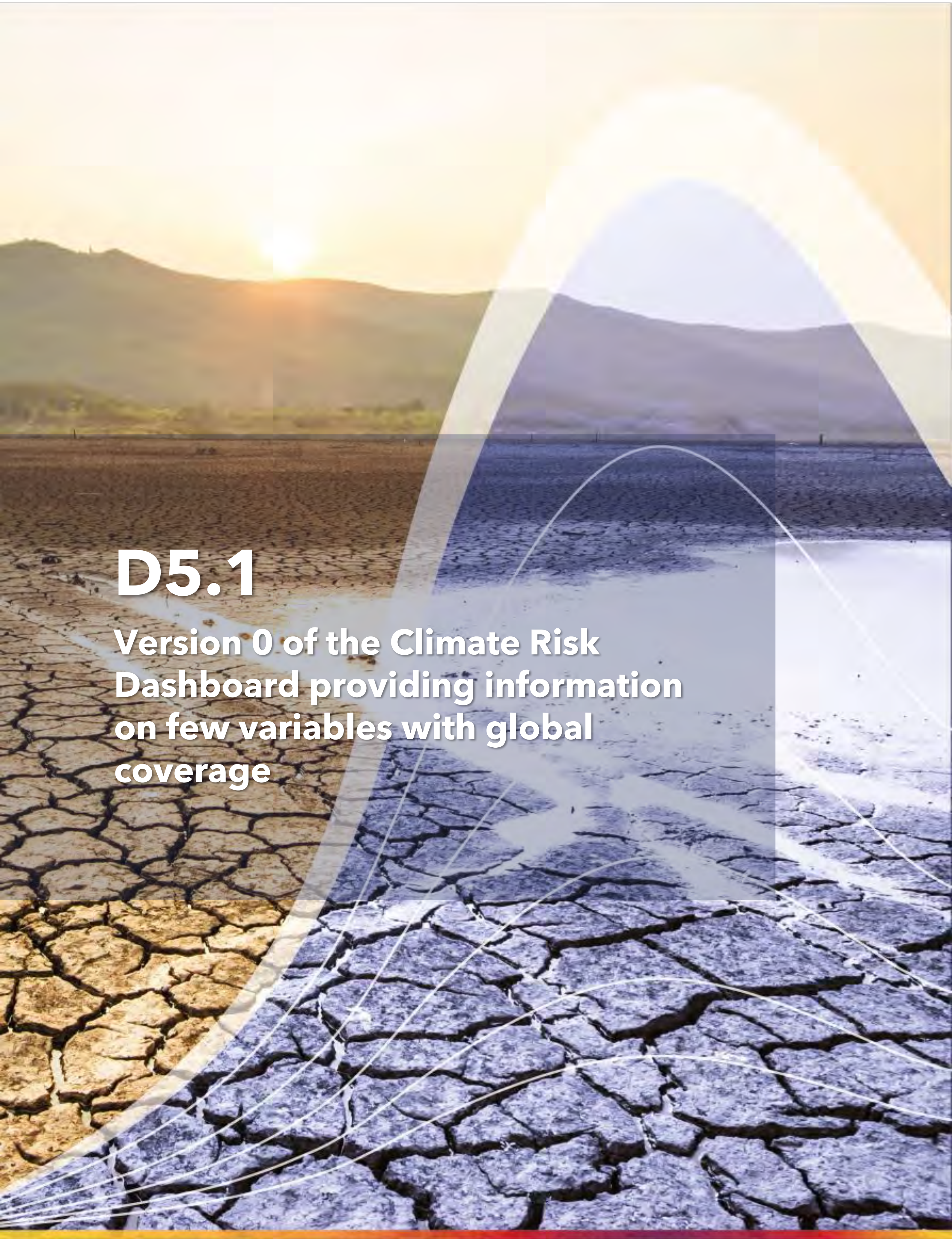

D5.1

Version 0 of the Climate Risk Dashboard providing information on few variables with global coverage

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D5.1 Version 0 of the Climate Risk Dashboard providing information on few variables with global coverage

Deliverable lead beneficiary: Climate Analytics (CA)
Authors: Quentin Lejeune (CA)

Internal Technical Auditor	Name (Beneficiary short name)	Date of approval
Task leader	Quentin Lejeune (CA)	15.09.2022
WP leader	Quentin Lejeune (CA)	15.09.2022
Coordinator	Carl-Friedrich Schleussner (HU)	26.09.2022
Project Office	Sophie Rau / Andreas Schweinberger (AI)	26.09.2022

Abstract: This report describes the version 0 of the Climate Risk Dashboard, the webtool that will provide climate impact information summarising the outcomes of the PROVIDE project. The report contains a guided tour through the version 0 of the webtool, and describes the data it allows to visualise as well as the processing steps that were applied to them.

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Project duration:	36 months

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Dissemination Level
PU Public

Table of content

1. Introduction

The PROVIDE project aims to better understand and illustrate the potential environmental and economic impacts that would result from overshooting the 1.5°C temperature goal set out in the Paris Agreement, to better equip researchers and adaptation practitioners. To attain these objectives, the PROVIDE consortium first strives to advance science on the implications of overshoot pathways in terms of local impacts and adaptation needs, and then will also deliver resulting information through an innovative web tool.

This webtool, called the PROVIDE Climate Risk Dashboard, will illustrate the outcomes of the research and stakeholder engagement activities conducted under the PROVIDE project. This first means that it will deliver information for different future global warming scenarios and their expected impacts on the climate, natural, and human systems, covering a suite of future climate impacts such as: extreme events, biodiversity loss, cryosphere loss, sea-level rise, agriculture, economic loss etc., at the global, regional, and city level. Moreover, the Climate Risk Dashboard will include state-of-the-art assessments of overshoot scenarios - in which average global temperatures would temporarily 'overshoot' the 1.5°C target of the Paris Agreement before being brought back down again. Overshoot scenarios are prominent in the latest IPCC reports, but specific risks inherent to them, including potentially irreversible impacts (such as species extinction), have so far been under-researched. Then, the Climate Risk Dashboard allows researchers, adaptation practitioners and other users to take a risk-based approach. Users will be able to set risk thresholds for societal and geophysical impacts for example, heatwaves or sea level rise that should be avoided, and then access information on the conditions and characteristics of emissions scenarios under which the selected threshold can be avoided, or not. The Climate Risk Dashboard is being co-developed with stakeholders such as adaptation practitioners. To promote knowledge exchange, it will eventually feature information on how it has been used for adaptation planning in various contexts within the PROVIDE project.

A final version of the Climate Risk Dashboard including information covering a range of scientific outcomes from the PROVIDE project will be released towards its end (planned for August 2024). This report describes the structure of a first version of the Climate Risk Dashboard, 'version 0' (short, v0), its development process, the data it features as well as how they have been obtained then processed for integration in the tool, and the type of information and scientific conclusions that can be drawn from it.

2. Guided tour through the Climate Risk Dashboard v0

The development of the Climate Risk Dashboard v0 is based on the wireframes of the tool that were developed during the first seven months of the project and were finalised in April 2022 (Milestone 5.1). This section describes a fraction of the pages that will eventually be included in the tool, hereby reflecting the designs originally suggested in the wireframes for those same pages.

The tool is accessible at this url: *https://climate-risk-dashboard.climateanalytics.org*.

2.1. Landing page

The landing page or home page of the Climate Risk Dashboard (Figure 1) constitutes the entry point to the tool for its users. The panel at the top of the page includes a slide show featuring some of the analyses that can be explored on the tool and that its maintainers can choose to highlight. For example, the item shown on Figure 1 provides a quick entry point that leads – with a single click – to an analysis comparing the evolution of mean temperature in Australia under three greenhouse gas emission scenarios.

Below this part of the page, a very short text is meant to provide guidance on what the tool allows users to do and how to navigate it. Following this section is the last part of the page, located at the bottom, which offers the possibility to choose between two user modes. Each user mode will eventually be accessible by clicking on either of the two squares located at the bottom of this page.

The first mode, labelled 'Impacts', follows the classic mode of information provision used in many climate services webtools, through which users can visualise climate impacts for their scenario and geography (for now a country, but future versions could include cities, for example) of interest. This mode was chosen to be integrated in the Climate Risk Dashboard to provide a user experience in which common users of climate service webtools can easily comprehend, while displaying data that reflect the specific scientific outcomes of the PROVIDE project (new emissions scenarios, data produced using climate model emulators, see also Section 3).

The second mode, labelled 'Emission Scenarios', will eventually make use of the reversed impact modelling developed in PROVIDE to allow for a completely new user experience centred on local impacts experienced by a natural or human system. Adaptation to local impacts is often designed to cope with a certain level of impacts (or threshold) that are deemed critical for the functioning of that system of interest (for example, a dyke is dimensioned to protect against a 1-in-100-year flood event). Therefore, in this mode users will first have the possibility to set a threshold for a climate impact indicator for their geography of interest (for example, increase in mean temperature by +2°C compared to pre-industrial levels over Denmark), then to explore the characteristics of greenhouse gas emission scenarios under which this threshold will or will not be exceeded. This second mode relies on scientific results produced later in the project and is thus not included in the Climate Risk Dashboard v0.

Additionally, a header and a footer will be included in every page of the tool and provide the opportunity to access other pages of the webtool. They also include the name of the PROVIDE project and of the partner institution responsible for the development of the Climate Risk Dashboard as well as hosting and maintaining it (Climate Analytics).

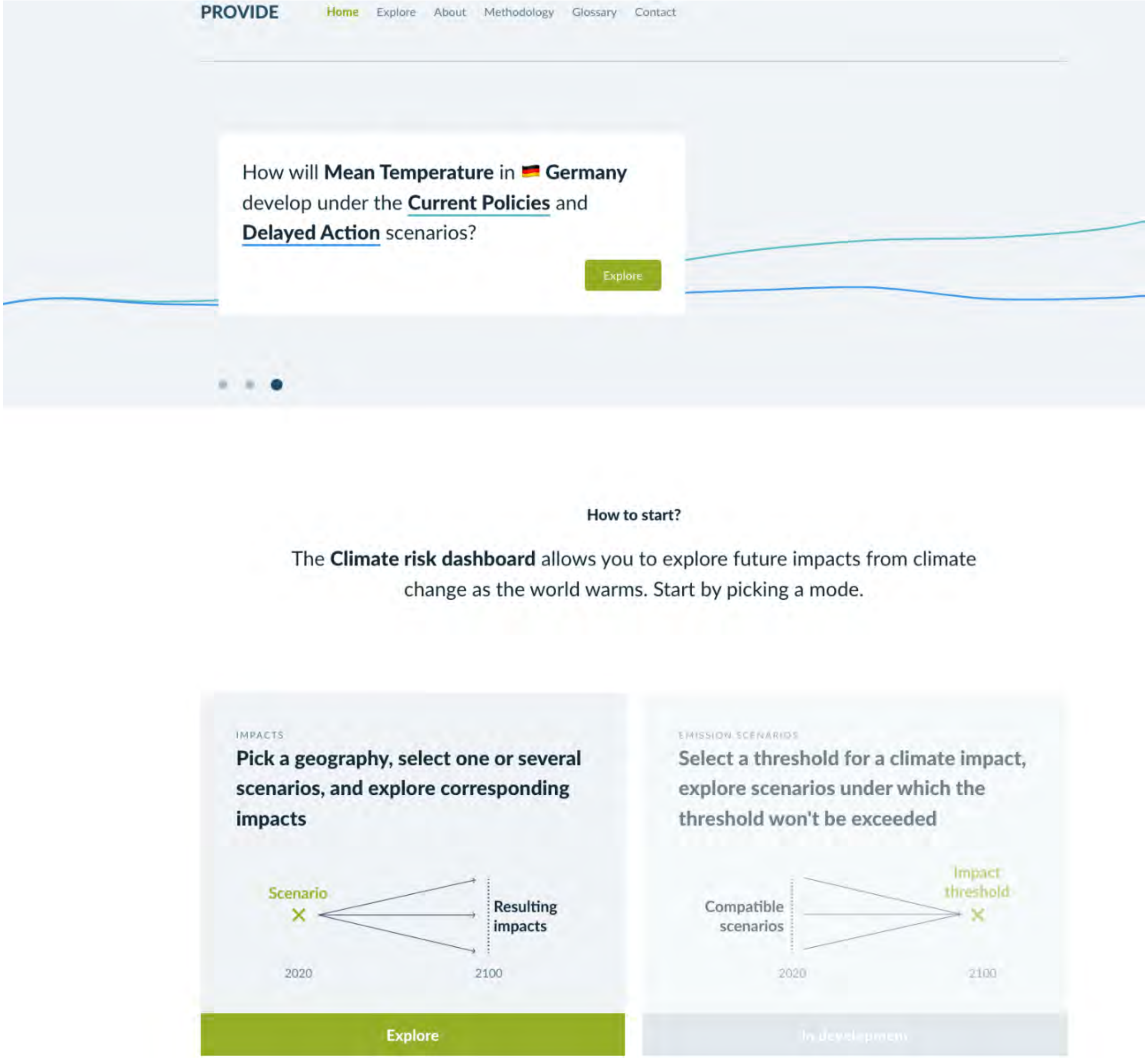

Figure 1: Landing page of the Dashboard v0.

2.2. 'Explore Impacts' page

After clicking on the left square at the bottom of the 'Explore Impacts' page, users will arrive on a page of which a complete view (including parts that will only be accessible by scrolling up/down in the browser) is provided in Figure 2.

The upper part of this page (in grey below the header) offers again the possibility to switch between the two user modes via a single click. It includes a description of what type of information can be accessed for each user mode.

Below that, the user can select three parameters for their exploration: the geography, the greenhouse gas emission scenarios as well as the indicators for which they want to visualise future climate impacts. The selection of these parameters is described in more detail in sections 2.2.1, 2.2.2 and 2.2.3. The three squares located at the transition between the upper grey part and the middle part allowing for parameter selection constantly recall to the user the current selection of parameters (in Figure 2, this is 'Ukraine', '1.5 - shifting pathway' and 'Mean Temperature').

Further below, climate impacts corresponding to the user selection can be visualised via different graphs accessible by clicking on the different tabs. This part of the 'Explore Impacts' page is described in Section 2.2.4.

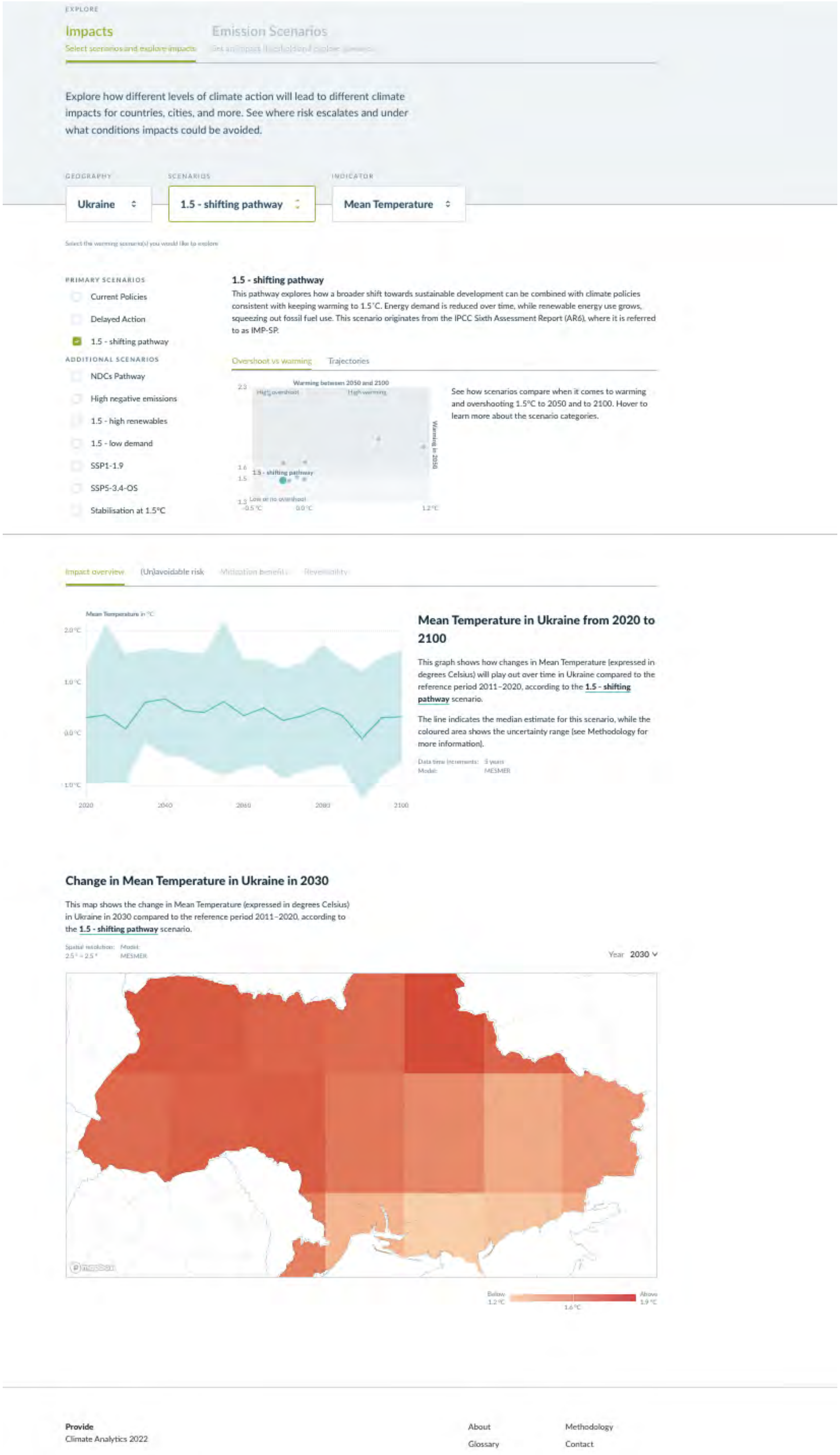

Figure 2: Full view of an 'Explore Impacts' page. Zooms on specific parts of this page are provided in figures below. Note: these plots are based on preliminary, non-published data, we explicitly ask not to re-use them.

2.2.1. Geography selection

Users can first select the type of geography they are interested in the list on the left-hand-side. In v0, only 'Countries' can be selected, but in future versions 'Cities' will also become available. The selection of a country can then be refined by typing a country in the field on top of the list visible in the middle part of Figure 3 or selecting it from the list. When hovering over a country name in the list, it becomes highlighted on the map visible on the right-hand-side of Figure 3.

Figure 3: Zoom on the Geography selector on the 'Explore Impacts' page. As an example, the country 'Germany' is currently selected but the tool shows possible results if a user searches for a country containing the letters 'Ango'.

2.2.2. Scenario selection

By clicking on the square below 'Scenarios', users can access the view visible on Figure 4. Here they can refine their choice of a scenario among the list of 10 scenarios visible on the left-hand-side of Figure 4. Up to three scenarios can be selected at the same time. The tool provides two ways to visualise how the main defining characteristics of these scenarios compare, in order to inform the scenario selection by the user. These two ways are accessible by clicking on either of the two tabs 'Overshoot vs warming' or 'Trajectories'.

Figure 4 illustrates what can be seen when clicking on the tab 'Overshoot vs warming'. This schematic ways of categorising the scenarios focuses on two of their defining characteristics: the amount of global warming compared to pre-industrial levels that they lead to by 2050 as well as between 2050 and 2100. This divides the space of possible scenarios in four possible clusters, the 10 PROVIDE scenarios accessible on the 'Explore Impacts' page falling in three of them:

- **High overshoot** scenarios exceed 1.5°C by more than 0.1°C by 2050 but exhibit a decrease in global mean temperature in the second half of the 21st century. These scenarios are especially useful to see if climate impacts are reversible after warming has stopped and temperatures have been brought back down.
- **Low or no overshoot** scenarios exceed 1.5°C of warming level by at most 0.1°C, and if so exhibit a decrease in global mean temperature in the second half of the 21st century. These scenarios are primarily used to explore climate impacts close to the 1.5°C warming limit of the Paris Agreement.

- Scenarios with **high continuous warming** exceed 1.5°C of warming by 2050, and see further warming thereafter. They are useful to see the climate impacts that would result from high levels of global warming.

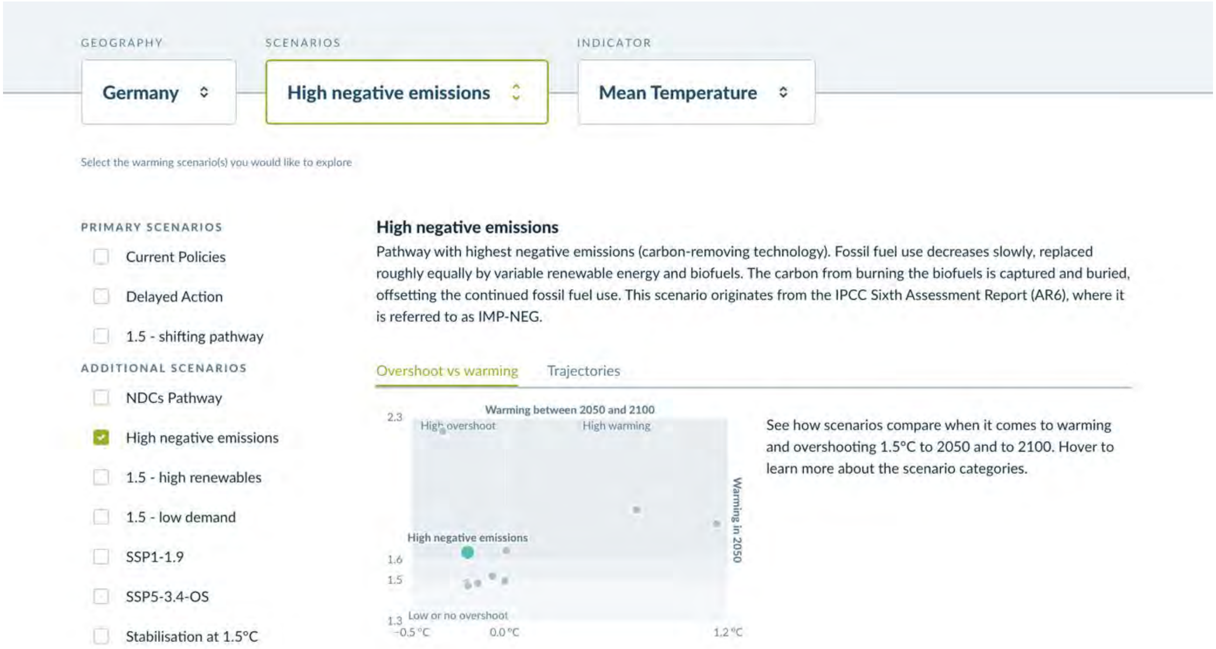

Figure 4: Zoom on the Scenario selector on the 'Explore Impacts' page, when the tab 'Overshoot vs. warming' is selected. As an example, the scenario 'High Negative Emissions' (contained in the 'High overshoot' quadrant) is currently selected. Note: this illustration is based on preliminary, non-published data, we explicitly ask not to re-use it.

Clicking on the tab 'Trajectories' leads to the view shown in Figure 5. Here, users can visualise the evolution of global greenhouse gas emissions between 2020 and 2100 for each of the 10 scenarios (in $GtCO_2eq$/year), as well as the median of the distribution of resulting Global Mean Temperature trajectories (calculated with the simple climate model FAIR, see Section 3).

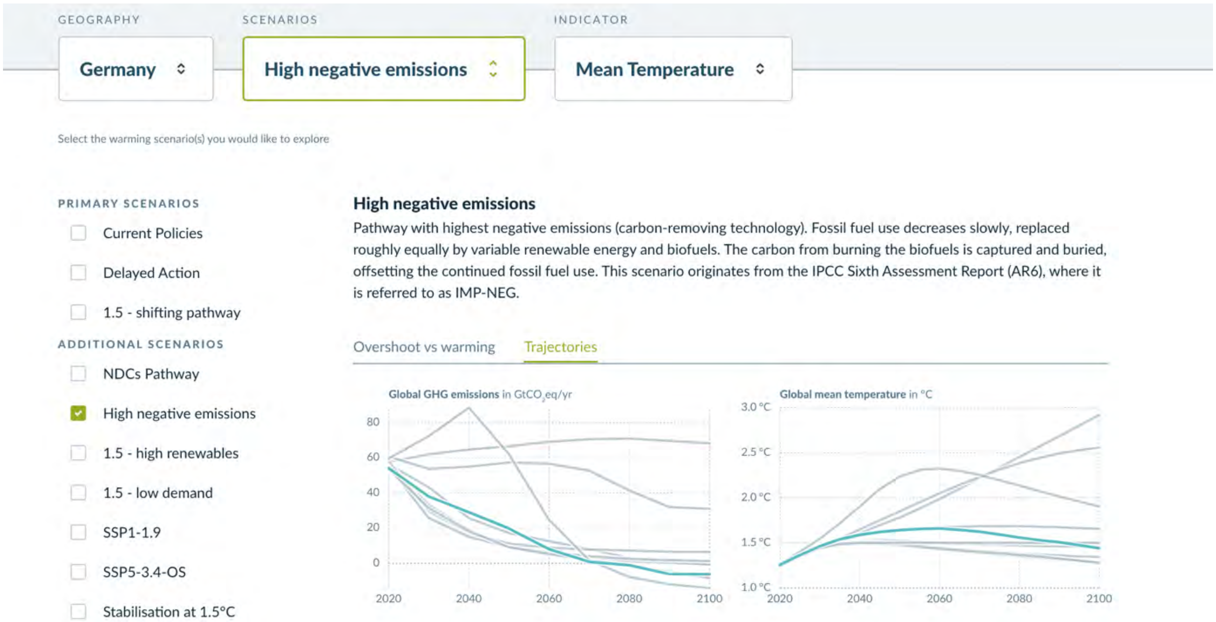

Figure 5: Zoom on the Scenario selector on the 'Explore Impacts' page, when the tab 'Trajectories' is selected. As an example, the scenario 'High Negative Emissions' is currently selected. Note: these graphs are based on preliminary, non-published data, we explicitly ask not to re-use them.

2.2.3. Indicator selection

By clicking on the square below ‘Indicator’, users can access a view close to what is visible on Figure 6. Here they can choose an indicator from the list of available ones by clicking on the corresponding thumbnails, which display a quick overview of the trajectories of impacts for the currently selected country-scenario combination. Indicators are classified in categories called sectors; a list of sectors for which indicators will eventually become available is visible on the left-hand-side of Figure 6. A range of options can be specified to refine the indicator definition. For example, the reference period over which the baseline values to which future changes in the indicator should be compared can be selected by the user among two possibilities: 2011-2020 and 1850-1900.

Figure 6: Zoom on the Indicator selector on the ‘Explore Impacts’ page. As an example, the indicator ‘Mean Temperature’ and the reference period 2011-2020 are currently selected. This indicator belongs to the Sector ‘Terrestrial Climate’.

2.2.4. Visualisation of impacts

At the bottom of the ‘Explore Impacts’ page, future impacts can be visualised through various graphs and maps for the geography, scenario(s) and indicator selected by the users. These graphs and maps are sorted in different tabs that focus on specific aspects of the impact projections.

2.2.4.1. Impact overview

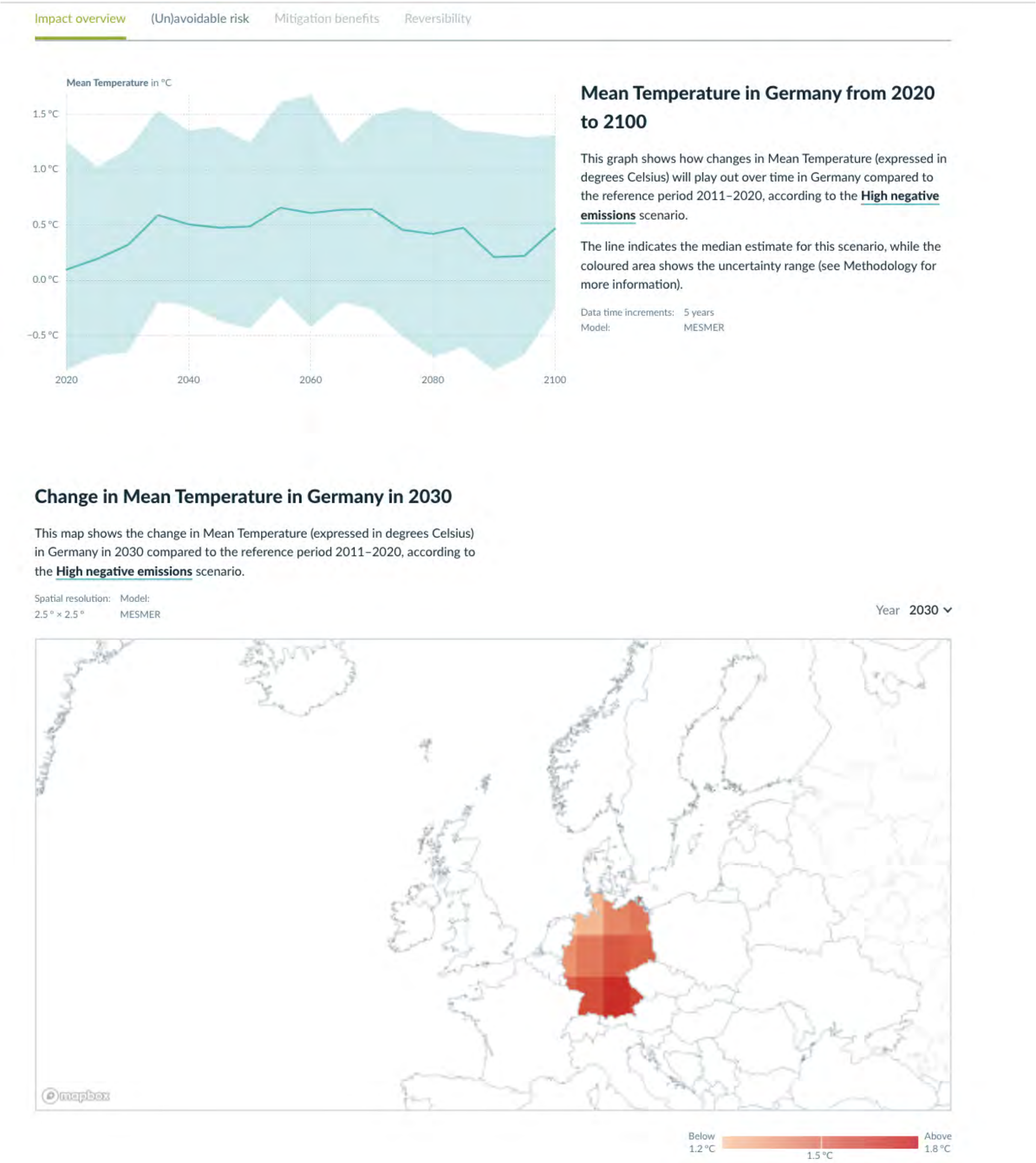

Figure 7: Zoom on the bottom part of the 'Explore Impacts' page, when the 'Impact Overview' tab and one single scenario have been selected. As an example, the indicator 'Mean Temperature', the geography 'Germany' and the scenario 'Shifting Pathways' have been selected. Note: these plots are based on preliminary, non-published data, we explicitly ask not to re-use them.

The tab 'Impact overview' provides an overview of future impacts for the user selection (Figure 7). A time series graph shows how changes in the selected indicator will play out over time for the selected geography and scenario. The median estimate is indicated by the thick line, while the uncertainty range is visualised via the shaded envelope around this line. Below, a map visualises changes for the selected geography, indicator, and scenario, for a specific year which can be selected by the user from three possibilities (2030, 2050 and 2100).

When multiple scenarios are selected, the time series graph only shows the median estimates for each scenario (without the respective confidence intervals). Below, three maps are then provided side by side, allowing for comparison of impacts across scenarios.

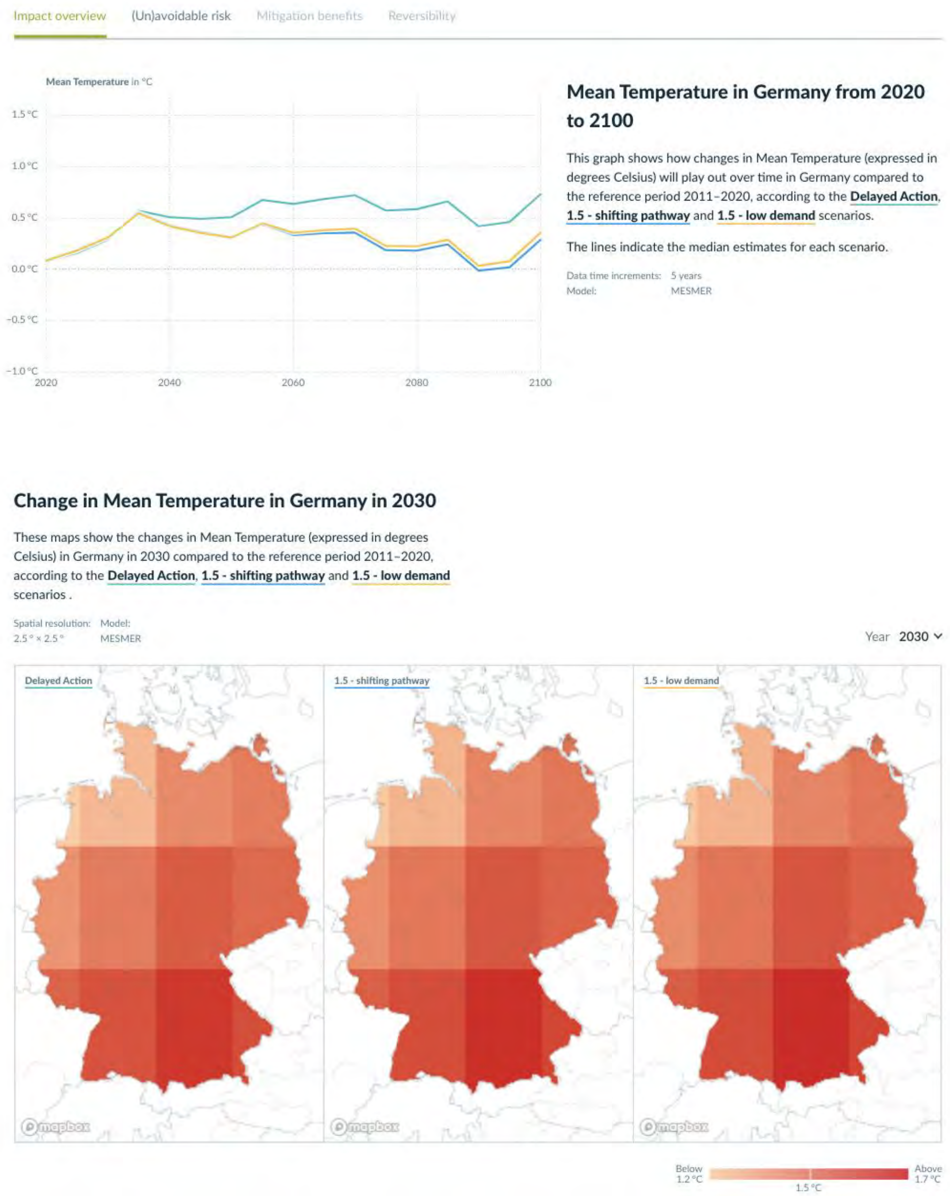

Figure 8: Zoom on the bottom part of the 'Explore Impacts' page, when the 'Impact Overview' tab and three scenarios have been selected. As an example, the indicator 'Mean Temperature', the geography 'Germany' and the scenarios 'Delayed Action', '1.5 - Shifting Pathways', and ' 1.5 - Low Demand' have been selected. Note: these plots are based on preliminary, non-published data, we explicitly ask not to re-use them.

2.2.4.2. (Un)avoidable risk

The tab '(Un)avoidable risk' allows the visualisation of projected impacts in a different manner, this time focusing on the risk of changes in a mean climate variable crossing a specific threshold, or changes in the risk of occurrence (hence, frequency) of climate extreme events.

Figure 9 illustrates an example of what can be obtained when selecting the indicator 'Mean Temperature', the reference period 2011-2020, the geography 'Germany' and the scenarios '1.5 - shifting pathway', '1.5 - low demand' and 'Delayed Action'. For this indicator, a threshold can be selected from the list available above the graph (in Figure 9, 0.5°C is selected). The bar chart then shows how the risk of changes in mean temperatures in Germany exceeding 0.5°C from 2011-2020 levels evolves in the 21st century: today (defined as 2011-2020), as well as in 2030, 2050, and 2100 according to the 10 PROVIDE scenarios. Because these scenarios span over the range of possible climate outcomes in the 21st century – between the Current Policies scenario, leading to the highest global mean temperature increase by 2100, and the Shifting Pathways scenario, considered as the scenario with the highest feasible mitigation levels – this bar chart illustrates what fraction of the described risk will remain unavoidable (even with the highest-ambition scenario), and what fraction of that risk is avoidable through mitigation.

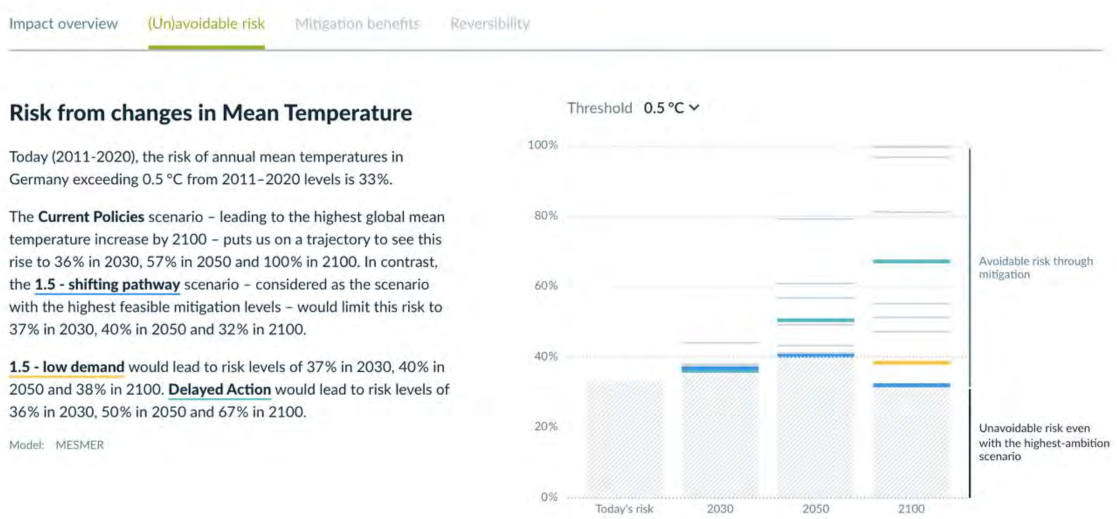

Figure 9: Zoom on the bottom part of the 'Explore Impacts' page, when the ''(Un)avoidable risk' tab and three scenarios have been selected. As an example, the indicator 'Mean Temperature', the geography 'Germany' and the scenarios 'Shifting Pathways', 'Low Demand' and 'Delayed Action' have been selected. For the indicator, a threshold needs to be selected by the user – here it is 0.5°C. Note: these plots are based on preliminary, non-published data, we explicitly ask not to re-use them.

If users select the indicators 'Cold Extreme' or 'Hot Extreme', they don't need to specify a threshold. This is because by specifying the frequency of occurrence of this type of extreme (for example, 1-in-20-year) and the reference period of interest (for example, in 2011-2020), they automatically define the return period of such an extreme event and therefore their risk of occurrence (for example, once in 20 years in 2011-2020).

The (un)avoidable risk graphs are meant to illustrate the benefits of global mitigation in terms of avoided local impacts beyond critical thresholds, with the possibility for the users to specify here the thresholds that characterise their systems of interest.

2.3. About, Contact, Glossary and Methodology pages

The PROVIDE Climate Risk Dashboard also includes four additional pages:

- The About page contains a short description of the webtool and the type of information it allows to explore, a list of contributors to its development, a mention of the funding source, information on the licence applied to the data featured on the tool, on how to cite these data, as well as a list of acknowledgements.
- The Contact page lists links to subscribe to newsletters to receive updates on the tool development and the PROVIDE project, as well as email addresses to which users can write for media enquiries or clarification questions.
- The Glossary lists definitions of key terms employed in the tool, as well as of the indicators it allows to explore.
- The Methodology page contains descriptions of the models that were used to produce the data featured in the Climate Risk Dashboard, a description of the scenarios for which resulting climate impacts are visualised, as well as of how the data produced by WP2 were processed before being visualised on the Climate Risk Dashboard

3. Data and Methods

The PROVIDE Climate Risk Dashboard v0 allows to explore data produced by WP1 and WP2 of the PROVIDE project. These data are preliminary and for some of them not published. The models used to produce them, as well as the processing steps applied before their inclusion in the Climate Risk Dashboard v0 are described in this section.

3.1. Models

The projections of climate impacts that are visualised on the PROVIDE Climate Risk Dashboard were computed with numerical models (algorithms). These models describe the evolution of human or natural systems under different global warming scenarios by solving a range of mathematical equations. One characteristic of the PROVIDE project is that it largely makes use of emulators, that is, relatively simple models that imitate the behaviour of more complex ones. Their simplicity also means that they require less computing power, thus allowing to explore more scenarios or to conduct multiple runs to more finely distinguish actual impacts from the noise induced by natural variations.

3.1.1. FaIR

FaIR is a simple climate model, replicating the warming behaviour of more complex climate models without the computational complexity. It simplifies the Earth system to consist of a few boxes that each store carbon, and which may be interpreted as deep Earth (its crust, mantle and core), the biosphere, deep ocean, and the ocean mixed layer at its surface. The levels of carbon in each layer are influenced by emissions, both human and natural. FaIR then calculates how these emissions translate into concentrations of greenhouse gas and aerosols using simple relationships, and combines them with estimates of other climate change drivers (such as cloud-formation from aviation, solar variability and land use reflectiveness changes) to give a model of the total strength of the forcing imposed on the climate system. This is then used to calculate the change in the Earth's temperature. The many parameters required by these relationships are constrained to match both historic warming and the expected levels of future warming in idealised experiments agreed on in the IPCC assessment (cross-chapter box 7 of WG1 chapter 5). To derive the characteristics of the PROVIDE emissions scenarios and their resulting Global Mean Temperature trajectories, WP1 of PROVIDE used FaIR version 1.6.4.

3.1.2. MESMER

The **Modular Earth System Model Emulator with spatially Resolved output (MESMER)** is a statistical model that simulates the possible evolution of key climate variables over land areas for a given Global Mean Temperature (GMT) trajectory, by emulating) the behaviour from more computationally expensive Earth System Models (ESMs). Calibrated on existing scenario projections produced by ESMs, it combines estimates of the local forced response of the climate to increasing emissions, as well as of the impact of natural climate variability. Its simplicity and flexibility allow it to produce very robust estimates of future possible climate outcomes within minutes, even for GMT trajectories it hasn't been trained on. The current MESMER analyses are based on Beusch et al. (2020) and Beusch et al. (2022); for a full description of the data see Schwaab et al. (in preparation).

3.2. Scenarios

Information on future climate impacts is commonly produced and provided for scenarios defined by their greenhouse gas emissions or concentrations trajectories. While the evolution of global mean temperature (GMT) that these trajectories are leading to is a more direct driver of climate impacts, depending on the employed climate model, there is considerable uncertainty on how GMT responds to emissions (a measure called climate sensitivity). Moreover, scenarios used for impact assessments are often not related to implemented climate policies, nor to policy objectives such as from the Paris Agreement. Furthermore, although temperature overshoots feature prominently in the literature on mitigation pathways, their implications for impacts have so far been under-researched. Finally, because climate and climate impact models are often complex and thus expensive to run, impacts are commonly calculated for a limited number of scenarios, and few ensemble members can be run to assess the influence of natural variability for one single scenario.

In the PROVIDE project, a core idea of the scenario design is that GMT is the defining feature for assessing climate impacts. This means that the PROVIDE WP1 selected scenarios that span a range of GMT outcomes with regard to near-term warming, peak warming, and overshoot, according to our best understanding of climate sensitivity and associated uncertainty. They made sure to include some scenarios that reflect currently implemented or formulated policies, or that align with the long-term temperature goal of the Paris Agreement. They consider scenarios that remain below the 1.5°C warming limit of the Paris Agreement or overshoot it by various extents, with some exhibiting a decrease in GMT after reaching peak warming, or not. Finally, because impact assessment in the PROVIDE project mostly relies on a suite of lightweight climate or climate impact model emulators, up to 10 scenarios can be explored.

Eventually, the 10 PROVIDE scenarios for which resulting climate impacts can be explored in the Dashboard can help address the following research questions, which were kept in mind during the scenario selection and design process:

- What is the difference between (a) permanently exceeding 1.5°C and stabilising at a higher level, (b) stabilising at 1.5°C of warming, (c) peaking above 1.5°C and returning to 1.5°C in either 2100 or 2300?
- What is the difference between following current trends until 2100 and a 1.5°C-compatible world?
- Assuming current policies until 2100, how much can temperatures be reversed until 2300?
- What are the differences in societal risk for similar 1.5°C compatible pathways?
- What can be said about the emergence of avoided climate risks in the near-term? What’s the range of different climate risks outcomes in 2050 – a timescale relevant for climate adaptation?
- What are long-term (multi-century) climate outcomes from achieving and sustaining net zero greenhouse gas emissions?
- Is climate change fully reversible?
- How does impact and overshoot reversibility depend on different levels of peak warming?

These emissions scenarios fall into three categories:

- Seven of them were defined for the contribution of the Working Group III of the IPCC (focusing on mitigation of climate change) to its Sixth Assessment Report (AR6);

- Two were defined as part of phase six of the Coupled Model Intercomparison Project (CMIP6), designed to provide multi-model climate projections that constituted the basis for many scientific assessments included in AR6;
- One – the 'Stabilisation at 1.5°C' scenario – is designed by the PROVIDE consortium

In the case of the first nine scenarios, they were selected from the AR6 database or other published datasets, and the GMT evolutions resulting from their greenhouse gas emissions trajectories were derived using the climate model emulator FaIR version 1.6.4 (see Models). For further information on the scenarios, please refer to the white paper describing them (Lamboll et al., 2022). The scenario data are publicly available via Zenodo.

3.2.1. Scenarios defined for the IPCC Working Group III contribution to AR6

Most information included in this section is adapted from Section 1.5 of Chapter 1 of the IPCC Working Group III (WG3) contribution to AR6 (IPCC AR6 WG3 Ch1 | 2022, Grubb et al., 2022).

For AR6, the IPCC WG III considered more than 2500 model-based scenarios published in the scientific literature. Drawing from this database, five so-called Illustrative Mitigation Pathways (IMPs) were defined for the report to illustrate different possible global mitigation strategies that are recurrent across the entire WG III assessment. Additionally, two scenarios were selected from the database that illustrate the consequences of current climate policies and pledges. Originally defined for their characteristics with regard to global mitigation, these seven scenarios are re-used in the PROVIDE project so that resulting impacts can be assessed and compared. More information on them is provided in this section.

The PROVIDE scenarios based on the five Illustrative Mitigation Pathways are:

- 1.5 - Shifting Pathway (short, SP)
- 1.5 - High Renewables (Ren)
- 1.5 - Low Demand (LD)
- High Negative Emissions (Neg)
- Delayed Action (DA)

In AR6 these were originally called IMP-SP, IMP-Ren, IMP-LD, IMP-Neg, and IMP-GS, respectively. The five IMPs are organised around two dimensions: the level of ambition consistent with meeting the Paris Agreement goals and key characteristics of the scenario related to mitigation strategies (for example, high levels of renewables deployment).

DA exhibits the lowest level of ambition of the five; it follows current policies until 2030 but could stay below 2°C if followed by very fast emissions cutbacks. The Neg scenario is characterised by somewhat higher emission reductions by 2030, and a significant decrease in GMT in the second half of the 21st century achieved through the large-scale deployment of Carbon Dioxide Removal technologies in the energy and industry sectors leading to net global emissions. According to the best estimate of the calculations conducted with the FaIR climate model emulator, this decrease in GMT would bring global warming back to below 1.5°C after significant overshoot.

SP, Ren and LD illustrate other key characteristics related to mitigation strategies and all achieve rapid emission reductions in the short-term, which would keep global warming close to the 1.5°C limit of the Paris Agreement without large overshoot. A key mitigation strategy featured in LD is exploiting opportunities for demand reduction. Ren shows how transforming energy systems through upscaling electrification and renewable energy penetration can also achieve massive emission reductions. In contrast, SP explores how shifting development pathways to achieve sustainable development goals can also result in deep emission reductions.

Apart from the IMPs, Current Policies (CurPol) was designed to investigate the outcomes of climate policies implemented in 2020, in case they only get gradually strengthened after 2030. The NDCs Pathway (NDC), originally called Moderate Action by the IPCC, explores the consequences of the implementation of the Nationally Determined Contributions to 2030 and no further reinforcement of climate policies thereafter. Both scenarios result in Global Mean Temperature levels above 2°C.

These seven scenarios are meant to illustrate a range of climate futures linked to future emissions reductions. They also show that there are several ways to achieve the long-term temperature goal of the Paris Agreement. However, these scenarios are not intended to be comprehensive, and do not aim at illustrating the range of possible themes in the IPCC WG3 contribution to AR6. They are primarily scenarios of technological evolution and demand shifts that echo various global trends in societal choice. This means that they do not aim at capturing the whole range of possible future socioeconomic pathways and their consequences for mitigation, at reflecting regional variations in development and climate action, nor do they explore issues around income distribution and environmental justice.

Nevertheless, selecting these scenarios on the PROVIDE Dashboard offers a good basis to explore impacts resulting from the GMT outcomes they would lead to, ultimately linked to the ability of the world's individuals and societies to cut back greenhouse gas emissions. Because they span a range of possible climate futures, they are also helpful to approximate impacts from other scenarios defined by other characteristics with regard to global mitigation, but leading to similar outcomes in terms of emissions and resulting global warming.

3.2.2. Scenarios defined as part of phase six of the Coupled Model Intercomparison Project (CMIP6)

Most information included in this section is adapted from the paper by O'Neill et al., 2016. For more extensive information, please refer to this document.

The scenarios ssp1-1.9 and ssp5-3.4-OS were defined as part of Phase 6 of the Coupled Model Intercomparison Project (CMIP6). This numerical experiment was designed to compare climate projections of various climate models for a common set of greenhouse gas emissions or concentration scenarios. The resulting climate and climate impact projections have been described in many peer-reviewed studies. Given their prominence in the climate and climate impact modelling community, they are being considered under the PROVIDE project to provide an easy way to compare our results to previously published ones.

Both ssp1-1.9 and ssp5-3.4-OS are driven by emissions and land use trajectories produced with integrated assessment models (IAMs) based on future pathways of societal development, the shared socioeconomic pathways (SSPs, see Riahi et al., 2016). There are five SSPs in total, which follow distinct broad narratives and describe potential futures in which challenges for adaptation and mitigation vary from low to high:

- SSP1: Sustainability (taking the green road, low challenges to mitigation and adaptation)
- SSP2: Middle of the road (medium challenges to mitigation and adaptation)
- SSP3: Regional rivalry (a rocky road, high challenges to mitigation and adaptation)
- SSP4: Inequality (a road divided, low challenges to mitigation, high challenges to adaptation)
- SSP5: Fossil-fuelled development (taking the highway, high challenges to mitigation, low challenges to adaptation)

The narratives of SSP1 and SSP5 were used as a basis to derive the emissions trajectories for ssp1-1.9 and ssp5-3.4-OS, respectively.

ssp1-1.9 and ssp5-3.4-OS are also related to representative concentration pathways (RCPs; van Vuuren et al., 2011), a set of pathways of land use emissions and emissions of air pollutants and greenhouse gases that span a wide range of future outcomes through 2100 and have commonly been used in the climate modelling community.

Produced within CMIP5 using IAMs, their use was central for climate science research conducted during the IPCC Fifth Assessment Report (AR5) cycle. The change in energy flux in the atmosphere due to human activities (called radiative forcing and expressed in W/m2) achieved at the end of the 21st century and relative to pre-industrial levels, define the RCPs as well as the SSP-RCP combinations: for example, 1.9 W/m2 for ssp1-1.9 and 3.4 W/m2 for ssp5-3.4-OS.

Because it doesn't exceed relatively low radiative forcing values along the 21st century, ssp1-1.9 is considered as being compatible with the long-term temperature goal of the Paris Agreement (keeping the global mean temperature increase compared to pre-industrial levels well below 2°C, and bringing it back down to below 1.5°C by 2100).

ssp5-3.4-OS investigates the implications of a substantial 21st century overshoot in radiative forcing relative to a longer-term target. This scenario follows SSP5-8.5 through 2040, at which point aggressive mitigation is undertaken to rapidly reduce emissions to zero by about 2070 and to net negative levels thereafter. Such a level of mitigation would be more ambitious than what is happening in most high-ambition scenarios simulated with IAMs, and is thus deemed unfeasible. However, ssp5-3.4-OS provides a way to explore the consequences of such colossal variations for the climate system.

3.2.3. The 'Stabilisation at 1.5°C' scenario

This scenario has been designed through the PROVIDE project. It is meant to assess climate impacts if global mean temperature is held constant at 1.5°C above pre-industrial levels, and how these would differ from other scenarios where global mean temperature would exceed and potentially be brought back down to below this global warming level.

3.3. Processing of MESMER data

This section describes the data that were produced by the PROVIDE WP2 using MESMER (see Section 3.1.2) for integration in the Climate Risk Dashboard, and how they have been processed in order to be implemented in the webtool. The information provided here reflects the status at the time of the submission of this report, but the data as well as the processing steps will be subject to some modifications over the course of the project.

In total, WP2 conducted 22500 runs with MESMER (i.e., produced 22500 MESMER emulations):

- For each of the 10 PROVIDE scenarios (see Section 3.2);
- For 9 quantiles of the GMT distribution calculated by FAIR for each scenario (see Section 3.1.1);
- For 25 configurations, each obtained by calibration on a different Earth System Model from the CMIP database;
- Additionally, 10 stochastic realisations were conducted for each scenario, quantile of the FAIR distribution and MESMER configuration in order to account for natural climate variability.

These data will be described in a peer-reviewed paper by Schwaab et al., currently in preparation.

3.3.1. List of available countries

The data produced by MESMER have a spatial resolution of 2.5x2.5°. We chose to only include in the Dashboard v0 information for countries that are large enough to cover an area at least as large as 1.5 equivalent grid cells (i.e., once the fraction of grid cells included within the borders of the countries has been summed up).

3.3.2. Data featured in the ‘Impact Overview’ tab of the ‘Explore Impacts’ page

The data showed on the map were obtained by calculating the median of the distribution of MESMER results over each grid cell, for each of the 10 scenarios and for each year that can be selected by the user (2030, 2050, and 2100).

The data showed on the time series plot were calculated as follows. First, for each scenario and each country, area-weighted averages over the whole country were calculated for each MESMER emulation (10 stochastic realisations, 9 quantiles of the GMT distribution produced by FAIR, 25 configurations). As a result, 2250 time series were obtained for each country-scenario combination.

The median estimates (thick line on the graph, see 2.2.4.1) were calculated as follows:

- For mean temperature, the median of the 2250 time series was calculated for each possible reference period and for each time step used in the projections (2020 to 2100 in 5-year increments). Reference values for the 1850-1900 and 2011-2020 reference periods were obtained by calculating the median values over the respective time periods. Values for each time step in the projection period are calculated by getting the median of all values in a 11-year window centered over the time step of interest pooled together.
- For cold and hot extreme, the percentile corresponding to each possible frequency (1-in10, 1-in-20, 1-in-50, 1-in-100) was assessed from the distribution constituted by the 2250 time series, for both the reference periods and each time step used in the projections (2020 to 2100 in 5-year increments). Reference values for the 1850-1900 and 2011-2020 reference periods were obtained by calculating the percentile values over the respective time periods. Values for each time step in the projection period are calculated by getting the percentile of interest from all values in a 11-year window centered over the time step of interest pooled together.

The uncertainty bounds (shaded envelope on the graph) around the median were calculated as follows:

- For mean temperature: the 10th and 90th percentiles of the distribution constituted by the 2250 time series were assessed for the reference periods and each time step used in the projections (2020 to 2100 in 5-year increments). Reference values for the 1850-1900 and 2011-2020 reference periods were obtained by calculating the percentile values of all values in a 11-year window centered over the time step of interest pooled together.

For cold and hot extremes, a bootstrapping (resampling with replacement) was applied to the 2250 time series to calculate several estimates of the percentile values corresponding to each possible frequency of an extreme event. The bootstrapping procedure was applied 100 times, keeping a sample size of 100 time series. It was applied to the whole time series (not to each year individually). The percentile values (for hot or cold extremes) are recalculated for each new sample obtained with the bootstrapping procedure (steps described above are repeated 100 times). Eventually, 100 values for the percentile of interest were obtained, from which a 95% confidence interval was calculated (i.e., the spread between the 2.5th and 97.5th percentiles of this sample of 100 values).

3.3.3. Data featured in the '(Un)avoidable risk' tab of the 'Explore Impacts' page

The risk values showed on the bar charts available in the '(Un)avoidable risk' tab of the 'Explore Impacts' page were calculated differently for the 'mean temperature' indicator than for 'hot extreme' and 'cold extreme'.

For the indicator 'mean temperature', the risk estimates were calculated by assessing the fraction of the distribution constituted by the 2250 MESMER runs available for each scenario exceeding each threshold selectable by the user. To compute this risk today (defined here as 2011-2020), all values for all years included in this period or were pooled together. To estimate the projected risk in 2030, 2050 and 2100, all values contained in a 11-year window centered over the year of interest were pooled together.

For the indicators 'hot extreme' and 'cold extreme', the risk estimates were calculated by assessing the frequency of occurrence of the event of interest today (i.e., in 2011-2020) and in 2030, 2050 and 2100. To do so, the percentile to which the magnitude of this event corresponds was identified from the distribution of values derived from each MESMER realisation and each year contained in the 2011-2020 period, or within 11-year windows centered over 2030, 2050 and 2100.

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