. Hence, monitoring water quality is justified because it supports planning ahead and improving the cost-efficiency of capital investment for water treatment which may be needed when water quality gets worse.

Table 2: Results of qualitative assessment of selected policy measures for the four policies in the Scottish Case Study. Not all policy measures were assessed in all scenarios.

POLICY MEASURE	SSP1	SSP3	SSP4	SSP5
Land use 1	Yes	Yes	Partial	No
Land use 2	Yes	Yes	Yes	Yes
Land use 3	Yes	No	No	Yes
Land use 4	Yes	Yes	Partial	No
Land use 5	Yes	No	--	Yes
Land use 6	Yes	Partial	Yes	No
Biodiversity 1	Yes	No		
Biodiversity 2	Yes	Partial		
Biodiversity 3	Yes	Partial		
Biodiversity 4	Yes	No		
Biodiversity 5	Yes	Partial		
Biodiversity 6	Yes	No		
Water 1	Yes	Partial	Yes	Yes
Water 2	Yes	Partial	No	No
Water 3	Yes	No	Yes	Yes
Water 4	Yes	Partial	Partial	Yes
Flood 1	Yes		Partial	
Flood 2	Yes		No	
Flood 3			Partial	
Flood 4			Partial	

3.3 Hungarian case study

The Hungarian case study focuses on two local communities, Szekszárd and Veszprém, and three major topic areas: urban and agriculture land use, water availability and human health. Due to the relatively small scale of the case study, the stress testing exercise carried out at the second stakeholder workshop in Veszprém in 2016, focused on one of the two communities only – Szekszárd – and two policy areas – water management and health.

There is no one comprehensive water management strategy in Szekszárd, but there are national and local strategies that have a water aspect (e.g. the National Water Strategy, the Economic Development Strategy of Tolna county, the Urban Development Concept of Szekszárd, the Sustainability Strategy of Szekszárd, the Water Damage Protection Plan of Szekszárd).

Policy measures for the health sector were taken from the Health Development Plan of Szekszárd. Tables 3 and 4 show the policy measures that were selected for the stress-testing exercise.

Table 3: Water policy measures used for stress-testing in the Hungarian case study workshop.

Policy area	Policy measures
Water management	1. Improve water retention capacity of the surface and soil
	2. Minimal erosion of hillsides
	3. Minimal standing water in flat areas
	4. Reduction of damage caused by extreme precipitation events
	5. Construction and maintenance of drainage ditches
	6. Construction of rainwater storage reservoirs

Table 4: Health policy measures used for stress-testing in the Hungarian Case Study workshop.

Policy area	Policies measures
Health	1. Reduction and addressing the harmful impacts of heat stress for the population, flora and fauna (domestic and wild)
	2. Improve climate risk related awareness and adaptive capacity of the population and relevant enterprises
	3. Improve the climate stress related response capacity of the healthcare system
	4. Engagement of the part of population most exposed to heat stress (elderly, singles, the sick, families with many children, etc.) in local emergency response plan
	5. Development of the knowledge of the population related to safe exposure to sunshine
	6. Reduction in the number of skin pathologies and death related to sunburn

At the workshop, stakeholders were asked whether the above policy measures could be effective in achieving the vision for Hungary in the context of a specific scenario. Below is summary of comments for each SSP.

SSP1 (coupled with the RCP4.5 climate scenario)**:** Water management in general was viewed very optimistically. Water retention (#1) and water drainage (#5) were identified as two key elements to be better regulated in the future. Stakeholders suggested to increase individual responsibility in implementing policy measures. For example, they proposed that the current water drainage system should be paired with individual, home-based solutions. This would help to cope better with extreme events in the long-term.

According to stakeholders, heat stress (#1) is the most important issue to tackle as it relates to all other policy measures on health. Although in SSP1 people are generally healthy, stakeholders identified 'prevention' (both at the individual and institutional level) as an element that should be emphasised in all policy measures. They also listed a series of preventive measures (e.g. expanding green areas, improving housing regulations, developing warning systems, educating lifestyle change, optimising shading and ventilation, investing in technology) that should be included in the long-term strategy on health. Similarly to water management, stakeholders emphasised the role of individual actions and suggested community-based policy-making and implementation.

SSP3 (coupled with the RCP8.5 climate scenario)**:** All six policy measures on water will be crucial in SSP3. Since precipitation is expected to be distributed unevenly throughout the year, improving rain water storage capacity (#6) will be essential. Water rentention capacity (#1) and erosion of hill-sides (#2) is already problematic, therefore, stakeholders suggested that land use should be optimised in the long-term. For example, instead of planting crops, the hilly countryside should be reforested to reduce erosion and increase water retention capacity.

For health, in general, all of the policy measures fit well within SSP3, except #3 on improving the climate stress-related response capacity of the healthcare system. Stakeholders mentioned that currently the healthcare system is neglected and not ready to cope with climate stress. Furthermore, in SSP3 there is no healthcare system to invest in. Individual survival mechanisms should be developed (such as storing emergency survival kits at home) as people can only count on themselves.

Tackling heat stress (#1) is the most important issue, as well as raising climate awareness and coping capacity (#2). However, there will not be a national heat warning system or emergency response plans in place in this scenario, therefore people should organise themselves. Families should develop their own coping methods (e.g. through adapting their diet, their housing and surroundings). Similarly, knowledge related to safe exposure to sunshine (#5) should start at the individual and local level, and therefore the policy measure should be adapted accordingly.

SSP4 (coupled with the RCP4.5 climate scenario)**:** In general, all of the policy measures fit the scenario. The major issue within SSP4 is the gap between the rich and the poor and this is also true for policy-making. Current policies do not account for this divide, therefore, this is something to improve in both the water management and health strategies. The rich will have the funds to implement adaptive measures for their own benefit, but the question remains on what will be left for the 'have-nots'. Stakeholders proposed that through sensitising the rich, the rich-poor divide could be reduced. The main goal therefore is the reduction of social differences and this should be reflected at the policy level as well.

SSP5 (coupled with the RCP8.5 climate scenario)**:** In general all policy measures on water are compatible with and should run throughout the scenario. Under SSP5, water shortages and extreme precipitation events will vary, therefore, policy measures should also adapt to larger and increasing extremes. Stakeholders also listed a series of concrete recommendations, such as reforestation, planting climate resistant crops, improving the current infrastructure, the multifunctional use of space and facilities, capacity building, awareness raising and the use of traditional knowledge.

As for health, improving climate risk related awareness and the adaptive capacity of the population and relevant enterprises (#2) was identified as the most important measure. Stakeholders argued that the success of all other measures depend on this one. If people are sufficiently educated, they will then be able to better cope with and adapt to climate extremes. Therefore they suggested that awareness-raising should be a fundamental part of all policy measures from the very beginning.

3.4 Iberian case study

At the Iberian case study workshop in Toledo in 2016 two policies were tested: the EU Water Framework Directive (WFD) and the Common Agricultural Policy (CAP). In the four scenario groups a discussion was then held on how policy measures of these broader policies would fare in the respective scenario, followed by an identification of responses for each.

The **Water Framework Directive** was established in 2000 to develop a common EU water policy aimed at achieving good quality and quantity status of all EU water bodies by 2015. The directive introduced the concept of Water Districts, not defined by political boundaries but by river catchments/basins. It includes both surface and groundwater and also waters one nautical mile from the shore. It entails strengthening cooperation between various Member States of trans-boundary river basins via River Basin Management Plans (RBMP) to be updated every 6 years.

The measures considered in the Iberian case study workshop were:

- WFD 1: Current implementation of systems of incentives and sanctions to ensure minimal ecological flows and good quality status of the River Basin and prevent non-compliance;
- WFD 2: Joint planning and management of international river basins between Portugal and Spain;
- WFD 3: Integration of climate change scenarios when taking account of long-term planning and management of water supply and demand. Assessment of options that are robust to the uncertainty in climate projections;
- WFD 4: Implementation of participatory processes at river basin level.

The **Common Agricultural Policy** is described above as it was also used in the EU case study workshop (Section 3.1). The measures considered in the Iberian case study workshop for CAP were[12]:

- CAP 7: Increasing access to water resources for farmers (e.g. by building dams);
- CAP 8: Development of agri-environment and climate measures including the support for organic farming, via the Organic Farming Scheme and direct payments to farmers;
- CAP 9: Farm and land-use diversification;
- CAP 10: Reducing GHG from livestock production and fertiliser use and increasing carbon sink potential from agro-forestry activities.

Overall, the results of this qualitative assessment show that for CAP, the measures are deemed to work in the SSP1 and SSP4 scenarios, but only partially in SSP3 and SSP5, where the stakeholders noted that the measures would only work until 2040 (see Table 5). For the WFD measures, the measure that works in most scenarios is "Joint planning and management of international river basins between Portugal and Spain" (WFD 2), which cannot work in SSP3 due to the fragmentation of a world of regional rivalry.

[12] The measures considered for the Iberian case study were different from those considered in the EU case study, see Section 3.1.

Table 5: Stakeholder qualitative assessment of how the selected measures of current policies (Common Agricultural Policy, CAP) and (Water Framework Directive, WFD) would work in the 4 IMPRESSIONS socio-economic scenarios.

POLICY MEASURE	SSP1	SSP3	SSP4	SSP5
CAP 1	Yes	Partial	Yes	Partial
CAP 2	Yes	Partial	Yes	Partial
CAP 3	Yes	Partial	Yes	Partial
CAP 4	Yes	Partial	Yes	Partial
WFD 1	Yes	No	Yes	No
WFD 2	Yes	No	Yes	Yes
WFD 3	Yes	No		
WFD 4	Yes	No		No

Specific comments by stakeholders for each scenario are given below.

In **SSP1** (which is coupled with the RCP4.5 climate scenario), the WFD was felt to be effective, although it was noted that it is hard to control compliance. For the CAP, the stakeholders were skeptical about the policy, pointing out that in Spain and Portugal the CAP supports the production of products that do not meet the needs of the countries. Compliance checks are not thorough and linking CAP to biodiversity conservation has not been effective. Overall, it was concluded that the CAP is not a policy that contributes to sustainability or equity (especially outside the EU). However, the measures that were tested were felt to be important in the SSP1 context in the future.

For **SSP3** (which is coupled with the RCP8.5 climate scenario), the participants noted that the societal and institutional fragmentation taking place in this scenario works against policies like the WFD. The high-end climate change also works against the directive. Indeed, it is plausible that regulation of water quality would be relaxed in favour of increasing water quantity – considering that there will be tremendous water stress under this scenario. It was felt that CAP would work until 2040, thereafter it would not be “common” – also because of the fragmentation in this scenario.

For **SSP4** (which is coupled with the RCP4.5 climate scenario), the stakeholders noted several problems with the WFD, including that it is not updated regularly, and the availability of and need for water are very different from when the directive was developed. Furthermore, one of the objectives of the directive is to decrease environmental degradation, which will be very difficult to achieve considering increasing water demand (also by the ‘have-nots’) and less availability. The stakeholders felt that it was important to charge a real price for water. A system of monitoring of compliance could be implemented by the elite in SSP4. Regarding the CAP, the stakeholders noted that it is necessary to have water available for human use, industry etc., so it is necessary to take measures for the rationalisation of the use of land and water. This includes, for example, looking at both the production and techniques for irrigation, but also at abandoning land. Furthermore, it was pointed out that forest areas should be planned according to ecosystems and that attention should be paid to maintaining population in rural areas.

For **SSP5** (which is coupled with the RCP8.5 climate scenario), the stakeholders felt that the CAP could be a strong tool, at least until 2040, although some modifications would be needed. Since this is a scenario of corporate power, agricultural companies would be the focus of the CAP, not individual farmers. Changes that would be necessary include putting more focus on innovation, more subsidies to local agriculture, more focus on forest fires and support for climate adaptation measures. Regarding the WFD, the participants noted that in this scenario achieving good ecological status would not be a main priority. Integrated watershed management (e.g. managing pollution sources to reservoirs through land use planning) would function. Protecting water resources would work through policies and technologies – but not because of environmental considerations.

4. Stress-testing using the Integrated Assessment Platform (IAP2)

The overarching idea with the stress-testing with the IAP2 was to select a few EU-level policies, identify associated policy measures, stress-test them against the vision of the EU case study and finally assess different measures of robustness. A simplified ‘portfolio analysis’ was also carried out.

4.1. Selected policies and vision elements

Three policies at the EU level were analysed:

1. The Common Agricultural Policy (CAP);
2. Water Framework Directive (WFD);
3. The EU Adaptation Strategy (EAS).

The **CAP** is described in Section 3.1. Table 6 shows the CAP policy measures that were tested, the model element that was changed to do the test, the vision element against which the test was made and the model indicator used to represent that vision element. In this case the policy measures selected needed to be linked to what can be modelled in the IAP2. The following four policy measures were used for the CAP in the model-based approach[13]:

- CAP11: Crop diversification;
- CAP12: Increase farm management and organic farming;
- CAP13: Maintaining permanent grassland;
- CAP14: Increase ecological focus areas AND Conservation of high-value habitats.

As mentioned above, the policy measures were tested against the vision developed for Europe. Figure 2 (Section 2.2.1) shows the vision elements for the vision developed in the EU case study. Two vision elements were used for stress-testing the CAP policy measures: “Food security for all” and “Respect planetary boundaries” (which includes a boundary for biodiversity loss). These elements were examined in the IAP2 by simulating the number of people vulnerable to a change in food production per capita and the area vulnerable to a change in the biodiversity index.

[13] We continue the numbering from the Iberian case study, Section 3.3.

Table 6: Summary of test of the CAP policy measures using the IAP2.

CAP policy measure tested	IAP2 slider changed to simulate the policy measure	Vision element tested	IAP2 indicator to represent vision element
Crop diversification	Reduce food imports	"Food security for all"	Number of people vulnerable to change of food production per capita
Increase farm management and organic farming	Reducing diffuse source pollution from agriculture	"Food security for all"	
Maintaining permanent grassland	Increase dietary preference for red meat	"Respect planetary boundaries"	Area vulnerable to change of biodiversity index
Increase ecological focus areas AND Conservation of high-value habitats	Change protected areas to 'connectivity then buffering'	"Respect planetary boundaries"	Area vulnerable to change of biodiversity index

The **WFD** is described in Section 3.4. The following policy measures were identified for WFD that could be modelled:

- WFD 5: Reducing mineral fertilisers and reducing pesticide pollution;
- WFD 6: Water pricing with 'adequate' incentives (behavioural change);
- WFD 7: Water pricing with 'adequate' incentives (technological change);
- WFD 8: Increase water efficiency in irrigation systems.

The vision element selected for WFD was "Sustainable use of water" and this was modelled in IAP2 via the indicator "Number of people vulnerable to over-exploitation of water".

The overall aim of the **EU Adaptation Strategy** is to contribute to a more climate-resilient Europe. According to the strategy, this means enhancing the preparedness and capacity to respond to the impacts of climate change at local, regional, national and EU levels, developing a coherent approach and improving coordination. The Strategy has three objectives: (i) to promote action by Member States in order to achieve coordination and coherence at the various levels of planning and management; (ii) to promote better informed decision-making by addressing gaps in knowledge about adaptation; and (iii) to help to "climate-proof" EU action by mainstreaming adaptation measures into EU policies and programmes and promoting adaptation in key vulnerable sectors.

On 1 September 2016 the EU Commission issued an evaluation of the Adaptation Strategy that will be running from Q4 2016 until Q4 2018[14] . The purpose is to provide a first evaluation of the strategy and examine its actual implementation and performance. The evaluation covers the implementation in all 28 EU Member States but also takes into account the international context, in particular the implications of the Paris Agreement and the direct and indirect effects of climate change outside the

[14] ec.europa.eu/smart-regulation/roadmaps/docs/2016_clima_011_evaluation_adaptation_strategy_en.pdf

European Union[15]. The reference period for the evaluation of the Strategy is April 2013 to December 2016.

It was more difficult to identify specific policy measures for the EU Adaptation Strategy as the strategy is rather vague and does not provide precise measures. The most concrete ones found were the following eight ‘actions’:

1. Encourage all Member States to adopt comprehensive adaptation strategies;
2. Provide LIFE funding[16] to support capacity building and step up adaptation action in Europe (2014-2020);
3. Introduce adaptation in the Covenant of Mayors framework (2013/2014)[17];
4. Bridge ‘the knowledge gap’;
5. Further develop Climate-ADAPT[18] as the ‘one-stop shop’ for adaptation information in Europe;
6. Facilitate the climate-proofing of the CAP, the Cohesion Policy[19] and the Common Fisheries Policy (CFP);
7. Ensuring more resilient infrastructure;
8. Promote insurance and other financial products for resilient investment and business decisions.

Only Action 2 could be related to input policy drivers in the IAP2. To do this, we created three policy measures corresponding to ‘step up adaptation action’ (EAS 1, 3 and 4 below) and one corresponding to ‘support capacity building’ (EAS2). Since the overarching aim of IMPRESSIONS states that the project should strive for helping decision-makers apply knowledge about the impacts of high-end climate change within an integrated adaptation and mitigation framework, we also included a policy measure about mitigation of greenhouse gases (EAS5 below), despite the fact that this ‘indirect’ adaptation measure is not explicitly mentioned in the EU Adaptation Strategy. In the IAP2 runs, EAS5 implies using emission scenario RCP2.6 instead of RCP4.5 (combined with either SSP1 or SSP4) or RCP8.5 (combined with SSP3 or SSP5).

Hence, the IAP2 changes used for the EAS were:

- EAS1: Improve irrigation, reduce food imports, and improve flood protection;
- EAS2: Increase human and social capital;
- EAS3: High spatial planning for urban and coastal development; water demand prioritisation for the environment;
- EAS4: Increase efficiency (technological and social), increase agriculture yields, increase set aside;
- EAS5: Mitigation of greenhouse gases.

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[15] See IMPRESSIONS work on indirect impacts (or ‘cross-border impacts of climate change’), for example Benzie et al. (2016) and Deliverable 3A.2 (Benzie et al. 2017).

[16] LIFE is the *EU's* financial instrument supporting environmental, nature conservation and climate action projects throughout the EU*;* http://ec.europa.eu/environment/life/funding/life2016/.

[17] Adaptation in cities.

[18] http://climate-adapt.eea.europa.eu/.

[19] Economic and social cohesion is about ‘reducing disparities between the various regions and the backwardness of the least-favoured regions’.

The vision element that the EAS aims to achieve is “Resilience: Acting pre-emptively”. This can be tested in the IAP2 by looking at the total number of people vulnerable to its six vulnerability indicators: vulnerability to change of food production per capita; vulnerability to change of the water exploitation index; vulnerability to change of the flood index; vulnerability to change of the biodiversity index; vulnerability to change of the land use intensity index; and vulnerability to change of the land use diversity index. This is illustrated in Figure 6.

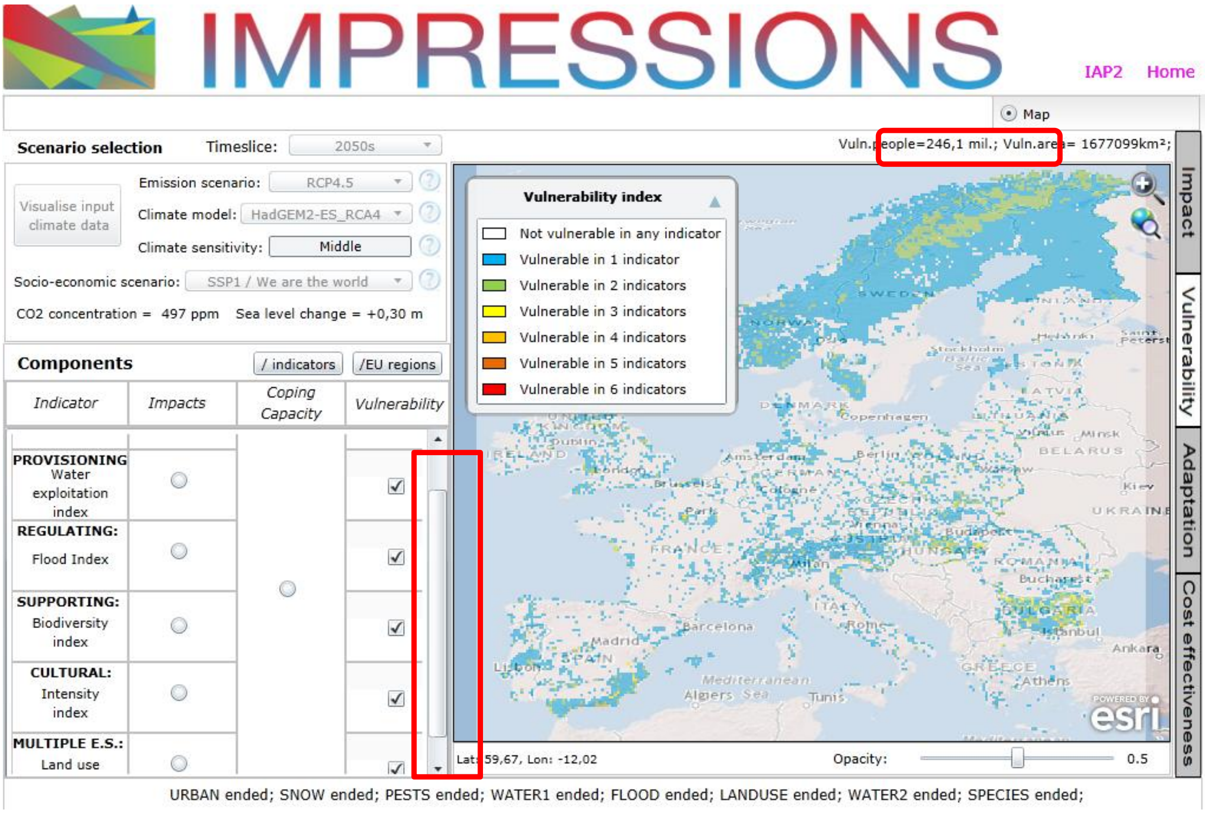

Figure 6: The vulnerability screen showing the possibility to mark all six vulnerability indices (the food vulnerability index is not shown here) and read off the total number of people vulnerable (top right).

4.2 Testing policy measures quantitatively with IAP2

Table 7 below summarises the results from the IAP2 runs for all of the policy measures for the three selected policies. It should be noted that costs associated with implementing any of the policy measures are not considered in this analysis, hence cost-benefit and cost-effectiveness analysis cannot be applied (see discussion in Sections 3.1 and 3.2, and D5.1 - Tinch et al. 2015).

The vulnerability projections are shown in the first two rows of Table 7 for the CAP (based on number of people vulnerable to a change of food provision and area vulnerable to change in the biodiversity index), the first row for WFD (based on number of people vulnerable to over-exploitation of water) and the first row for EAS (based on a combination of the number of people vulnerable to over-exploitation of water, food, flooding, vulnerability to change in biodiversity index, land-use intensity index, land use diversity index = ‘total vulnerability’). For the ‘optimistic’ scenario (moderate climate change and generally positive societal development – SSP1 combined with RCP4.5) vulnerability goes down in the first time-slice (2050s) compared to the second time-slice (2080s). This is also true for water vulnerability under the other moderate climate change scenario (SSP4 combined with RCP4.5). However, all other vulnerability measures increase in vulnerability over time for all other scenario combinations.

Table 7: Summary of IAP2 runs for the three selected policies and their associated policy measures: CAP11 – CAP14 for the Common Agricultural Policy, WFD5 – WFD8 for the Water Framework Directive and EAS1 – EAS5 for the EU Adaptation Strategy. The first rows for each policy (2 for CAP, 1 for WFD and EAS) shows vulnerability (number of people and area) before adaptation (i.e. before applying the policy measures). Red colour indicates negative outcome of applying the policy measure (i.e. things get worse), and green colour indicates that vulnerability goes down. M = million.

POLICY MEASURE	SSP1		SSP4		SSP3		SSP5	
Time-slice	2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
P = # of people vuln. food (M)	122	46.7	258	312	234	262	235	261
A = Vulnerable area (M km^2)	0.54	0.12	2.4	3.1	2	2.1	1.8	2.4
CAP 11 (P)	+14	-6.7	-8	+1	0	-3	0	-38
CAP 12 (P)	+11	-4.7	+1	-4	+6	+7	+8	+9
CAP 13 (A)	+0.18	+0.04	-0.1	+0.1	+0.1	+0.1	-0.1	-1.7
CAP 14 (A)	-0.39	+0.3	+0.2	0	+0.1	+0.1	+0.1	0
CAP 11 & CAP 12 (P)	+3	-17.7	-8	-2	+1	+62	-3	-37
CAP 13 & CAP 14 (A)	+0.18	+0.5	-0.1	0	0	+0.1	-0.1	-0.2
# of people vuln. water (M)	8.7	1.4	50	44	126	333	131	175
WFD 5	+0.4	+5.6	+1	0	-26	-9	0	+4
WFD 6	-1.4	0	-5	0	-25	-10	-1	0
WFD 7	-7.1	0	-14	-6	-33	-10	-6	-31
WFD 8	+3.8	+5.6	+20	0	-28	-8	-2	-31
WFD 6 & WFD 7	-7.1	0	-14	-6	-33	-14	-6	-31
WFD 7 & WFD 8	-0.4	+5.6	+16	-6	-35	-10	-4	-31
WFD 6 & WFD 8	+3.8	+5.6	+20	0	-28	-9	-4	-3
WFDs 6 & 7 & 8	-0.4	+5.6	+20	0	-35	-10	-4	-28
# of vuln. people (M)	243	152	350	374	398	477	422	475
EAS 1	+24	-1	-23	-27	+1	+1	-2	-11
EAS 2	-13	-10	-34	-38	-17	-28	0	+9
EAS 3	+14	-2	-12	-2	-6	+1	-13	+44
EAS 4	+23	+8	-2	+10	+2	-2	+10	+45
EAS 5	-2	+2	+22	-7	-32	-18	+22	-52

The effects of the policy measures on vulnerability are mixed. This is seen in Table 7 as a mixed green/red pattern where green numbers represent a positive outcome of the policy measure and red numbers show a negative outcome, i.e. increased vulnerability. The policy measures associated with the WFD are generally very positive in most scenarios; for the two high-end scenarios (SSP3 and SSP5) all measures deliver decreased vulnerability except WFD1 for SSP5, with no change for the 2050s time-slice and an increased vulnerability by 4 million people for the 2080s time-slice.

For the **CAP**, we see that a very complicated picture emerges. There is no single policy measure that is green for all scenario combinations and for both time-slices. In terms of the number of vulnerable people (food), CAP11 (Crop diversification) is very good for the later time-slice for scenario SSP5 (-38 million people). It also results in improvements in the later time-slice for SSP1 and the earlier time-slice for SSP4 (both of which are associated with the moderate RCP4.5 climate change scenario). However, applying CAP11 increases vulnerability substantially for the earlier time-slice for SSP1. This example presents the decision-maker with a highly complex situation. CAP12 (Increase farm management and organic farming) has some good effects for the later time-slice in the two moderate climate change scenarios (associated with SSP1 and SSP4), but it delivers very negative effects over both time-slices for the two high-end scenarios (associated with SSP3 and SSP5). CAP13 (Maintaining permanent grassland) has a very good outcome for SSP5 in the 2080s and only marginal effects on the others, except SSP1 in the 2050s. CAP14 (Increase ecological focus areas AND Conservation of high-value habitats) has very good effects in the earlier time-slice for SSP1 and only marginal effects in all other cases. This is, therefore, an example of a measure that could be applied for the benefit of only one possible outcome without compromising the other outcomes.

For the **WFD**, the results are clearer and less complex. As already mentioned, most measures result in improved vulnerability for most time-slices under the high-end scenarios (SSP3 and SSP5). In addition, WFD6 (Water pricing with 'adequate' incentives (behavioral change)) and WFD7 (Water pricing with 'adequate' incentives (technological change)) are obvious good choices since they deliver reduced vulnerability for all scenarios for both time-slices. WFD7 is dominant over WFD6 since the outcome is equal or better for all cases, hence there is no reason for not preferring WFD7 (however, see note on costs above). In fact, WFD7 is the best choice over all cases for both time-slices.

For the **EAS**, EAS2 (Increase human and social capital) shows improvements in vulnerability for all cases except the second time-slice in SSP5. Here, EAS1 (Improve irrigation, reduce food imports, flood protection) and EAS5 (Mitigation of greenhouse gases based on RCP2.6) deliver better results. EAS5 also delivers positive results for the two high-end scenarios as expected, with the exception of the first time-slice for SSP5. For the first time-slice for SSP5, EAS3 (High spatial planning for urban and coastal development; water demand prioritization for the environment) provides the greatest improvement in vulnerability.

The discussion hitherto has only concerned policy measures when applied individually. The importance of taking an 'integrated' approach to climate change impacts has been put forward, by the IPCC for example, although very little has been done on this topic as most impact studies still apply a single-sector approach (see Harrison et al. 2016 for an exception). Here we argue that the same logic also applies to adaptation; climate change adaptation modelling needs to include cross-sectoral interactions[20].

As can be seen in Table 7, shown as '*Measure X* & *Measure Y*' (e.g. CAP11 & CAP12 and WFD6 & WFD7), we also tested combinations of policy measures for CAP and WFD. In total, six combinations were tested, two for CAP and four for WFD[21].

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[20] This is exactly the same title as Harrison et al. 2016, except that we have replaced the word 'impact' in their title with 'adaptation'.

[21] In decision theory, the approach discussed here is sometimes called portfolio analysis.

Policy measures can be combined in different ways. For example, if we consider two policy measures *X* and *Y,* and assume that *X* › *Y* (i.e. that *X* is a better adaptation option than *Y*), then denoting the joint application of both measure with *X & Y*, there are seven possibilities*:*

(i) *X & Y* are as equally good as *X + Y;*
(ii) *X & Y* is less than both *X* and *Y;*
(iii) *X & Y* is less than *X* but equal to *Y;*
(iv) *X & Y* is equal to *X* and greater than *Y*;
(v) *X & Y* is better than *Y* but not as good as *X*;
(vi) *X & Y* is better than *X* and *Y* but not as good as *X + Y*;
(vii) *X & Y* is better than *X + Y* (the most positive outcome; could be called 'emergent adaptation' when the totality is more than the sum of the parts).

Interestingly, when testing combinations of policy measures almost all of these possibilities are found (see Table 8). The only one missing is the 'naïve guess' when combining the two measures together would result in a combined reduction of vulnerability that is the sum of two individual measures.

Table 8: Possible combinations for two policy measures assuming one is better than the other, and examples of such combinations based on values from Table 7. "Better than" is denoted by "›".

Possible cases	Example (policy measures, scenario, time-slice)
X › Y › X & Y	CAP13 & CAP14 for SSP1, 2080s
X + Y › X & Y › X › Y	WFD7 & WFD8 for SSP3, 2050s
X › X & Y › Y	CAP13 & CAP14 for SSP5, 2080s
X › Y = X & Y	WFD7 &WFD8 for SSP1, 2080s
X & Y = X › Y	WFD6 & WFD7 for SSP1, 2050s
X & Y = X + Y	*No example*
X & Y › X + Y	CAP11 & CAP12 for SSP1, 2080s

The examples in Table 8 illustrate the complexities of adaptation when including cross-sectoral interactions in modelling. The first example shows two bad policy measures (i.e. both CAP13 and CAP14 lead to increased vulnerability), but the outcome is even worse when the two policy measures are combined (0.04 + 0.3 < 0.5). The third row of Table 8 shows an example where the combination of measures is in between the two measures (*X › X & Y › Y*): CAP13 & CAP14 combined (-0.2) is better than CAP14 on its own (0), but worse than CAP13 on its own (-1.7). The fifth row of Table 8 illustrates the case where there is no point in adding another policy measure (*X & Y = X › Y*); adding WFD6 (-1.4) to WFD7 (-7.1) does not further improve vulnerability compared to when WFD7 is applied alone (-7.1). The final row of Table 8 provides an example of 'emergent adaptation', where the joint benefit of CAP11 and CAP12 is higher than the sum of the individual benefits, i.e. for SSP1 in the 2080s, CAP11 reduces vulnerability by 6.7 and CAP12 by 4.7, whilst combining the measures reduces vulnerability by 17.7 million people. This example highlights the non-trivial influences between different adaptation measures. Hence, modelling the effects of adaptation measures in isolation ('single-sector approach') might be misleading.

4.3 Exploring different robustness metrics

The last step of the process was to explore different strategies for assessing robustness. Different definitions of robustness will give different answers to the question of what policy measures to opt for (Giuliani and Castelletti, 2016). It should also be noted that there are indeed cases where different definitions of robustness lead to the same outcome (see for example Lempert and Collins, 2007).

Table 9 shows a hypothetical example with four policy measures (PM1 – PM4) and their pay-off[22] in the four scenarios (SSP1, SSP3, SSP4, SSP5), as well as the preferred choice for five different ways of defining robustness: Laplace, MaxMin, MaxMax, MinMax Regret, and Hurwicz criteria. We have restricted the selection of robustness definitions to non-probabilistic ones (see discussion on probabilities in the context of high-end climate change in D5.1 - Tinch et al. 2015 and in Eriksson and Carlsen, 2016).

Table 9: Illustrative example with four scenarios and four policy measures (PM1 – PM4) and five different ways of identifying the most robust strategy. The best choice for each definition of robustness is highlighted in green; highest regret in bold for MinMax Regret.

	Scenario				Laplace	MaxMin	MaxMax	MinMax Regret				Hurwicz
	SSP1	SSP4	SSP3	SSP5				SSP1	SSP3	SSP4	SSP5	
PM1	15	5	-5	0	3,75	-5	15	15	15	**15**	10	5
PM2	30	10	10	-40	2,5	-40	30	0	10	0	**50**	-5
PM3	-10	0	10	10	2,5	-10	10	40	**20**	0	0	0
PM4	-20	20	10	10	5	-20	20	**50**	0	0	0	-5

For the *Laplace* criterion all possible states, here the different scenarios, are considered equally probable. Hence, the indicator is calculated by simply averaging the values across the scenario, with the highest value being considered the most robust. The Laplacian approach has a tendency to emerge by default when trying to avoid probabilities, but here probabilities emerge implicitly. In Table 9, policy measure 4 emerges as the preferred robust choice for the Laplacian criterion (green box).

The *MaxMin* criterion is based on selecting the alternative with the best worst consequences (i.e. the approach totally disregards all outcomes from other scenarios except the worst case scenario). In Table 9, policy measure 1 is the best choice (highest value out of the worst cases) based on this criterion.

The *MaxMax* criterion is the opposite of *MaxMin* (i.e. it only considers the best scenario outcomes). In Table 9, policy measure 2 is the most robust choice under this criterion with a value of 30.

The *MinMax Regret* criterion looks across the set of policy measures for each scenario and calculates the maximum regret if an alternative policy measure is chosen compared to the measure with highest outcome. For example, policy measure 1 in SSP1: |15 – 30| = 15 and policy measure 2 in SSP5: |- 40

[22] Note that this example uses payoff, not reduced vulnerability. Hence, in the example higher numbers are better (higher payoff) than lower numbers. The reasons for this is that we think it is easier to introduce the basic ideas with this metric.

– 10| = 50). With this criterion, the policy measure that minimises the maximum regret without regard to probabilities is selected, i.e. policy measure 1 in the example.

The last definition considered here is the *Hurwicz's* criterion. This is a criterion designed to weight the maximum outcome and the minimum outcome with an 'optimist/pessimist' parameter α:

$$H(\alpha) = \alpha*Max + (1- \alpha)*Min.$$

For $\alpha = 1$, the Hurwicz's formula is equal to using the *MaxMax* criterion, and for $\alpha = 0$ it is equal to using the *MaxMin* criterion. Hence, the extreme optimist sets $\alpha = 1$ and the extreme pessimist sets $\alpha = 0$. In the example in Table 9, $\alpha = 0.5$; this can be called 'neutralism'.

This simple example is of course constructed in order to illustrate that the choice of a 'robust' strategy is non-trivial. It has been argued that, in general, different 'robustness metrics' should give similar results as to which policy measures are preferred (Lempert and Collins 2007). But others suggest in contrast that different robustness methods give different results while "none can be argued to be more natural and better than others" (Aven 2014, p. 153).

With these observations as a starting point we used the IAP2 results to test whether different robustness metrics could result in different choices of policy measures. Tables 10 and 11 show the result for the WFD.

Table 10: Summary of how the four policy measures considered for the WFD, and the four combined measures, perform under different definitions of robustness. Time-slice = 2050s. Calculations based on Table 7. The last row shows what policy measure(s) is (are) preferred given each of the robustness metrics (also indicated with green shading). For MinMax Regret bold numbers show maximum regret for each policy measure.

WFD 2050s	Laplace	MaxMin	MaxMax	MinMax Regret				Hurwicz
				SSP1	SSP4	SSP3	SSP5	
5	-6.2	1.0	-26.0	7.5	6.0	**9.0**	6.0	-12.5
6	-8.1	-1.0	-25.0	5.7	0.0	**10.0**	5.0	-13.0
7	-15.0	-6.0	-33.0	0.0	**9.0**	2.0	0.0	-19.5
8	-1.6	20.0	-28.0	10.9	**25.0**	7.0	4.0	-4.0
6&7	-15.0	-6.0	-33.0	0.0	**9.0**	2.0	0.0	-19.5
7&8	-5.9	16.0	-35.0	6.7	**21.0**	0.0	2.0	-9.5
6&8	-2.1	20.0	-28.0	10.9	**25.0**	7.0	2.0	-4.0
6&7&8	-4.9	20.0	-35.0	6.7	**25.0**	0.0	2.0	-7.5
Preferred policy measures	PM7; PM6&7	PM7	PM7&8; PM6&7&8	PM5; PM7; PM6&7				PM7; PM6&7

Table 11: As Table 10 but for the 2080s time-slice.

WFD 2080s	Laplace	MaxMin	MaxMax	MinMaxRegret				Hurwicz
				SSP1	SSP4	SSP3	SSP5	
5	0.2	5.6	-9.0	5.6	6.0	5.0	**35.0**	-1.7
6	-2.5	0.0	-10.0	0.0	6.0	4.0	**31.0**	-5
7	-11.8	0.0	-31.0	0.0	0.0	**4.0**	0.0	-15.5
8	-8.4	5.6	-31.0	5.6	**6.0**	**6.0**	0.0	-12.7
6&7	-12.8	0.0	-31.0	**0.0**	**0.0**	**0.0**	**0.0**	-15.5
7&8	-10.4	5.6	-31.0	**5.6**	0.0	4.0	0.0	-12.7
6&8	-1.6	5.6	-9.0	5.6	6.0	5.0	**28.0**	-1.7
6&7&8	-8.1	5.6	-28.0	5.6	**6.0**	4.0	3.0	-11.2
Preferred policy measures	PM6&7	PM6; PM7; PM6&7	PM7; PM8; PM6&7; PM7&8	PM6&7				PM7; PM6&7

It is clear that the different robustness metrics do not give similar results. In fact, the picture is very mixed, both over the different metrics but also over the two time-perspectives. The results can be summarised as shown in Table 12. Here, we can see that all policy measures except WFD6 & WFD8 are preferred for at least one robustness definition. Those policy measures selected most frequently as 'robust' are WFD6 & WFD7 and WFD7. For all five criteria there is at least one preferred policy measure over the two time-slices: Laplace – WFD6&7, MaxMin – WFD7, MaxMax – WFD7&8, MinMaxRegret – WFD7 and WFD6&7, and Hurwicz – WFD7 and WFD6&7.

Table 12: Summary of selected policy measure for the five different robustness definitions and for the two time-slices.

WFD	2050s					2080s					Sum
	Lapl.	**MMin**	**MMax**	**MMReg**	**Hurw.**	**Lapl.**	**MMin**	**MMax**	**MMReg**	**Hurw.**	
5				X							**1**
6							X				**1**
7	X	X		X	X		X	X		X	**7**
8								X			**1**
6&7	X			X	X	X	X	X	X	X	**8**
7&8			X					X			**2**
6&8											**0**
6&7&8			X								**1**

The same analysis was performed for the European Adaptation Strategy and the results are presented in Table 13. The results are more stable for the EAS analysis compared to the WFD. For instance, policy measure EAS2 is the preferred choice for all robustness definitions for the 2050s, except MinMax Regret. For the 2080s, policy measure EAS5 is the preferred choice for three of the definitions.

Table 13: Summary of how the five policy measures considered for the EU Adaptation Strategy perform under different definitions of robustness. Calculations based on Table 7. The last row shows what policy measure(s) is (are) preferred given each of the robustness metrics.

EAS 2050s	Laplace	MaxMin	MaxMax	MinMaxR				Hurwicz
				SSP1	SSP3	SSP4	SSP5	
1	0.0	24.0	-23.0	10.0	**11.0**	1.0	**11.0**	0.5
2	-16.0	0.0	-34.0	**27.0**	0.0	17.0	13.0	-17.0
3	-4.3	14.0	-13.0	0.0	**22.0**	6.0	0.0	0.5
4	8.3	23.0	-2.0	9.0	**32.0**	2.0	23.0	10.5
5	2.5	22.0	-32.0	16.0	**56.0**	32.0	35.0	-5.0
Preferred policy measures	PM2	PM2	PM2	PM1				PM2
EAS 2080s	**Laplace**	**MaxMin**	**MaxMax**	**MinMaxR**				**Hurwicz**
				SSP1	**SSP3**	**SSP4**	**SSP5**	
1	-9.5	1.0	-27.0	9.0	25.0	19.0	**55.0**	-13.0
2	-16.8	9.0	-38.0	0.0	**36.0**	10.0	35.0	-14.5
3	10.3	44.0	-2.0	8.0	0.0	**19.0**	0.0	21.0
4	15.3	45.0	-2.0	**18.0**	12.0	16.0	1.0	21.5
5	-18.8	2.0	-52.0	12.0	5.0	0.0	**96.0**	-25.0
Preferred policy measures	PM5	PM1	PM5	PM4				PM5

5 Discussion and Conclusions

This deliverable reports on the stress-testing of policy measures in the IMPRESSIONS case studies in order to assess the social-ecological robustness of policy measures to high-end scenarios. Key policies from each case study were selected in consultation with the case study leaders.

The first stage of the work included stress-testing in workshops with stakeholders in four of the IMPRESSIONS case studies. The European case used a slightly more complicated set-up compared to the other three later workshops. Experience from the European case study were used to modify and simplify the work in the three regional case studies. These changes resulted in a better process according to stakeholder evaluations.

The results of the stress-testing in the case studies are mixed. In all cases, it was impossible to devote a substantial amount of time to this task, since the workshops (generally 2 days long) had an enormous amount of other material to cover (see D6A.2 – Zellmer et al. 2016 and D6A.3 – Faradsch et al. 2017). As a result, not all of the policy measures were addressed by all scenario groups, so a full comparison across scenarios to assess robustness is not possible. Nevertheless, the sessions were generally rated positively by the stakeholders and they led to additional material being added to the pathways developed in the workshops. The session also raised awareness of the importance of discussing how current policies might fare in the context of high-end scenarios.

With the aim of identifying the robustness of policies to both moderate and extreme levels of climate change, as well as different socio-economic futures, a quantitative stress-testing exercise has been carried out for the European case study, using the IMPRESSIONS Integrated Assessment Platform (IAP2). Policy measures for the Common Agricultural Policy, the Water Framework Directive and the European Adaptation Strategy have been tested. The results of this testing demonstrate the importance of cross-sectoral impacts (e.g. changing water efficiency does not only affect the water sector but also the agriculture sector and others). As a result of these impacts, a policy measure does not necessarily lead to the desired end-point. Overall, the assessment showed, however, that policy measures to induce water saving are the most robust and work even in the most challenging of socio-economic scenarios. Furthermore, policy measures that increase social and human capital increase the capacity to cope with high-end socio-economic and climate change and work in all scenarios except SSP5 (Fossil-fuelled development).

It is important to note that quantitative assessments of impacts and adaptation vary strongly depending on the model used. Here we employed the updated version of the Integrated Assessment Platform originally developed in the CLIMSAVE project (www.climsave.eu). This platform, which is based on linked meta-models, has been extensively used and tested (e.g. Holman et al. 2016, Harrison et al. 2015, Dunford et al. 2015). Furthermore, Harrison et al. (2016) performed a 'benchmarking exercise' comparing the impacts from the IAP (not the IAP2 version used in this study) with the impacts reported in the IPCC AR5 chapter on Europe (Kovats et al. 2014), which showed good agreement. However, that comparison only considered impacts and not the adaptation and vulnerability results used here for stress-testing. For the latter there has been no benchmarking exercise showing the quality of the IAP2 (or the original IAP).

The quantitative analysis also considered 'portfolios of policy measures'. The cross-sectoral features of the IAP2 were clearly shown when analysing different combinations of policy measures. It is rarely the case that the combined benefit of two measures are the trivial sum of the individual contributions. Although these are preliminary findings they show the complexity of adaptation when moving outside the 'comfort zone' of only studying effects within one sector. This has earlier been shown for impacts and here we also show it for adaptation. This is a new field of research and much work remains to be done.

As a final step in the quantitative analysis we considered different ways of interpreting robustness. The 'naïve' approach is to talk about something along the line of sufficiently good performance across the whole scenario set. Our analysis showed that different robustness metrics actually lead to different policy measures being selected as the preferred ones.

On the basis of the above results and reflections, we make the following recommendations:

1) Stress-testing of policies in a workshop setting with stakeholders can be extremely valuable in stimulating discussion about how current policies will fare in different socio-economic and climatic futures and whether the policies would work better, if they were changed. It is essential that such a discussion is well-prepared (selecting relevant policies, selecting policy measures that can be tested and choosing an appropriate endpoint against which the effectiveness of a policy

measure can be tested). Furthermore, enough time has to be allocated to this discussion. Quantitative assessment using a simple scoring system produces useful results but can nevertheless produce ambiguous results, which can only be interpreted if detailed notes of the discussion are taken. Qualitative assessment can likewise often only be interpreted correctly, if detailed notes are kept. Using a prepared flip-chart or poster to record results of a stakeholder-led stress-testing supports the cross-comparison of results of different workshops.

2) Stress-testing of policy measures using the Integrated Assessment Platform shows the cross-sectoral impacts of policy measures, which is very useful if the results are to be used in providing policy advice. However, without detailed knowledge of the underlying meta-models, and how they are linked, interpretation of the results is often very difficult. It is important therefore to work with colleagues who have developed and used the models to ensure that the results are interpreted correctly. Using a model-based platform in a quantitative stress-testing activity is, however, limited in terms of the kinds of policy measure that can be tested. For example, the Water Management strategy in Scotland has an important policy measure on monitoring the quantity and quality of water. Such a strategy could clearly have a positive effect on achieving the goal of sustainable water use but it cannot be tested as such in the IAP2.

3) Adaptation planning needs to adopt a cross-sectoral approach in order to grasp the influences between different sectors. Adaptation that is good for one sector might be negative for another sector (maladaptation). This is a complicated task, both qualitatively and quantitatively. Very few models exist that explicitly take into account cross-sectoral interactions, and this is especially the case for adaptation. Multi-sectoral adaptation is also very complicated from an institutional perspective. All these complexities should not, however, hinder further research on this topic.

4) To provide policy advice on robust strategies in the face of high-end scenarios, our work thus shows that both a stakeholder-led and a model-based assessment are useful and indeed they are complementary.

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