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COACCH

CO-designing the Assessment of Climate CHange costs

H2020-SC5-2016-2017/H2020-SC5-2017-OneStageB

D1.5 Impact and policy scenarios co-designed with stakeholders

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Deliverable	D1.5: Impact and policy scenarios co-designed with stakeholders

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Dissemination Level		
PU	Public	X
CO	Confidential, only for members of the consortium (including the Commission Services)	
CI	Classified, as referred to in Commission Decision 2001/844/EC	

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Table of contents

Summary

To develop challenge-driven and solutions orientated research, COACCH is proactively involving stakeholders in co-design, co-production and co-dissemination.

The first part of this process is to co-design the research programme with the potential users of the research. One aspect of this co-design has been the '*Participatory Development of Scenarios'* with stakeholders.

This deliverable, D1.5, summarizes the development of scenarios for the COACCH project. It reports on the participatory discussion on the choice of scenarios, held with stakeholders at the 1st co-design workshop in May. On the basis of analysis and stakeholder co-design, the deliverable sets out the final choice of scenarios to be consistently used throughout the COACCH project.

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1. Introduction

The COACCH (**CO**-designing the **A**ssessment of **C**limate **CH**ange costs) project aims to improve the downscaled assessment of the risks and costs of climate change in Europe. A key focus of the project is to work together with end users to shape results that are directly useable by research, civil society, business, investment and policy.

To implement this, COACCH is using a co-production process to deliver the co-creation of knowledge and co-delivery of outcomes with economic, industrial and research actors, public authorities and civil society. A key part of this co-production process is to design the research programme (co-design) with potential users of the research.

One aspect of this co-design process (as set out in the work programme) is the '*Participatory Development of Scenarios'* with stakeholders. This task has developed the potential options for scenarios and held a participatory workshop session at the first co-design workshop (in May 2018) to discuss the selection and choice of climate and socio-economic scenarios.

The findings are written up in this report, Deliverable 1.5 of Work Package 1 of the COACCH project. The report identifies the set of scenarios to be consistently used throughout the COACCH project. The set of scenarios are based on i) research questions, ii) discussions with stakeholders, and iii) data availability.

The report is organized as follows. Chapter 2 provides background on the concepts of Shared Socioeconomic Pathways (SSPs), Representative Concentration Pathways (RCPs) and Shared Policy Assumptions (SPAs), which are used as starting points for the discussion. It also discusses the role of climate models in impact assessment and explains why scenario choice is important in the project. Chapter 3 discusses relevant scenarios in light of our research questions. Chapter 4 provides the results of stakeholder workshop on scenario choice, and Chapter 5 discusses for which scenarios socioeconomic, climate, and impact data are available. Finally, chapter 6 brings this information together to provide a recommended set of scenarios to be used throughout the project, taking into account all of the above considerations and research capacity constraints.

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2. Background on SSPs, RCPs, SPAs, and climate models

2.1 Shared Socio-economic Pathways (SSPs)

The modelling of the economic costs of climate change requires scenarios. These are used to provide qualitative and quantitative descriptions of how socio-economic parameters may evolve in the future. These in turn influence the economic costs that arise, for example, the population affected or the assets at risk. Most studies assess the impacts of future climate change on future socio-economic projections, as a failure to do so implies that future climate change will take place in a world similar to today.

The **Shared Socio-economic Pathways** (SSPs) provide a common set of socio-economic data for alternative future pathways. They include differing estimates of future population and human resources, economic development, human development, technology, lifestyles, environmental and natural resources and policies and institutions.

The SSPs are the successor of the SRES scenarios published in 2000, on which most of the older global and European impact studies are based (e.g. ClimateCost). Practically all recent climate impact studies at the global and European scale are based on the Shared Socioeconomic Pathways (SSPs), including the European projects PESETA 3, RISES-AM, and IMPRESSIONS. The global Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) also base their impact modeling on the SSPs.

There are five SSPs, each presenting alternative storylines with respect to aspects of human development relevant to mitigation and adaptation policies, including population, land use, primary energy consumption, etc. (Table 1).

Table 1: Starting points of SSPs. Based on O'Neill et al. (2014) and Riahi et al. (2017)

SSP	Challenges	Key elements
SSP1	Adaptation: low Mitigation: low	<u>Sustainability</u>: Sustainable development, low inequalities, rapid technological change directed toward environ-mentally friendly processes, high productivity of land
SSP2	Adaptation: moderate Mitigation: moderate	<u>Middle of the Road</u>: An intermediate case between SSP1 and SSP3
SSP3	Adaptation: high Mitigation: high	<u>Regional Rivalry</u>: Moderate economic growth, rapidly growing population, slow technological change in the energy sector. High inequality, reduced trade flows, unfavorable institutional development, leaving large numbers of people vulnerable to climate change
SSP4	Adaptation: high Mitigation: low	<u>Inequality</u>: A mixed world, with relatively rapid technological development in low carbon energy sources in key emitting regions. In other regions, development proceeds slowly, and therefore inequality remains high
SSP5	Adaptation: low Mitigation: high	<u>Fossil-fuel Development</u>: Rapid economic development and high energy demand, most of which is met with carbon-based fuels. Low investments in alternative energy technologies. More equitable distribution of resources, stronger institutions, and slower population growth

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At an aggregated world regional level, data are available on many aspects of these SSPs, such as energy supply and demand (Bauer et al., 2016), land use and land cover change (Popp et al., 2017), greenhouse gas emissions (Riahi et al., 2017), air pollution and aerosol emissions (Mallampalli et al., 2016), and mitigation costs (Riahi et al., 2017) . For an overview of the data of SSPs see Riahi et al. (2017) and the SSP database (https://tntcat.iiasa.ac.at/SspDb/). Use of this set of scenarios allows common comparison across impact estimates.

2.2 Representative Concentration Pathways (RCPs)

The SSPs can be combined with different Representative Concentration Pathways (RCPs), which consists of emission, concentration and land-use trajectories, with corresponding climate model projections. The RCPs were developed for the IPCC 5th Assessment Report and include a set of four climate (forcing) pathways, which cover futures consistent with the 2°C goal through to high-end (>4°C) scenarios. Unlike the earlier SRES scenarios, the RCPs are not aligned to specific socioeconomic scenarios, and can be combined with the set of SSPs. This provides the flexibility to combine alternative combinations of future climate and socio-economic futures.

The four RCPs span a range of future emission trajectories over the next century, with each corresponding to a level of total radiative forcing (W/m^2) in the year 2100 (Table 2). The first RCP is a deep mitigation scenario that leads to a very low forcing level of 2.6 W/m^2 (RCP2.6), only marginally higher compared to today (2.29 W/m^2, IPCC, 2013). It is a “peak-and-decline” scenario and is representative of scenarios that lead to very low greenhouse gas concentration levels. This scenario has a likely (more than 66%) chance of achieving the 2°C goal. There are also two stabilization scenarios (RCP4.5 and RCP6.0). RCP4.5 is a medium-low emission scenario in which forcing is stabilised by 2100. Even in this scenario, annual CO_2 emissions will need to sharply reduce in the second half of the century, which will require significant climate policy (mitigation). Finally, there is one rising (non-stabilisation) scenario (RCP8.5), representative of a non-climate policy scenario, in which GHGs carry on increasing over the century leading to very high concentrations by 2100. The RCP characteristics are shown in Table 2.

Table 2: RCP characteristics

Scenario Component	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Average temperature change in 2100	Well below 2 °C	2.5 °C	More than 3 °C	4.5 °C
Greenhouse gas emissions relative to pre-industrial	Very low	Medium low mitigation Very low baseline	Medium baseline; high mitigation	High baseline

Combining the SSPs with the RCPs gives a matrix with the different possible combinations of socio-economic and climate assumptions (Figure 1). Some

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combinations of SSPs and RCPs are not likely, notably combinations of sustainable socioeconomic assumptions with high radiative forcing and vice versa. These are marked up in the matrix with a cross.

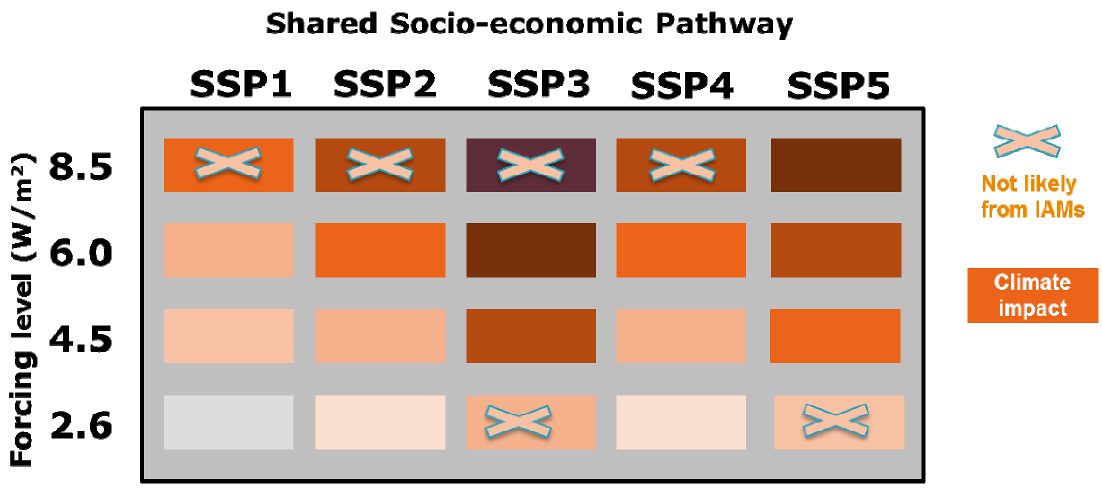

Figure 1: Feasibility of alternative forcing agents across the SSPs. Based on Riahi et al. (2017)

Achieving low radiative forcing levels (4.5 or below), requires mitigation efforts in all SSPs – with higher efforts required under SSP3 and SSP5. Under the latter two socioeconomic scenarios, a 2.6 W/m^2 forcing level cannot be attained by the IAMs. Currently, RCP2.0 pathways are being constructed to analyze impacts of a 1.5 degree warming.

2.3 Shared climate Policy Assumptions (SPAs)

Finally, to analyze the effect of different mitigation strategies given a specified forcing target level, different Shared climate Policy Assumptions (SPAs) have been identified (Kriegler et al., 2014).

All SPAs foresee a period with moderate and regionally fragmented climate action until 2020, but differ in the development of mitigation policies regarding energy (fossil fuels and industry) and land use thereafter (Riahi et al., 2017). Both for energy and land use, three different SPAs are defined.

For energy, one SPA has full regional cooperation from 2020 onwards, one assumes a linear convergence to a global carbon tax by 2040, and one assumes a linear convergence to a global carbon tax by 2040 only for rich countries, with developing countries starting and ending convergence 10 years later.

For land use, the SPAs differ with respect to pricing of land use emissions: one SPA assumes immediate pricing at the same level as energy GHG emissions, one SPA has limited pricing of land use emissions (0-20% of the price on energy sector emissions), and one SPA depicts an intermediate case between these two extremes. Similarly, also

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SPAs would need to be developed dealing with adaptation. As for mitigation, one might expect policies to be more efficient in SSP1 than in SSP5.

2.4 Climate Models

Climate models are numerical representations of the climate system and are based on physical properties and feedback processes. Coupled atmosphere/ocean/sea-ice general circulation models, commonly referred to as global climate models (GCMs) provide a comprehensive representation of the global climate system. This modelling has been conducted through a series of Coupled Model Intercomparison Projects (CMIP), the latest of which is CMIP5.

However, these models provide outputs at a high aggregation level: the horizontal resolution of the GCMs involved in CMIP5 was between 100 and 300 km. Therefore, to derive a finer resolution at local-scale , different downscaling approaches are used. Dynamical downscaling uses the output of GCMs to force regional climate models (RCMs) to obtain a finer representation of climate conditions, producing results in the order of 10 to 40 km resolution. The Coordinated Regional Climate Downscaling Experiment (CORDEX) and the EUROCORDEX database provides the most recent and highest resolution simulations for Europe, covering the historical period and different future scenarios with different RCMs.

However, the various global and regional models have different characteristics and this means that even for a single SSP and RCP scenario, there will be a large range of projected change from different climate models, which in turn will affect the level of economic costs. As an example, for the European domain, the differences in climate models (even for downscaled EUROCORDEX data) are large, as shown by Vautard et al. (2014). For some parameters these changes are robust in direction but involve a wide range (e.g. the exact level of temperature warming), while for others, the range is wide and can even vary in terms of sign (e.g. rainfall in some parts of Europe).

In impact assessment, an ensemble of model runs is typically used (a group of parallel model simulations for the same RCP) with analysis of both the average and ensemble range. In many cases, for impact analysis, a number of global or European climate model runs are used that reflect drier or wetter, or hotter or cooler models. This sampling approach has been used in previous European research projects such as IMPACT2C and IMPRESSIONS, which both used regional climate model sampling (including both global driving models and regional climate models) for multiple RCP scenarios.

However, the inclusion of climate model uncertainty expands the matrix above along a third dimension, as typically for a given SSP-RCP combination, there would need to be multiple climate models used to fully capture the range of possible economic costs.

2.5 Why scenario choice is important?

There are a very large number of possible RCP—SSP combinations, which expand further when climate model uncertainty and climate model sampling is included.

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Indeed, sampling the whole of the RCP-SSP matrix, as well as all climate models, would involve more than one hundred model runs.

As a result, it is common practice to sample across the RCP-SSP matrix, complementing this with some form of climate model uncertainty analysis.

As the COACCH project has strong flows of information from sector to economic models, it is important to agree on a set of harmonised and consistent scenarios for all teams to use. In line with the COACCH co-production principles, the aim is to also select the combinations of most interest to stakeholders. The following chapters explore the possible choice of scenarios.

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3. Research questions

Arguably one of the most interesting questions for the selection of scenarios is how climate impact – and economic costs - differ under different future climates. To analyze this, the differential effects of alternative climate scenarios relative to a common socio-economic scenario needs to be identified. In Figure 1, this implies selecting two or more RCPs under the same SSP (i.e. selecting a vertical column).

The dependence of climate impacts on socio-economic circumstances is also a relevant research question, as this provides insight on how impacts are sensitive to different exposure levels. In Figure 1, this question can be addressed by selecting different SSPs for the same RCP (i.e. selecting a horizontal row).

For considering the effects of climate change, and the full benefits of mitigation, it is not just the average climate impacts that have to be considered, but also tipping points or low-probability, high-impact events. Therefore, it is also interesting to consider extreme scenario combinations (the darkest coloured cells in Figure 1), as these combinations will have the highest probability of the occurrence of such tipping points.

A further question is how to deal with adaptation in the scenarios. Ideally, under each of the SSP and RCP combinations, we would define scenarios with different assumptions with regard to adaptation (e.g. optimal adaptation, no further adaptation, and adaptation assumptions reflecting the storyline of the respective SSP). However, this would lead to a doubling or even tripling of the scenarios to be considered. Another option could be to analyze different levels of adaptation in, say, a small number of core SSP-RCP combinations.

As highlighted at the end of Chapter 2, there is also an issue of climate model uncertainty. In order to capture multi-model information, not just the climate model ensemble mean needs to be taken, but also climate models that span the range of outcomes as well. In previous EC research projects, this has been done with three to five regional downscaled models, but as highlighted above, this further multiplies number of runs. One possibility is to include a dry and wet, and/or a low and high temperature model and analyse for a small number of core SSP-RCP combinations.

Finally, there is the question of the SPAs. Currently, these have limited usefulness since they exist only for mitigation policy and so mainly affect mitigation costs. However, there are two ways in which SPAs influence impacts from climate. The first one is directly, as different SPAs have (slightly) different temperature pathways throughout the century. The second is indirectly: the way in which climate change impacts GDP partly depends on the economic structure, which is affected by mitigation. This implies that the same climate change projections can have different GDP impacts under different mitigation assumptions. However, both effects are arguably relatively small compared to the effect of different SSPs and RCPs. Since each SSP has its own default SPA, it makes sense to use the SPA that is attached to the SSP.

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4. Stakeholder discussion

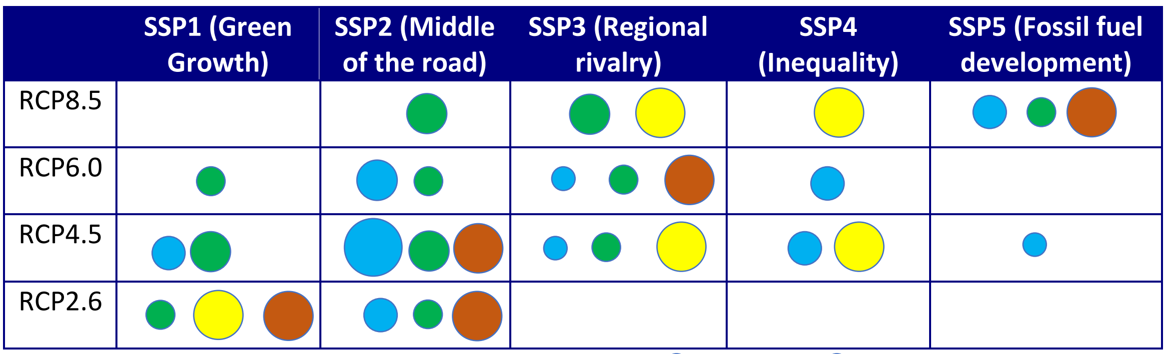
In the first co-design workshop on 17th May 2018 in Brussels, over 40 participants discussed their preferences for scenarios and time periods to be used in the COACCH project. A short summary of the outcome of the workshop is provided here, with a more detailed report provided in deliverable D1.3 (Workshop Report: First COACCH Co-Design Workshop).

As an introduction, Detlef van Vuuren (PBL) presented the RCPs, SSPs and SPAs, after which table discussions were held on the scenarios and time periods of interest, using large printed RCP-SSP matrices. The stakeholder discussion was organised into the working groups of the COACCH project, i.e. : i) national policymakers, ii) EU and international policymakers, iii) businesses and industry organizations, and iv) research organisations and non-governmental stakeholders. Each group were given five coloured dots to jointly vote on their core RCP-SSP preferences.

In general, stakeholders indicated that the scenario selection should not lead to complex assessments, and therefore they preferred the selection of the most likely scenario with some uncertainty analysis.

The results of the voting show that policymakers mainly have interest in the middle-of-the-road scenario SSP2 and especially for the combination with RCP4.5. followed by SSP3 (Table 3). Furthermore, the RCP2.6-SSP1 and RCP8.5-SSP5 combinations were considered to be interesting, showing the extremes (positive and negative). While the SSP4 (inequality) was less prioritized overall, there was interest in this SSP from the Business group.

Table 3. Prioritization of different workshop groups in Scenario-matrix (SSP-RCP-combinations)



= international policymakers; = national policymakers; = business; = NGO
The size of the dots represent the share of the total votes from the respective groups

Based on supplementary discussion, it was clear that the reason for the interest in the RCP4.5-SSP2 combination is that this is regarded as the most likely one, with middle-of-the-road socioeconomic assumptions combined with a level of climate change that might be expected from current Nationally Determined Contributions (NDCs).

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Most participants agreed on the need to include extreme scenarios. This included one best case scenario involving SSP1 (Green growth) and one worst case scenario including RCP8.5 linked to SSP5 (fossil fuelled development) or even to SSP3 (regional rivalry). The combination with SSP3 would show higher climate impacts, but is a rather unlikely combination, while the combination with SSP5 would have slightly lower climate impacts but is a more likely combination.

In general, it was agreed that there was a need to link several RCPs to the same SSP to be able to compare different climate mitigation efforts. National and international policymakers showed a preference to link RCP4.5 with SSP1-SSP3 and national policymakers also showed interest in linking RCP8.5 across SSP2, SSP3 and SSP5.

Alongside the choice of RCP-SSP combinations, the stakeholders were also asked their preferences on the time periods to consider. It is noted that the natural inter-annual variability of weather/climate, which is simulated by models, requires long time periods to be considered. Climate model results are therefore typically presented for a period of 30 years - the minimum period sufficient to capture this internal variability of the climate system. Stakeholders were given the choice of 30-year time periods to consider and to vote on their preferences. This revealed a clear preference for short-term (2020-2040) and mid-term (2041-2070) assessments. There was much less interest in the long term (2071-2100), although some stakeholders did express an interest.

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5. Data availability

One final issue that the COACCH project considered was whether there are any constraints on the choice of combinations, e.g. due to data availability or model runs. This would include whether relevant data was available for all SSPs (availability of socioeconomic data such as population, GDP, urbanization rates), as well as whether climate runs are available for all RCPs.

Regarding socioeconomic data, a down-scaled (0.125^{o}) dataset of population exists for all SSPs, a down-scaled (0.5^{o}) data-set for GDP, population, and urbanisation is only available for SSPs 1-3 (Murakami and Yamagata, 2016).

Regarding climate data, downscaled data from the Coordinated Regional Downscaling Experiment (CORDEX) is mostly available for RCP4.5 only (though there are some RCP2.6 and RCP8.5 runs also available). Global climate model data is available for all RCPs.

Finally, the Inter-Sectoral Impact Model Inter-comparison Project (ISIMIP) is considering all RCPs for SSP2, as well as all SSPs for RCP6.0 and RCP2.6. However, it is also in the process of moving to the consideration of all combinations.

It is noted that a new RCP, RCP1.9, which is consistent with the 1.5°C scenario, is now being developed. However, data is only likely to become available in 2019.

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6. Scenarios to be used throughout the project

Given that practically all recent impact studies are based on the SSPs, we propose to use the SSPs as starting point for COACCH, for consistency and comparability. However, analyzing the whole SSP-RCP-SPA matrix is too much, as this matrix provides more than 100 scenarios (24 baseline scenarios and 81 mitigation scenarios when including different model interpretations of SSPs; see Riahi et al, 2017).

To take into account relevant uncertainties without having to analyze a huge number of scenarios, a careful consideration of combination of SSPs, RCPs, and SPAs is needed. During the project meeting and model workshop on July 9 and July 10, 2018, in Graz, a final decision was made for the selection of scenarios to be used throughout the COACCH project. This built on the stakeholder preferences and the other factors considered in this report. For more detail on the discussion see also the "means of verification" of COACCH Milestone M4 "second project meeting" reporting the minutes of the meeting.

A key limiting factor for this choice was that the core set of scenarios (mandatory for all teams to run) was capped at **15**, given the capacity limitations of some models, although teams were encouraged to do as many further scenarios as possible.

To select these 15 core runs, the first primary criterion was the need to assess the differential effects of alternative climate scenarios relative to a common socio-economic scenario. Given the preference of stakeholders for SSP2, it was agreed to analyze alternative climate scenarios (RCP2.6, RCP4.5 and RCP 6.0) for SSP2.

Within these combinations, the highest preference among stakeholders was for SSP2-RCP4.5 and SSP2-RCP2.6. For this reason, these two combinations are chosen for more detailed analysis of climate model uncertainty and different adaptation assumptions (Table 4). As such, SSP2-RCP2.6 and SSP2-RCP4.5 can be regarded as the central scenario combinations in the COACCH project.

For all other SSP-RCP combinations, no sensitivity analysis regarding climate model or adaptation will be conducted consistently throughout the project due to capacity limitations (although for some specific assessments this might still be done if useful).

Based on stakeholder inputs, as well as research interests, it was also considered important to explore extreme scenario combinations. For this reason, the choice of SSP5-RCP8.5 was agreed to analyze the important aspect of impacts under high-climate change futures and SSP1-RCP2.6 under low climate change futures.

A further criterion is to be able to explore the effects of different SSPs on given future climates. For this reason, RCP4.5 was selected for SSP1, SSP2 (core), SSP3 and SSP5. This gives a comprehensive overview of the sensitivity of different socioeconomic

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futures for the stakeholders preferred RCP scenario and it allows the project analysis to separate out the climate component of the impact of respectively the SSP1-RCP2.6 and SSP5-RCP8.5 combinations.

Finally, we include SSP3-RCP2.6 and SSP3-RCP4.5 since these can be compared with the central scenario combinations SSP2-RCP2.6 and SSP2-RCP4.5, as well as with SSP1-RCP2.6 and SSP1-RCP4.5.

The selection of RCP-SSP combinations as described above are summarized in Table 4 and represent both a prioritisation from stakeholders and a reflection of the capabilities across the impact models in the project.

Table 4: Selected scenario combinations to be used in the COACCH project

	SSP1 (Green Growth)	SSP2 (Middle of the road)	SSP3 (Regional rivalry)	SSP4 (Inequality)	SSP5 (Fossil fuel development)
RCP8.5					🟡
RCP6.0		🟡			
RCP4.5	🟡	🟢 🟡 🔴 🔵	🟡		🟡
RCP2.6	🟡	🟢 🟡 🔴 🔵	🟡		

🟢 = "low signal" climate model; 🟡 = "average" climate model; 🔴 = "high signal" climate model;
🔵 = fixed adaptation, "average" climate model

* With "low signal" and "high signal" climate model, we mean adopting a climate model which leads to relatively high impacts. This can be a model which leads to relatively low/high temperature change and/or to low/high precipitation changes. The exact climate models to be used will be decided upon in Deliverable D1.6

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