FINAL REPORT

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Study on 'Digital Climate Service Applications'

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Consultants: Dr. Stefan KIENBERGER & Dr. Jonas FRANKE

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Executive Summary

The 'Digital Climate Service Applications' study report presents the outcomes of an in-depth investigation conducted by consultants in close cooperation with GIZ between November 2022 and August 2023. The primary aim of this study was to assess the existing trends and prospects concerning the technical, service, and institutional capabilities of Digital Climate Service Applications (DCSAs). The study aimed to offer valuable decision support to potential users, including institutions of the German development cooperation and public authorities in partner countries, to enhance data-driven climate risk assessments.

The report reflects the outcome of the stakeholder dialogues and interviews as well as the outcome of the analysis of the technical feasibilities of DCSAs, which includes the conceptualization of two example DCSA use cases with relevance for the German development cooperation. An overview of the current and potential technical and service capabilities of DCSAs, insights into the human capacity needs for handling DCSAs and recommendations for the development cooperation sector to enhance sustainable planning of DCSA operations are provided. Key trends include for instance further development around artificial intelligence, the use of cloud-based applications which bring the users to the data and the increasing opportunities and demands to define requirements with users. For the implementation of DCSAs in the framework of activities of the German development cooperation, the conceptual design should therefore follow a co-creation approach with partner institutions accompanied by a political dialogue to ensure acceptance at various levels. Regarding the diversity and suitability of service to providers to cooperate with in the development of DCSAs, the choice of providers should be use case dependent also aiming at a long-term cooperation. Hence, the study has shed light on the crucial aspects of DCSAs, and the findings will be instrumental in guiding stakeholders towards leveraging the potential of DCSAs for climate risk management and adaptation decision making. The implementation of the study was carried out by knowledgeable consultants with expertise in the field.

Key messages of the study are focussing on three different aspects, i.e., service implementation, cooperation with identified service providers and development of capacities. A clear identification of the purpose and the benefit of a DCSA is fundamental to ensure the scalability of services. User-friendly interfaces and communication should be in the focus, including translations of complex data analytics to non-expert users. Cooperation with strategically selected service providers and relevant stakeholders, including governments, NGOs, research institutions and international organizations is key. Regarding the required capacities to conceptualise, develop, implement, and sustain DCSAs, the awareness of climate risk assessments must be raised, through improving the understanding of climate risk across disciplines and stakeholders. It is also relevant to build technical capacities among institutions that are involved in the operation of services, that must also provide user training and support. This can be achieved via partnership with educational institutions in the partner countries.

1. Introduction

1.1. Scope and aim of the report

The report summarizes the findings of the Study on 'Digital Climate Service Applications'. The **main objective** of this study was to assess the current trends and outlook about the overall technical, service and institutional capabilities of Digital Climate Service Applications (DCSAs). Furthermore, the study aimed to provide efficient and effective decision support for potential users (public authorities in partner countries, as well as the German development cooperation itself) to advance data driven climate risk assessments and risk treatment, especially in the context of climate change adaptation.

Specific objectives included:

- Definition of the requirements / benchmarks for climate service / risk assessment product development: generic requirements and specific requirements for selected ideal typical climate service and risk assessment products
- Provision of an overview of technical and service capabilities today and potentially in the future of DCSAs based on defined requirements, focusing on location- and object-specific climate risk assessments, including climate change analysis, exposure analysis and vulnerability analysis. Thereby, a focus was on private and public Cloud Platforms (incl. Google, Amazon Web Service (AWS), EU Copernicus, Microsoft, IBM) that provide access to data sets from different public institutions (incl. CMIP6 (Coupled Model Intercomparison Project Phase 6), NASA, ESA) and that offer their cloud services for processing the data free of charge and/or against payment. In addition, web-processing services and data fed tools for carrying out risk assessments were in focus
- Assessment of the human capacity needs today and, in the future, to handle DCSAs by partner countries and to sustain their services
- Assessment of potential obstacles for the public sector to utilize DCSAs for climate risk management purposes. Thereby, scope the anticipated changes in the institutional landscape and trends in international climate service value chain development
- Provision of recommendations for the German development cooperation with identified DCSA providers and with partner countries authorities how to develop capacity to make full use of DCSAs for diverse fields of applications

This report reflects on the following deliverables of the study:

- D1.1: Lead and facilitate up to two stakeholder dialogues with selected stakeholders
- D1.2: Development of a comprehensive research framework and respective methodological approach that reflects the objectives of the study.

- D1.3: Data collection analysis documentation, including list of interviews with key informants, scripts of semi-structured interviews and contact details, literature analysis, technical tool analysis, and graphical illustration of results.
- D1.4: Developed intuitive overview of commercial cloud services and their interlinkages and capacities to collect, store and process climate and climate risk data sets, including mechanisms of co-design based on agreed criteria aligned to key requirements for carrying out risk assessments.D1.5: Evaluation of usability and performance of State-of-the-art DCSAs (including cloud services but also other types of DCSAs) and future pathways / scenarios for carrying out data driven climate risk assessments based on defined criteria and a specific use case defined.
- D1.6: Specified ideal typical provider configuration best matching requirements for risk assessment taking the example of a defined use case.
- D1.7: Detailed description of opportunities and challenges that development cooperation partner countries face when using DCSAs for data driven climate risk assessments, considering data and governance framework conditions.
- D1.8: Recommendations for best matching cooperation partners in the field of cloud-based climate service and risk assessment delivery for cooperation partners and the German development cooperation itself (incl. contact details, mechanism of service delivery, required capacities for end users, costs, trends, and business models).

The study was carried out between November 2022 and August 2023 and was implemented by the consultants Dr. Stefan Kienberger and Dr. Jonas Franke.

1.2. Background and context

The piloting of data driven risk assessments in the CSI[1] (Enhancing Climate Services for Infrastructure Investments) countries/regions (Brazil, Costa Rica, Nile Basin, Viet Nam) has demonstrated that accessing and pooling risk assessment relevant data from multiple sources, as well as tailoring climate data to its objectives of risk assessment can become a lengthy, inefficient process. This is true as capacities for data management are low, unfavourable national data governance puts obstacles to data collection, sharing, as well as standardized handling, processing, and quality management of data. Particularly, low-income countries are struggling with creating enabling environments and meeting the requirements for data sufficiency, data handling and accessibility.

Here, Digital Climate Service Applications (DCSAs) become an important opportunity. Resolving the obstacles posed by climate and risk information delivery in partner countries of the German development cooperation and worldwide is the promising evolving trend of cloud services, web processing services as well as data repository and tools delivered by

[1] The project Enhancing Climate Services for Infrastructure Investments (CSI) CSI aims to empower decision-makers to make greater use of Climate Services when planning infrastructure investments and thus help increase infrastructure resilience. CSI is part of Germany's International Climate Initiative (IKI). In accordance with a resolution by the German Bundestag the IKI receives backing from the country’s Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU).

multiple service providers along the climate product development value chain. In the present study, DCSAs are defined as automated cloud-based systems that combine location-based climate station and satellite data (historical and forecast), climate scenarios and other relevant datasets with quality-checked algorithms, locally specific, historical to support transparent decision-making, especially on managing climate risks. Such cloud-based platforms enable a cross-analysis of data sets. Climate, hydrological, environmental, and social data on the built environment can be combined, compared, or contrasted. It is the vision that digitalization through the ability of tapping on big data repositories, machine learning functionalities, as well as user-friendly configured user-interfaces for the customization of climate risk assessments can help to reduce the mentioned drawbacks and restrictions in an effective and efficient way.

To better inform climate risk management, the concept of climate services has emerged and gained momentum in the past (e.g., WMO 2011, Hewitt et al. 2012, Weichselgartner & Arheimer 2019, Panenko et al. 2021). No common definition of climate services exists yet, whereas the WMO (2011) defines climate services "as providing climate information in a way that assists decision-making by individuals and organizations", with the addition, "that climate services require appropriate engagement along with an effective access mechanism and must respond to user needs".

In contrast, climate services have been criticized for being rather supply-driven than demand-driven (Lourenço et al 2016) and created a highly heterogeneous data- and information-oriented service landscape (Weichselgartner & Arheim 2019). They should better support the need for managing climate risk, vulnerabilities, and possible impacts by integrating also non-climate information (Räsänen et al. 2017), better address the science-policy gap through enhanced co-production efforts (Briley et al. 2015) and be clear on terminology (e.g., product vs. service) (Panenko et al. 2021). Moreover, the need for operational and standardized climate services as well as services focussing on climate risks have become even more evident in the recent past with ESG reporting requirements of sustainable activities. Overall, high and obvious relevance exists for climate (risk) services to support climate change adaptation strategies and the monitoring of its progress at various spatial scales around the globe.

In recent years, due to the increasing demand for cloud-based spatial data infrastructures, there have been various developments in the field of platform solutions as an interface between users and IT systems. Such infrastructures should promote access, storage, exchange, sharing and analysis of large amounts of climate and other data. A fundamental principle of these platform solutions is to bring users to the data and tools, instead of data to the users, which then must be analysed with special software. Nowadays, operational forecasting models are for example updated hourly or even much below and the data amounts have reached levels that make classical workflows (data download and processing on local infrastructures) is simply no longer possible (Montes et al., 2020). Especially in climate risk assessments, users must handle a high diversity of input data with different temporal, spatial and thematic characteristics. The increased computing power for climate modelling is leading to more accurate assessments of the impact of climate change (Montes et al., 2020). This requires analysis and data processing methods that can process multidimensional data, as well as interfaces and data standards to easily obtain and integrate these data into models.

2. Assessment framework and implementation

To guide the methodology of the study as well to have a common frame for the research questions, an assessment framework was developed. Figure 1 provides an overview of the assessment framework and indicates the respective results chapters of this report.

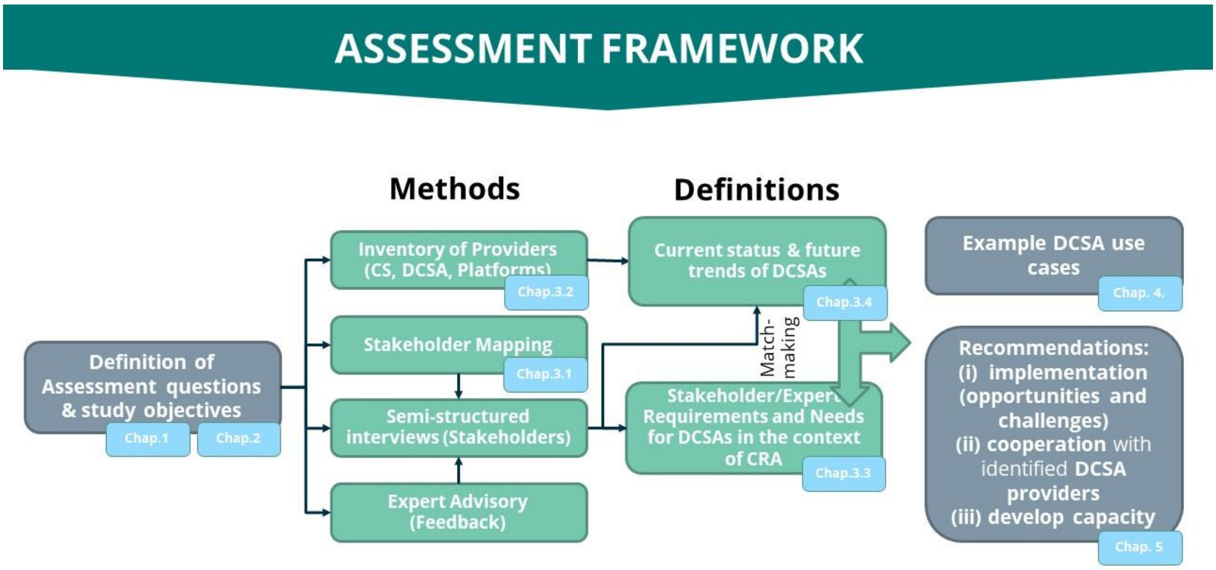

Figure 1: Assessment framework of this study as well as the reference to the respective chapters of this report (light blue boxes)

The process started with the definition of core assessment questions, which have been distilled from the Terms of References as well as from the aims of this study. The following questions define the core of the assessment:

- What are the requirements/benchmarks for climate service/risk assessment product development
- How are the technical and service capabilities of DCSAs regarding specific climate risk assessments, including climate change analysis, exposure analysis and vulnerability analysis
- What are the obstacles for the development of DCSA considering the status?
- How are the human capacity needs defined to handle DCSAs by partner countries and to sustain their services?
- What are the advantages and disadvantages of trends in business models in DCSAs for the public sector to utilize them for climate risk management purposes
- Which capacity must be developed among German development cooperation and partner countries' authorities to make full use of DCSAs?

To structure relevant questions as well as the application of assessment tools, we developed the following assessment criteria (Figure 2) based on exchange among the expert group and the knowledge of the consultants, which are grouped along three main pillars focussing on the topic of climate risk assessment, the inventory of providers as well as human capacities. This framework served as a backbone especially to guide the identification of key stakeholders, the analysis of results achieved and especially to guide the development of recommendations and the structure of the results section of this report:

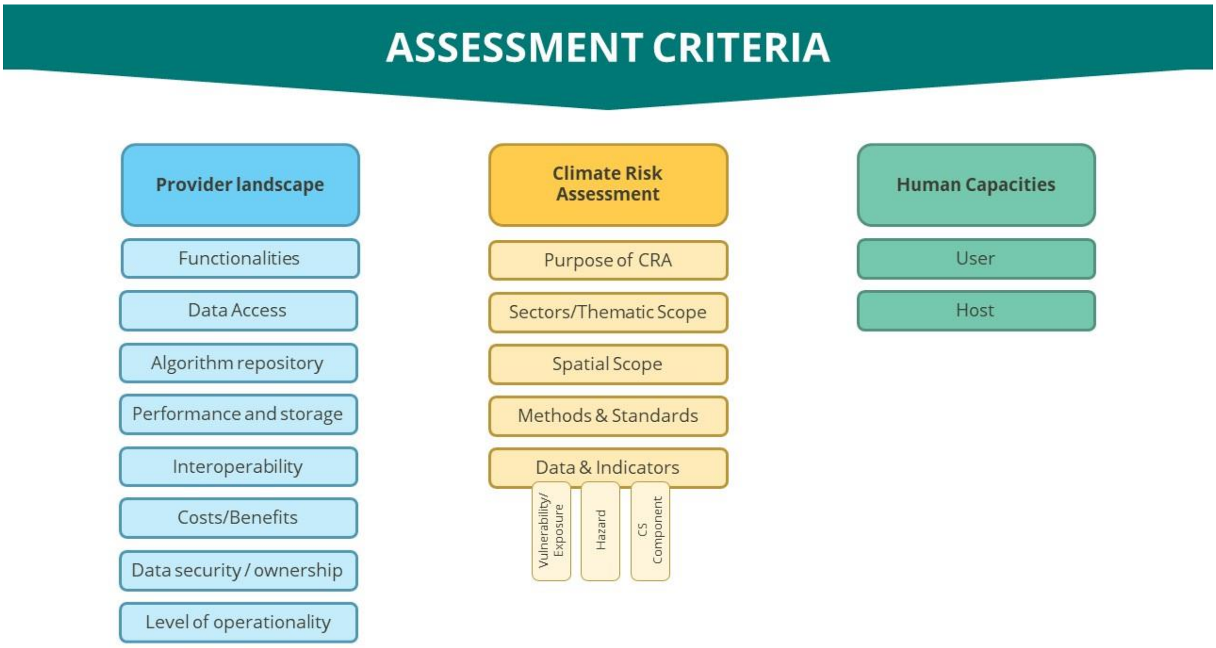

Figure 2: Assessment criteria with the main three pillars and respective sub-categories

To be able to respond to these questions, we built on the following methodologies:

2.1. Stakeholder mapping

Based on a typology we mapped relevant stakeholders in the context of DCSAs with a focus on climate risk assessments. Stakeholders were grouped along the following domains: science, governmental, inter-governmental, private sector, donors, and NGOs. We also categorized three levels of these stakeholders, which include key, primary and secondary stakeholders. The stakeholders were identified based on desktop research, recommendations by experts as well as relevant GIZ stakeholders as well as building on our knowledge and network. The main aim of the stakeholder mapping was the identification of key players in the climate risk assessment landscape, which were then addressed in the further inventory of providers and the interviews.

2.2. Assessment of the provider landscape

An inventory of providers of climate data, climate risk assessments and online platforms was conducted to assess the current state of digital services in this domain. Each provider was intensively studied regarding the technical feasibility of their services, the documentation of technical and institutional aspects as well the potential limitations of their services. While many providers were assessed during this desktop research, a final focus was mainly set on those providers who **offer services at a global scale**, to fulfil the requirements of the German development cooperation for potentially planned future DCSA operations. Whenever possible, the data portals and processing platforms have been tested or a demo was requested from the respective providers. The essence of the assessment of providers was the development of 1) a DCSA provider value chain/landscape map, 2) a provider functionality matrix, 3) short high-level descriptions per provider and 4) derived recommendations regarding the future choice of service providers in the context of development cooperation programmes. The results are provided in chapter 3.2 and Annex 5 contains a short description of each listed provider.

2.3. Online Survey and Semi-structured interviews

Based on the stakeholder map and the recommendations of the expert advisory board (see next chapter), persons from the mapped key and primary stakeholder institutions have been identified for in-depth analyses via online surveys and semi-structured interviews. A two-step approach was followed, in which first a short online survey was realized (using Google Forms) using standardized "meta-level" questions. This online survey allowed for a more quantitative assessment of the main perspectives of stakeholders in the DCSA domain. We received 15 responses in total. In a second step, in-depth semi-structured interviews were conducted with those persons who indicated (in the online survey) their interest in such interviews. 12 semi-structured interviews were carried out with selected key experts. The guiding questions have been structured around the assessment criteria (Figure 2) and are listed in Annex 1 (Guiding questions for the Semi-structured interviews). As different experts have been consulted, we applied varying weights to the different questions building on the expertise and background of the interviewed expert. The results of the online survey are outlined in Annex 3 (Overview of results of the online survey) and are discussed below in the results chapter 3.3. The institutions interviewed are provided in Annex 4. Summary of key insights as well as recommendations identified during the interviews are also provided in the results section.

Figure 3 provides some statistics on the background of the participants. A strong majority of the respondents (online) are providers (more than ⅔). This needs to be considered when judging the results of this study. Overall, the identification of clear users is a challenge in the context of climate services, especially in the context of climate risk services due the broadness and complexity of the topic (see further details below).

Diversity exists in the background of the respondents, with a majority in the inter-governmental sector as well as private sector. This also reflects the context of the study and also the observation that such DCSAs are currently largely supported from international organizations.

The frequency of using climate services varies strongly across the respondents; while a strong majority of 66% uses them frequently once a week, one third uses them only a few times a year. However, this also shows - at least across the respondents of this survey - that climate services are operational and used within their work.

Half of the respondents do already use cloud-based services in the context of climate related-data. This underlines on one hand, that such services are available and are being used, on the other hand there is a strong potential to increase the uptake and application of cloud based-services.

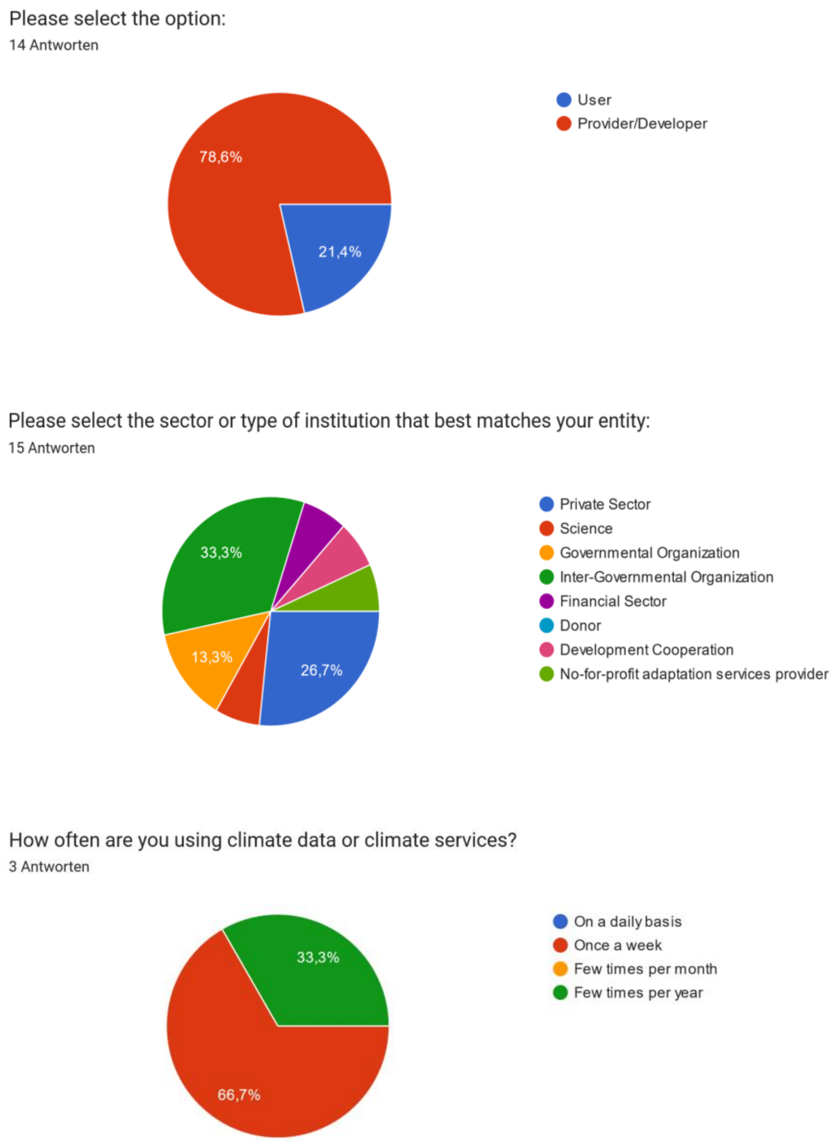

Figure 3: Statistics from the online survey indicating the background of the participants

2.4. Expert Advisory Board

To receive feedback on the research design (including the assessment framework) as well as to validate the results in a final workshop, we conducted two online meetings. In the first one, the assessment framework and the overall aims of the study were presented to an expert advisory board whose members were selected by the GIZ. Important feedback was received which led to a final adaptation of the framework. In addition, the experts provided relevant links and contacts for the interviews, as well as participated partly also as experts for the interviews. The expert advisory board included seven persons from the German development cooperation sector, the private sector, research institutions and inter-governmental organizations.

3. Results

The following chapters summarize the results of the stakeholder mapping (chapter 3.1.) and the results for the three assessment pillars including the results of the online survey and in-depth interviews with key stakeholders in the field of DCSA. In this two-step approach (short online survey followed by in-depth semi-structured interviews) the Assessment of the Provider Landscape (chapter 3.2.), Climate Risk Assessment (chapter 3.3.), and Human Capacities (chapter 3.4.) are addressed. Finally, we summarise key trends in the context of DCSAs (chapter 3.5).

3.1. Stakeholder mapping

The result of the mapping of DCSA stakeholders that have been identified through internet research is shown in Figure 4, which categorizes the DCSA stakeholders into different domains and activity levels (key, primary and secondary stakeholders). DCSA stakeholders that are very active in the field of climate service applications and that have a strong focus on various climate service applications, are defined as key stakeholders, while stakeholders that contributed to the DCSA landscape via specific use cases are categorized as primary stakeholders. Stakeholders with single use cases, services or fewer intensive contributions are defined as secondary stakeholders. The DCSA stakeholder map has no claim for completeness, since it maps mainly DCSA stakeholders with relevance for the assessment framework of this study, which focuses on applications in the development cooperation context.

The stakeholder map reflects that most providers of digital climate data are from the governmental and intergovernmental sector, while the largest share of DCSA providers (including climate risk assessments) are from the private sector. Many providers can be found in the financial sector, which built risk assessment platforms, using mostly (inter)governmentally funded climate data, for asset (risk) management. The science sector is also playing a key role, since most DCSAs are using scientifically developed algorithms and indicators for their assessments. While many financial consultancy firms are developing DCSA services for commercial purposes, only few donors in the development cooperation domain are funding such services yet. Lowest DCSA activities are found among NGOs, which might be caused by the limited funding for development of services or purchasing existing services.

The backbone of the DCSA space are the more and more improved climate data sources that are mainly funded by (inter)governmental institutions.

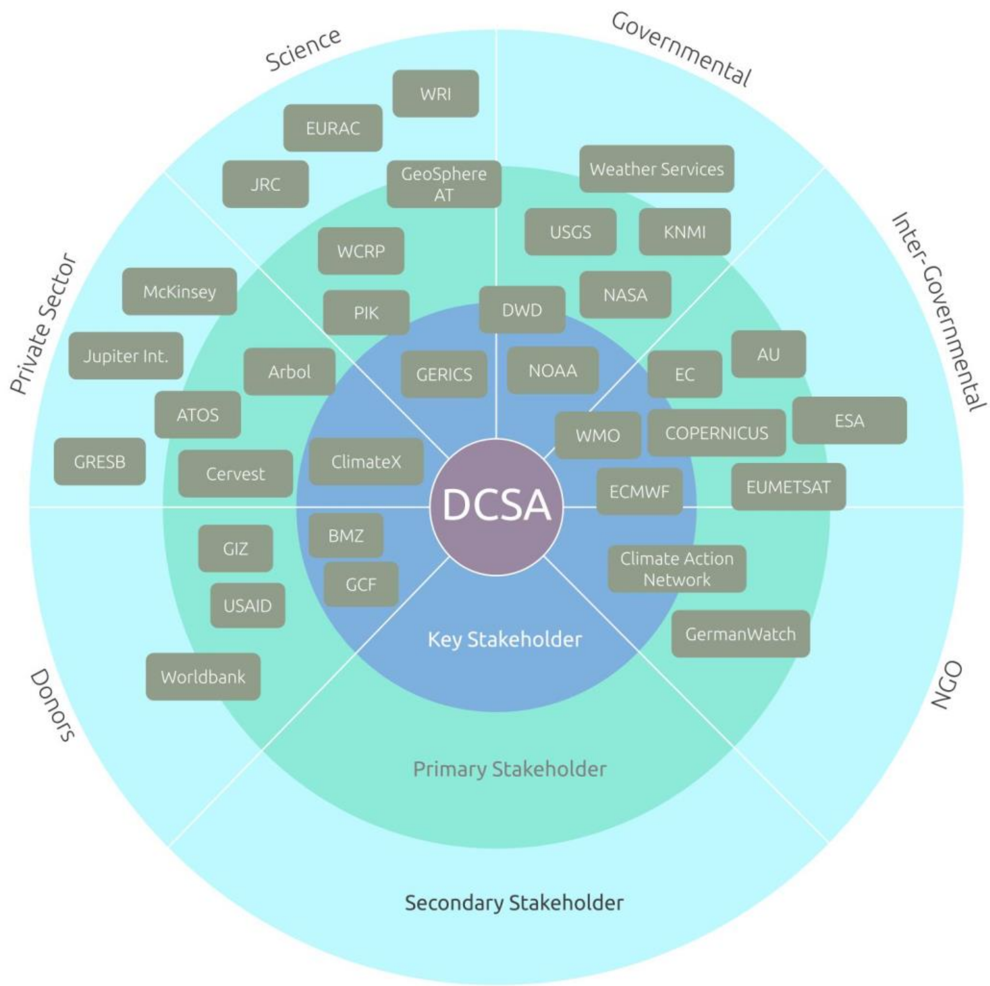

Figure 4: Stakeholder map showing the identified secondary, primary and key stakeholders in the field of climate service applications and climate risk assessments. Stakeholders are categorized in sectors, such as donors, private sector, science, governmental institutions, inter-governmental stakeholders, and NGOs. The stakeholder map has no claim to completeness and rather focuses on relevant stakeholders in the context of this study.

3.2. Assessment of the provider landscape

To assess the current state of digital climate services, an inventory of existing providers revealed the technical feasibility of their services, the documentation of technical and institutional aspects as well the potential limitations of their services. First, DCSA providers were analysed in accordance with existing value chains of services, and second, a provider functionality matrix was developed. For this assessment, evaluation criteria have been defined to ensure a structured assessment, focussing on the main technical criteria with high relevance for potential applications of the German development cooperation. These criteria were defined in the assessment framework of this study (data accessibility, availability of ready-to-use algorithms, scripting possibilities, costs etc.), which were then reflected in the provider functionality matrix below.

3.2.1. Evaluation of general aspects regarding usability and performance

Aspects of usability and performance of digital climate service applications can be divided into four main components:

Scalable cloud capacities

The use and scaling of cloud capacities (infrastructure as a service (IaaS)) is primarily limited by the use of financial resources, since existing cloud infrastructures are technically easily scalable, but lead to increased usage costs from certain cloud resources. The existing cloud services have different cost structures, which in most cases are based on the processing capacities (virtual CPU and RAM) and the data storage. The advantage of this is that users usually only must pay for what is actually used. Thus, the number of users and the scope of the individual climate service application determine the costs. This can lead to very volatile costs, which requires a flexible financing structure on the host/user (depending on who is paying for the service) side.

The hosting of the service and its maintenance

For sustainable and long-term use, hosting, and maintenance of the platform solution (Platform as a service (PaaS)) must be guaranteed. It is fundamental to consider the control structures behind the platform services, to avoid choosing solutions that have an expected end of maintenance or even end of operation. This poses a risk, especially in the case of project-related and time-funded PaaS developments. The descriptions of the operator concepts are also often very vague and only allow limited conclusions to be drawn about this factor. Possibilities for minimizing this risk are the selection of already established providers. The same risk exists regarding the access to climate data or other data that are needed for the climate service applications. Long-term automatic data access via APIs is key for the sustainability of such PaaS.

Necessary data analytics & IT expertise

Depending on the complexity of the data analysis, different levels of expertise are essential for using platforms that provide DCSAs. Although there are already platform services for some applications that are easy to automate that offer very simple and user-friendly user interfaces, these already require a certain basic knowledge of data handling and processing (Software as a Service (SaaS)). The effort required to train users sufficiently to use such a platform must be estimated at the beginning of a conceptual design of a system. The majority of existing applications are rather designed for experts and still base on more complex data analytics using multidimensional data, which hinders a large-scale user uptake. A precise definition of the user group is required to optimally design platform solutions, which will in turn stimulate their global use and their institutionalization.

The (further) development capacities

The possibility and potential of future further development of digital climate service applications is also an important prerequisite for the long-term use and scaling of platform solutions. On the one hand, future technologies and new types of data should be easy to integrate to further strengthen established methods. On the other hand, it should be possible to develop new solutions (SaaS) based on the platform technology in order to expand the relevance of the platform solution across different sectors.

3.2.2. The climate data and climate application providers

One result of the assessment of providers is the service value chain/landscape map (Figure 5). This serves as an overview of existing cloud providers (IaaS, first panel in the figure) via which web processing services for climate (risk) assessments are provided (via PaaS that perform the SaaS capacities), indicated by the second panel in Figure 5. The figure also shows which climate data sources are used by the services (third panel) and which are the supporting institutions (fourth panel). Only the main connections are shown for the sake of clarity of the figure. **The service value chain map has no claim to completeness**, since only study-relevant providers are listed, that mainly provide globally applicable services/data and that have sufficient online documentation available. More connections between web processing services and data providers exist, but they are often not well documented in the service descriptions of the providers. In Annex 5, a short description of each data/service provider is provided.

Figure 5 can be interpreted in all directions along a service value chain. As an interpretation example, there are two web processing platforms, namely WEkEO and Creodias that use the cloud of CloudFerro as IaaS. Both web processing platforms provide PaaS solutions to perform or develop Software-as-a-Service (SaaS) with the aim to process climate and other geospatial data from various sources such as Copernicus services, EUMETSAT and ECMWF. These service value chains are mainly supported by the Copernicus programme and the European Commission, since it funds not only the Copernicus services, but also initially funded the first implementation phase of WEkEO and Creodias that are known as DIAS (Copernicus Data and Access Information Services).

In the in-depth assessment of the providers, the technical functionalities and characteristics have been studied and translated into a simplified functionality matrix using some standardized criteria according to some key questions (Figure 6). It provides an overview on which service providers for example offers processing tools that can be applied by the user, if it allows users their own scripting, if it offers user storage or ready-to-use DCSAs, if they are globally applicable and if they are cost-free. Unfortunately, many commercial services do not provide sufficient online documentation for a full assessment of the above criteria.

This matrix shows that a lot of data sources exist that offer global and free climate data as input for the various DSCAs. Regarding the development of potential DCSAs, there is so far no provider that matches all technical requirements that the German development cooperation would have for their use cases. However, the Copernicus C3S, the different DIAS, the Microsoft Planetary Computer, Google Earth Engine and climpact show the best matches with the criteria defined in this study. Due to some technical limitations or data access limitations, it might be required to combine some services for a later DCSA that can be used by the German development cooperation. While this functionality matrix provides a high-level overview, for a specific service definition or use case, it is important to further assess the technical and institutional aspects of the providers.

The provider functionality matrix shows a good potential of the technical feasibilities that could be combined to develop a DCSA, for example for use cases such as those conceptualized in chapter 4. In any case, software development (SaaS) must be realized within a PaaS, for any future DCSA in the context of the German development cooperation. This development would include the needed backend that handles all data inputs and orchestrates and performs the data processing, as well as the needed frontend, which is the user interface that allows any user to interact with the system (input and output).

3.2.3. Survey results on the assessment of DCSA providers

Functionalities

Results from the in-depth interviews:

- Very often mentioned and a key factor is the user interface and user experience, especially with a focus on data visualization and data access, which seems to be key to enable better decisions. A good practice is that the user is guided through the portal/tool as well as the tools provide a narrative ("the user interface is simple and straightforward enough that it doesn't take too much training"). Communication of data and insights are key in this context, targeting both the policy level as well as towards the engagement of citizens.
- To generate and customize context and site-specific reports was mentioned by several experts as a core functionality of a DCSA in the context of climate risk assessments.
- The possibility for scripting was also mentioned, especially within an expert mode. However, there is also a clear need for targeting the decision makers, as one expert put it: "Not everyone can afford a GIS and environmental data expert, but they want to get access to these sorts of datasets because it's relevant".
- In addition, there is also a strong need for sufficient documentation, on data as well as methodologies and procedures applied; also including documentation on uncertainty margins (see above).
- Furthermore, functionalities also depend on the deepness of the climate risk assessment approach and the needs for tools towards facilitating climate risk assessment - so overall, it was highlighted that functionalities depend strongly on the context.

Data Access

Results from the online survey

- The tools provided by the respondents in the online survey comprises a majority of open access tools (>63%). However, tools are also provided via cloud-services which are not open and for dedicated users only

Results from the in-depth interviews:

- The provision, accessibility and completeness of metadata has been identified by various interviewed persons as a key issue.
- Specifically in the climate risk domain it is required to integrate a variety of datasets from different sources, therefore access - especially to data from governmental institutions - is key. With the current evolution of globally available high-resolution (socio-economic) data, global and regional scales can be targeted well, with increasing possibilities also for sub-national applications. However, the more detailed the analysis gets the more challenges on data quality and robustness apply. On the international level there are various endeavours to harmonize data and provide recommendations in regard to access and documentation (e.g., such as UN-GGIM).
- While the access to data is key, it was also observed that "it tends to be these societal issues around policy frameworks that tend to be a bigger concern than the underlying technology" (see similar comment above).

Algorithms/Performance/Interoperability

Results from the online survey

- Tools being mentioned in the online survey include the following:
    - CEDA Archive (https://archive.ceda.ac.uk/): CEDA Archive utilizes GIS and a collection of open-source tools. The processing scripts for generating climate indices are openly available on GitHub. Computation is performed on a cloud platform and the results are accessible as downloads or through OGC web services from the cloud platform.
    - Google Environmental Insights Explorer (https://insights.sustainability.google/): Google Environmental Insights Explorer provides information and insights related to the environment.
    - Agriculture Risk Metrics (Genillard & Co - https://www.genillard-co.com/agriculture-risk-metrics/): The platform enables users in the agricultural value chain to better understand, monitor and manage the risks arising from natural hazards in the European market. It provides historical data and analysis of extreme weather events (drought, frost, hail, heavy rain, storm) alongside yield and loss information for the purposes of crop production.

- East Africa Hazards Watch (https://eahazardswatch.icpac.net/map/ea/): This is a regional public multi-hazards monitoring system. The system monitors droughts, climate change, pests, heavy rains, floods, or crop failures.
- Copernicus Climate Change Service (C3S) Climate Data Store (CDS) (https://cds.climate.copernicus.eu/): The Copernicus Climate Change Service (C3S) Climate Data Store (CDS) is freely available and functions as a one-stop shop to explore climate data.
- AWS: AWS refers to Amazon Web Services, a cloud computing platform. The specific context or application of AWS was not provided. Though in the interview, publicly available services by AWS on environmental data were highlighted
- Self-developed crop models: Some organizations use self-developed crop models, but no additional information was provided about the specific methodologies or tools used.
- In-house Python-based tool: Some organizations use in-house Python-based tool, but no specific information was given regarding its purpose or functionality.

Results from the in-depth interviews:

- There is currently a strong trend that different data formats are easier to integrate on the cloud service, an important push for that comes from the user community.

Costs/Benefits

Results from the in-depth interviews:

- It is in general perceived that public data should be publicly available. However, the potential as well as the willingness to pay for services may exist for premium applications and/or high-quality data.
- Another expert lowered the expectations on the willingness to pay for the service, there is more willingness to pay regarding advice and recommendation stemming from such services.

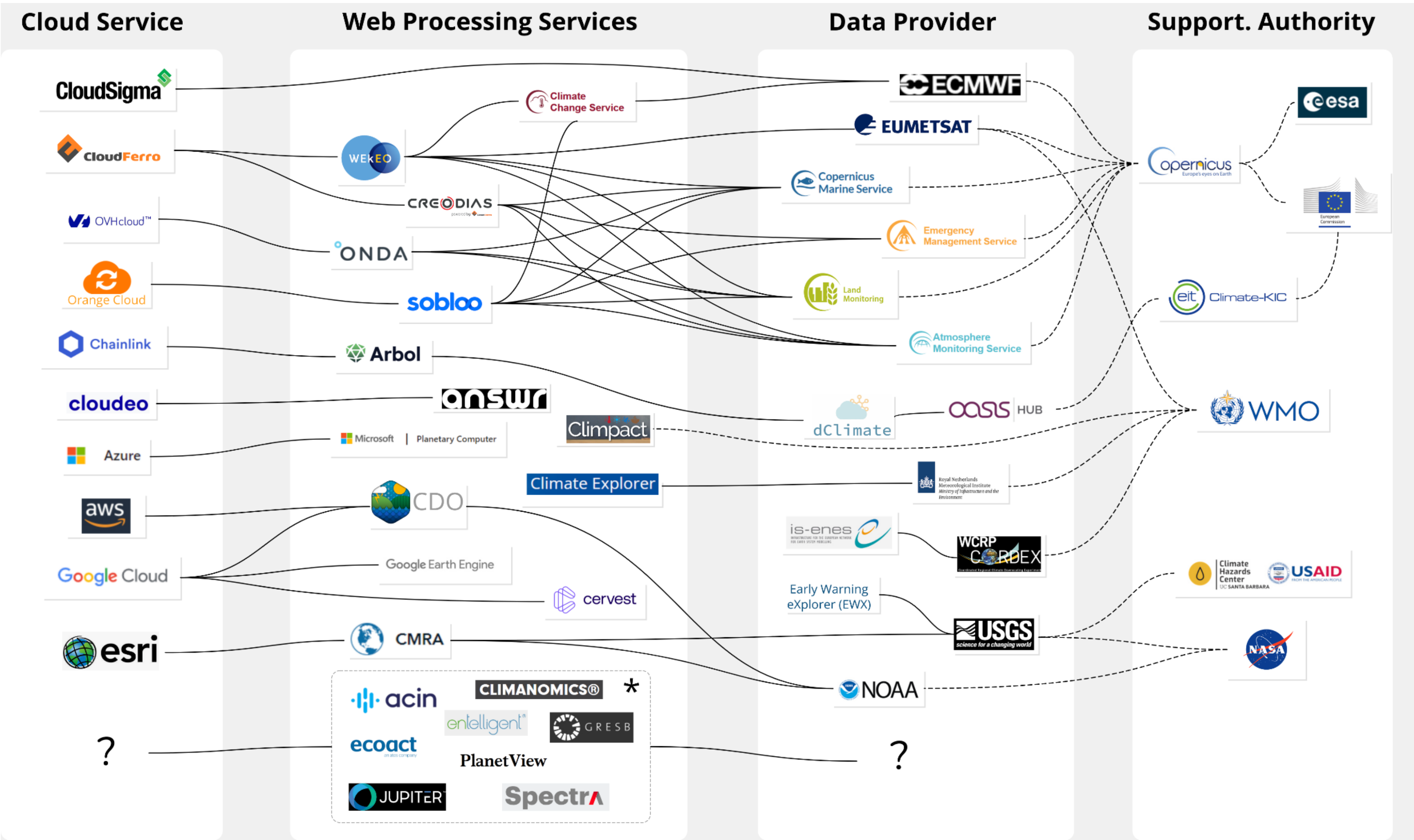

*Figure 5: Selected Digital Climate Data and web processing provider value chain/landscape. *The box shows commercial services that do not have sufficient online documentation available. This provider value chain has no claim to completeness (in regard to providers and linkages).*

	CS data access	Processing tools available	Own scripting possible	User data storage capability	Ready-to-use DCSA	Globally applicable	Cost-free	Website	Provider
EUMETSAT	x					x	x	https://www.eumetsat.int/acce	EUMETSAT
Copernicus Emergency Management Service (EMS)	x					x	x	https://emergency.copernicus.	Copernicus
Copernicus Marine Service (CMEMS)	x					x	x	https://marine.copernicus.eu/	Copernicus
Copernicus Land Monitoring Service (CLMS)	x					x	x	https://land.copernicus.eu/	Copernicus
Copernicus Atmosphere Management Service (CAMS)	x					x	x	https://ads.atmosphere.coper	Copernicus
dClimate	x					x	x	https://www.dclimate.net/	dClimate
Oasis Hub	x					x	x	https://oasishub.co/	Project co-funded by EC
KNMI Climate Explorer	x					x	x	http://climexp.knmi.nl/	WMO/KNMI
NOAA Climate Data Online (CDO)	x					x	x	https://www.ncdc.noaa.gov/cd	NOAA
Early Warning eXplorer (EWX)	x					x	x	https://earlywarning.usgs.gov/f	USGS, USAID
USGS	x					x	x	https://www.usgs.gov/	USGS
Climate Service Application Platforms									
Copernicus Climate Change Service (C3S)	x	x	x		x	x	x	https://climate.copernicus.eu/	ECMWF/Copernicus
anwwr	x	x	x			x		https://www.answr.space/	Cloudeo
Arbol	x				x	x		https://www.arbol.io/	Arbol
CMRA Climate Mapping For Resilience and Adaptation	x				x		x	https://resilience.climate.gov	US interagency partnership
DIAS (WEkEO, CREODIAS, ONDA, sobloo, Mundi)	x	x	x	x		x		see:https://www.copernicus.e	WEkEO, CREODIAS, ONDA, sobloo, Mundi
Microsoft Planetary Computer	x		x	x		x	x	https://planetarycomputer.micr	Microsoft
Climate Explorer	x	x				x	x	https://climexp.knmi.nl/start.cg	KNMI
Google Earth Engine	x		x	x		x	x	https://developers.google.com	Google
CDO	x					x	x	https://www.ncei.noaa.gov/cd	NOAA
climpact		x	x		x	x	x	https://climpact-sci.org/	Various R&D instit. & WMO recomm.
Platforms with few open documentation									
Jupiter ClimateScore™ Global								https://jupiterintel.com/	Jupiter Intelligence, Inc
CERVEST EarthScan								https://cervest.earth/earthscan	CERVEST
Climate-X SpectrA								https://www.climate-x.com/	ClimateX
EcoAct Climate Risk Platform								https://eco-act.com/climate-	ATOS
GRESB Climate Risk Platform								https://www.gresb.com/nl-	GRESB
CLIMANOMICS								https://www.ukgbc.org/solutio	UK Green Building Council/S&P Global
PlanetView/Planetrics								https://www.mckinsey.com/ca	McKinsey
Entelligent Smart Climate								https://www.entelligent.com/e	Entelligent
acin data platform								https://www.acin.com/solution	acin

Figure 6: Climate Data/DCSA provider functionality matrix. This functionality matrix has no claim to completeness.

3.3. Requirements and Needs for Climate Risk Assessments

Results from the online survey

- The respondents of the online survey highlighted the following opportunities for DCSAs for CRA (summary of free text responses):
  - Better-informed decision-making: Climate services can provide information to planners and policymakers, enabling them to incorporate climate risk into their decision-making processes. Climate services gather and synthesize various sources of climate information, tailoring it to the specific needs of decision-makers. This customization helps decision-makers better understand climate risks and implement appropriate adaptation practices.
  - Information delivery for risk management: Climate services play a crucial role in delivering climate information for effective risk management. This includes providing timely early warning dissemination and continuous monitoring to facilitate prompt action.
  - Streamlined assessments: Digital Climate Services Applications (DCSAs) simplify the process of accessing climate assessments by reducing data collection requirements, enabling further digital processing, and providing pre-processed historical and future-projected data aligned with relevant indices. This expedites vulnerability and climate risk assessments.
  - Integration of societal and behavioural considerations: Next-generation climate service tools should consider end-user needs and integrate societal and behavioural considerations. Developing metrics to measure uptake and institutionalizing these tools are essential for effective climate risk management.
  - Open data accessibility: Open data initiatives enhance data availability for assessing climate risks across various use cases, such as sea-level rise and wildfire monitoring. This allows users to make informed decisions and take appropriate actions based on climate risk assessments.
  - Improved data availability and operability: Climate services can aim to enhance the accessibility and operability of data, allowing users to work closely with the information relevant to their specific needs and context. This improves the usability and effectiveness of climate services for decision-making.
  - Overall, climate services provide opportunities to enhance decision-making, risk management, data availability, and customization of climate information to address climate risks in various sectors and applications.
- The respondents agree that CURRENT climate services applications provide a substantial benefit to climate risk assessments. However, the majority selected the medium options, which indicates that a substantial contribution might be limited:

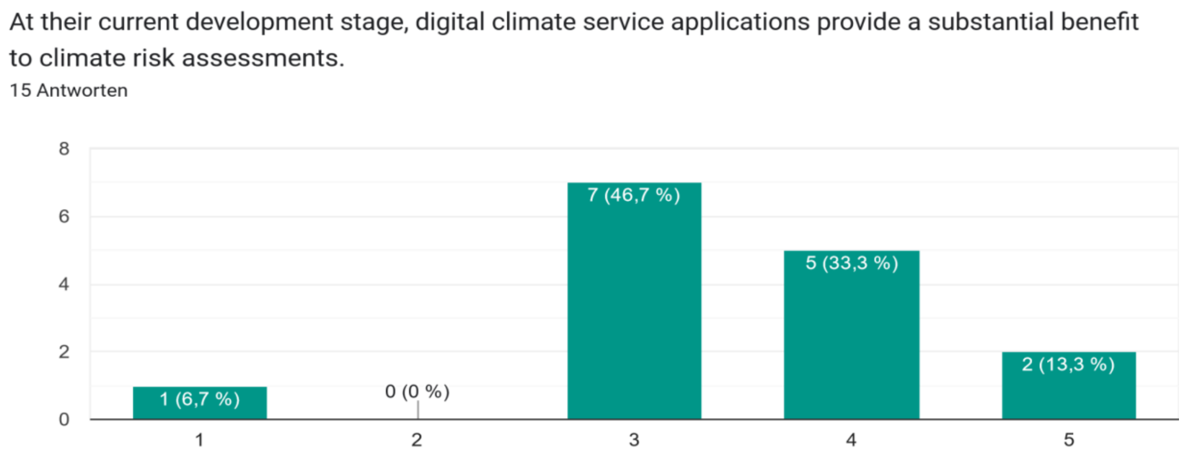

Figure 7: Result from the online survey regarding the benefit of current DCSAs for CRA. 1 means no benefit, 5 means great benefit.

- Overall, on the POTENTIAL of DCSAs for climate risk assessment and the identification of viable options, the majority of the respondents indicated 'high' to 'very high' opportunities:

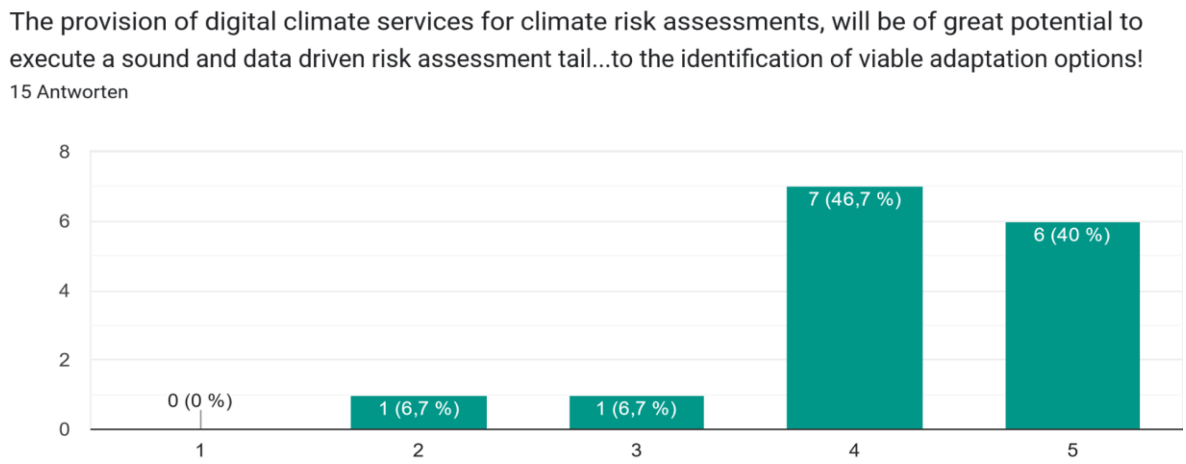

Figure 8: Result from the online survey regarding the potential of DCSAs for CRA. 1 means no potential, 5 means great potential.

- The following challenges were identified:
  - Data and tool availability: The general idea of DCSAs is to bring the user to the data and not the data to the user. However, it is still sometimes challenging to gather all the necessary data and tools in one place. The lack of a centralized platform (PaaS) hampers accessibility and efficient utilization of climate data.
  - Limited understanding and awareness: End users often have limited understanding of the assumptions underlying climate data and models. There is a need to bridge the gap in knowledge and raise awareness among decision-makers and users.

  - Poor data quality and models: Issues related to data quality, accuracy, and reliability pose obstacles in utilizing climate services effectively. Rigorous regional downscaling is not widely available globally, limiting the accuracy of climate projections in many parts of the world.
  - Overwhelming data and complexity: Cloud services may provide vast amounts of data and detailed information, overwhelming policymakers and planners who struggle to effectively use and interpret such complex data.
  - User-specific interface and information delivery: Tailoring climate services to address the specific information needs of users, such as farmers or insurers, is crucial. Customized interfaces and user-friendly information delivery methods are needed to ensure relevance and usability.
  - Digital divide and limitations: The development of climate services (both sides host and potential users) to prevent perpetuating existing digital divides should consider potential disparities in access, skills, and resources among users. Other limitations include the interpretability of climate information, costs associated with data usage, and the need for country-specific and regionally relevant data.
  - Communicating uncertainties and format of climate information: Decision-makers may not be familiar with the format in which climate information is delivered, and there is a need to effectively communicate uncertainties related to climate projections in a manner understandable to decision-makers.
- Inadequate spatial and temporal resolutions: Climate data may have overly coarse spatial and temporal resolutions, making it challenging to assess specific system components or evaluate the likelihoods of exceeding thresholds accurately.
- Learning curve and expertise: Researchers may face challenges in using cloud services efficiently due to a learning curve and the complexities of obtaining, processing, and scaling climate data.
- Lack of contact persons and consultancy: Difficulties in accessing contact persons or consultants who can provide guidance and expertise in utilizing climate services pose additional hurdles.
- Data proficiency, standardization, and accreditation: The proficiency and background of experts play a role in utilizing climate services effectively. Standardization, scalability, interoperability with other data sources, and accreditation requirements (e.g., for banking or insurance) need to be considered.
- These obstacles highlight the need for improved data access, user-friendly interfaces, better communication of uncertainties, and tailored climate services to overcome challenges in utilizing climate information for decision-making and climate risk assessments
- To solve the challenges, respondents vary in their view on how the challenges can be successfully addressed. The majority has chosen the middle category, which reflects the required attention to take a strong focus on the challenges identified.

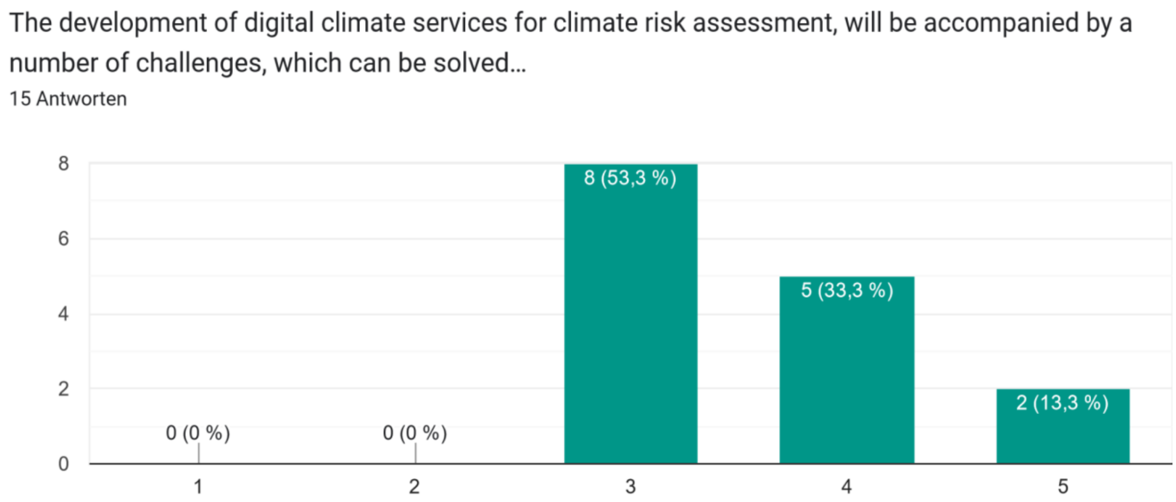

Figure 9: Result from the online survey regarding the challenges of DCSAs. 1 means challenges cannot be solved at all, 5 means easy to be solved.

Results from the in-depth interviews:

- In general, it was observed that information and data on hazard, exposure and vulnerability information is required for a full climate risk assessment, whereas a slight tendency is towards exposure as a key indicator. Especially for hazard data, information is requested to have return periods available to judge the frequency of certain events (past and future). In principle, all interviewed experts highlight the benefit of integrating this variety of data and related indicators in online GIS systems and tools.
- Furthermore, the integration of services towards climate risk (beyond general climate services) is essential and highly needed as perceived by a variety of stakeholders; in practice it is often implemented stepwise with a first focus on climate and hazard information. However, challenges arise in 'understanding risk' as one interviewee put it: "a lot of people who need to understand the concept of risk don't understand enough about what goes into assessing the risk and putting a confidence on that risk".
- In principle, climate risk assessments and in combination with online tools (such as web-portals) are now used in a variety of contexts - ranging from the public domain, to identify local as well as regional characteristics of climate risk, towards private companies in the engineering sector towards the business and financial sector.
- Currently a strong trend can be observed that CRA tools are more and more used in the context of decision making for investments and in the context of ESG assessments etc., especially to identify any climate risks before starting investments and allocate funds. This includes players such as the World Bank, the Green Climate Fund, the European Investment Bank etc.
- The potential users of such DCSAs strongly vary given the scope as well as spatial reach of implemented cases as well as experiences from the interviewed persons. Regional level tools tend to focus on international and regional actors such as the UN and NGOs,

but also private sector for instance from aviation, agriculture, infrastructure etc. sector. can be identified, whereas national and sub-national tools tend to focus more on the relevant in-country actors.

- A key issue highlighted several times and across the experts is the integration of stakeholders into a co-design process, users, and local experts; as quoted "And again, all the stakeholders, the users, they know that much better than any".
- Important in this context - and especially in the climate change adaptation context - is the user as the one at the very end of the value change, or those experts who translate the information to those at the very local level/taking decisions. In the context of DCSA it might be relevant to target both. This requires the translation of the relevant information to non-experts.
- Underlying this, it was also observed, that the user needs are still a blind spot, and that tools should be really focused on the decision makers - and as local as possible - to support their day-to-day policy decisions.
- A quote which summarizes the key issues around users very well is the following: "I think we struggle even at this point in time to really understand what the user is and what the user requirements are. I think the traditional view of the user as being, senior policymaker and environmental scientist, a specialist with some level of intrinsic knowledge is maybe not as relevant now and certainly won't be as relevant in the future. To be honest, I think we're still struggling to understand who the user is, that we're going to build these future services for". It should also be considered that "broader spatial data initiatives that were developed in the past that have been very much dominated by data producers [...] but it's not a real sense of who future users are, or actually what the real user need is as opposed to historically what users have accepted in the past".
- Overall, one expert raised an issue and asked: "Where does the DCSA stop and where does it become more like adaptation services", which highlights the purpose either being more on the climate and hazard side, as well as moving towards the risk assessment side and providing information to support climate change adaptation.
- Finally, it was recommended to take a stepwise approach, for instance with "demonstrators, small initiatives so that people get an example, so that they get an inspired by others on how to use it".

Sectors and Thematic Scope

Results from the online survey

- The respondents to the online survey have already used in a vast majority of >86% climate data in the context of climate risk assessments. The sectors for which a climate risk assessment was carried out varies strongly with agriculture, infrastructure, and natural resource management as the most mentioned sectors.

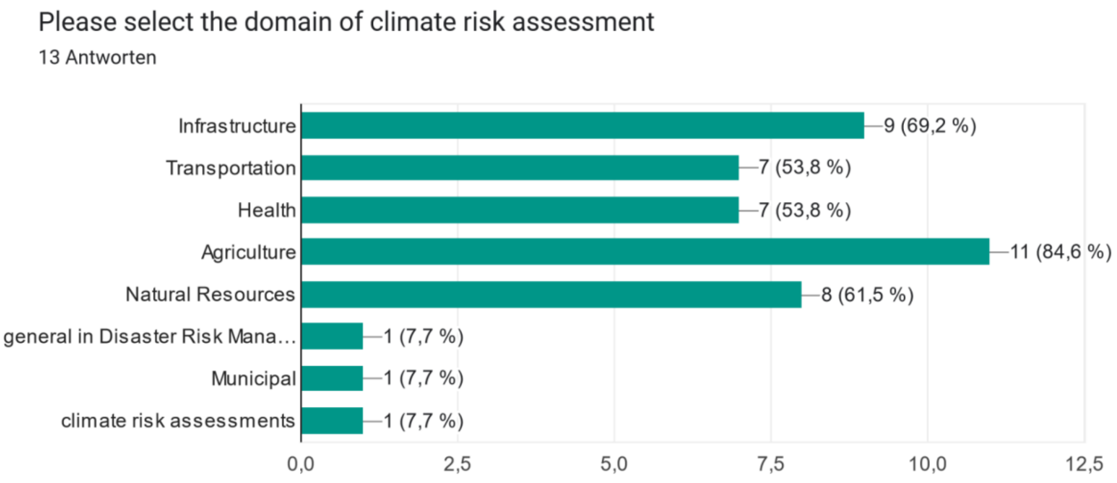

Figure 10: Result from the online survey regarding the CRA domain in which the participants are/have been working.

Results from the in-depth interviews:

- To foster access to different sectors, a one-stop shop mode was proposed to facilitate access as well as avoid redundancies.
- Overall, there is no specific sector preferred and it is perceived that this often depends on the context as well as the spatial scope of the actor/the study/the purpose (global, regional, sub-national; site-specific locations). However, it was highlighted that once getting down-to-earth for a concrete implementation a sector specific approach might be helpful to capture specific requirements.
- Whereas there was a tendency towards sector approaches, contrary one expert raised the issue that the sector is less of concern, instead the focus should be given on the data value chain. As it was put: "So how do you reach your end users? Who are the players? What's their knowledge? Are they aware of things? Do they understand the cloud? Can they work with the cloud? Do they know the tools? Do they have access to the local data or not? All these aspects are probably more important than pure sectorial elements".

Spatial Scope

Results from the in-depth interviews:

- Challenges arise especially for the sub-national level. Regional data is widely available - both on the climatic as well as socio-economic side; while on the national data level, quality issues as well as access do arise, issues do also exist with the lacking possibility to downscale climate models (e.g., especially in Africa).
- It was also mentioned that climate-data resolution might be less 'key' in the context of climate risk assessments, as most importantly is the access, availability, and quality of data of exposed elements and their vulnerability. The latter is often more challenging to access and have quality proven data available.

Methods and Standards

Results from the in-depth interviews:

- The importance of standards and guided methods was very much highlighted by most of the experts, especially in the context of approaches on climate risk assessment.
- Challenges do arise on the technological side, as this might be very dynamic and is characterized by fast developments, therefore guidance also needs to be dynamic as well; an example for a best-practice standard mentioned, was the Common Alert Protocol (CAP).
- Recommended important standards on the climate risk assessment include the ISO14091 (ISO 2021) as well as the PIEVC protocol (Sandinik & Lapp, 2021; https://pievc.ca/protocol/) for the infrastructure domain.

Data & Indicators

Results from the online survey

- Respondents of the online survey provide the following climate services:
  - Historical and modelled climate data/climate indices (incl. downscaled data, forecasts - weekly, monthly, climate; seasonal outlooks) - the vast majority provides such climate information
  - Environmental data management dashboards for Local Governments

Results from the in-depth interviews:

- The integration of tools and scripting possibilities is seen as beneficial to speed up the work and analysis, as well as to present information in a more user-friendly way and to communicate information better.
- A need to communicate ensemble agreement (comparison of different models and their spread) for climate models, was highlighted by a number of interviewed persons; especially also in the context of future projection on climate but also other indicators (if available, such as land use, population etc.).
- One expert put it that way on data and indicators: "It needs to be robust; it needs to be operational, it needs to be reference data at a global scale. Of course, it comes with a lot of uncertainty still, and the data is not always as reliable or comes with more uncertainties and certain regions than others". Therefore, it is very important to include estimations of robustness and the underlying uncertainty.
- A general challenge exists in the context of climate risk assessment, as one needs to deal with a variety of overwhelming data and variables and possibilities which is required to be narrowed down.
- In general, access to and availability of in near-real time to a variety of environmental data (especially from remote sensing) has been mentioned as an important development in the recent past, as well as an opportunity to integrate this data into cloud-based DCSAs on an operational level.

- It was highlighted that challenges do often not exist on the data side itself, but more on the "policy framework that will then take that information and do something with it".

3.4. DCSA requirements for Human Capacities

Results from the online survey

- Capacities to be improved focuses strongly on technical capacities to be able to make use of such services, to build such services and are related to governance issues independent of technical constraints. Additionally, in the online survey capacity building needs are around the customization for a wider range of purposes and on the institutional framing. Less focus is on the appropriate knowledge of end users and - surprisingly - to maintain the quality of the underpinning data.

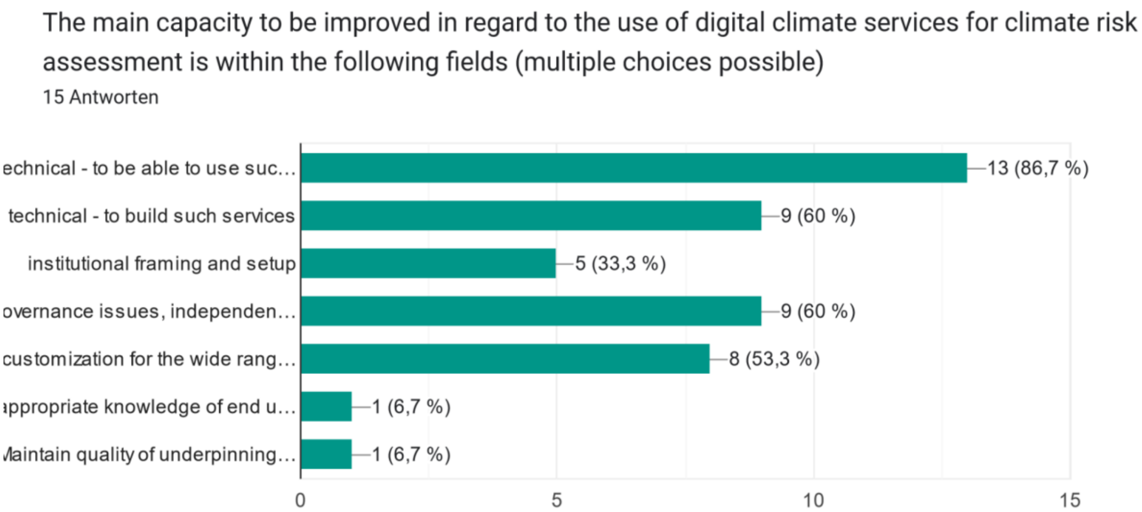

Figure 11: Result from the online survey regarding the necessary capacity development.

User

Results from the in-depth interviews:

- General agreement exists that users need to be trained, both on concepts of climate risk assessments and the methods.
- Important are capacities to interpret the results as well as data used, especially in the context of climate data, meaning "how to interpret the information, how to interpret the uncertainties from climate models"; but beyond that, it seems to be key to "use additional capacity development in helping people understand what the data means and how to interpret it and what some of the sort of base assumptions are".

Host

Results from the in-depth interviews:

- It was highlighted - especially for the development context (e.g., Africa) - that challenges exist to recruit local developers; however, this has been changing in the past years as some countries do offer a high number of specialists (e.g. in Kenya).
- It is also important to secure the continuation of portals/tools after the end of the projects ("Who will take care of that? What is the plan for this tool?"). As it was also stated "systems have to be owned by African institutions and they have to be public, and they have to be improved by African institutions".
- Besides technical and conceptual capacities, it was also highlighted to provide knowledge on how to develop communication and marketing plans.
- One expert put emphasis that often developers run are in essence following needs: "I think it's up to the community to decide what are the best tools and then come back to the providers of the data to say you know, here's what we want to use within the community".

3.5. Current status & future trends of DCSAs

The cross-sectoral and global significance of digital climate service applications and the associated potential for climate risk assessments have not yet been fully exploited. Climate change is increasingly posing a threat to almost all areas of human life, including health, economy, infrastructure and many more. The Intergovernmental Panel on Climate Change published the 6th assessment report (IPCC, 2023), according to which the effects of climate change in the form of extreme weather events (heat waves, heavy rainfall, long dry periods, etc.) is irreversible despite a possible 1.5-degree target with net zero emissions by 2050. Climatic parameters have been observed, recorded, and analysed for centuries. Through dedicated analyses of large amounts of data using extensive computing power, the complex relationships between climatic changes and their effects on the environment can today be better resolved. The exponential increase in the performance of computers and the networking of these enable more and more detailed, complex, and multidimensional analyses of data and the generation of information on climate change related aspects. With the use of high-performance technologies such as cloud computing and the use of artificial intelligence, a new dimension of big data analytics can be achieved. However, these new technologies also require higher levels of data processing complexity with at the same time higher level of automatization, which needs to be addressed. Aspects of energy consumption of constant cloud-based services should also be considered while planning a DCSA. Energy consumption can be minimized by technological advances such as "Serverless computing", in which cloud provider allocates machine resources only on demand (pay-as-you-go).

There are two main scenarios for the use of cloud-based climate data analytics, for which a clear benefit exists over traditional data analysis approaches. On the one hand, such systems can be used to carry out large-scale national, continental, or global assessments (scalability). On the other hand, there is often a need for repetitive analyses of large amounts of data (e.g., monitoring) at local, regional or national level (repeatability). That is why a clear definition of the purposes, sectors, and stakeholders for which a digital climate service is needed, since real added value only arises through spatial, thematic and user scaling of the application. Identified trends of the participants from the in-depth interviews include:

- A major trend almost identified by all interviewed persons is the fast and increasing trend around AI tools/machine learning, also including the ability to process data.
- One expert focused on the implications on the availability of data at higher scales: "And I think from this perspective it's about that scale question. We can start to ask questions at a scale that we couldn't do previously because we're getting machines reading machine generated data and we're taking".
- What can also be observed in general, is that IT capacity is steadily increasing also in developing countries.
- It was also mentioned that desktop computing capacities have increased in the past, so hybrid options between cloud and local computing can be highly relevant in the future.
- "There is value in more hybrid solutions where you do have some local repositories where you keep data, perhaps close to the user for requirements. But I think that will just follow the technology trends as they emerge in the broader community".
- Another trend mentioned is to communicate results of climate risk assessments and key messages with immersive technologies such as virtual reality, which allows improved visualizations of potential climate impacts.
- An interesting original quote from one expert on trends and their relevance: "Trends are difficult, because I think they are reactive. So, you'll see a trend based on a need or requirement as it pops up. Instead, I think there's much more value in listening to the community and understanding their needs and requirements where they're at and getting them to where you really want them to be".

4. Use Cases for DCSAs

A one-stop DCSA solution that meets all the requirements of the German development cooperation is an unrealistic scenario. However, the development of sector specific DCSA solutions could be realized based on existing technologies that could be put together in a modular way. Each DCSA consists of four main components.

(i) Infrastructure-as-a-Service (IaaS) offers the scalable computing and storage resources provided by cloud providers

(ii) Platform-as-a-Service (PaaS) hosts application developments and tools that are provided to the users via the internet

(iii) while Software-as-a-Service (SaaS) is the application that orchestrates the climate risk assessment via user interfaces that initiate the processing in the backend

(iv) Automated access to climate and ancillary data via APIs

To specify digital climate service applications that have a high potential for future implementation by the German development cooperation, two use cases were evaluated as part of this study that have been selected by the GIZ (one from the agricultural sector and one from the infrastructure/transportation sector). Based on the above findings, the two use cases were conceptualized regarding cloud-based applications that could be developed in the future. The technical criteria described above were considered in order to overcome existing obstacles in the use of input data, and a focus is placed on the fact that the concepts can be extended to other sectors of development cooperation in the future (scalability).

Since not every use case of climate risk assessment qualifies for a DCSA via automated cloud-based approaches, it is important to first evaluate if a use case can really benefit from a DCSA, or whether a classical approach is sufficient. There are two main scenarios under which the use of cloud-based DCSA capacities benefits activities of the German development cooperation:

1. **Repeatability:** Climate risk assessments that need to be done on a regular basis (repetitive evaluations)

2. **Scalability:** Climate risk assessments that need to be done at various locations and/or at various scales (local/regional/national/continental)

While use cases that require repetitive assessments can have a higher degree of specialization (can only be transferred or scaled to a limited extent), for use cases that demand assessments at various locations or scales, a stronger generalization of the DCSA is essential so that it can be applied globally and used by different projects and programs. Therefore, it is important to define already in the pre-assessment phase the purpose, the thematic sector and the stakeholders for which a cloud-based DCSA is to be developed, since real added value of such service only arises through repeatability or scalability of the application.

Following these baseline questions, two relevant use cases have been identified in this study that qualifies for the development of a DCSA, at least in modified versions. The DCSA use cases were evaluated by considering GIZ proven methodologies, specifically the concepts from the GIZ Vulnerability Sourcebook (Fritzsche et al., 2014) and its Risk Supplement (GIZ & EURAC, 2017) were followed. Figure 12 shows the structure of a generalized impact chain, which is an analytical tool that helps to better understand, systemize, and prioritize the factors that drive risk in the system of concern (GIZ, 2017). For the conceptualization of a DCSA that follows this impact chain approach, it is necessary to identify the parts of the impact chain that can be highly automatized and for which relevant data sources can be accessed automatically.

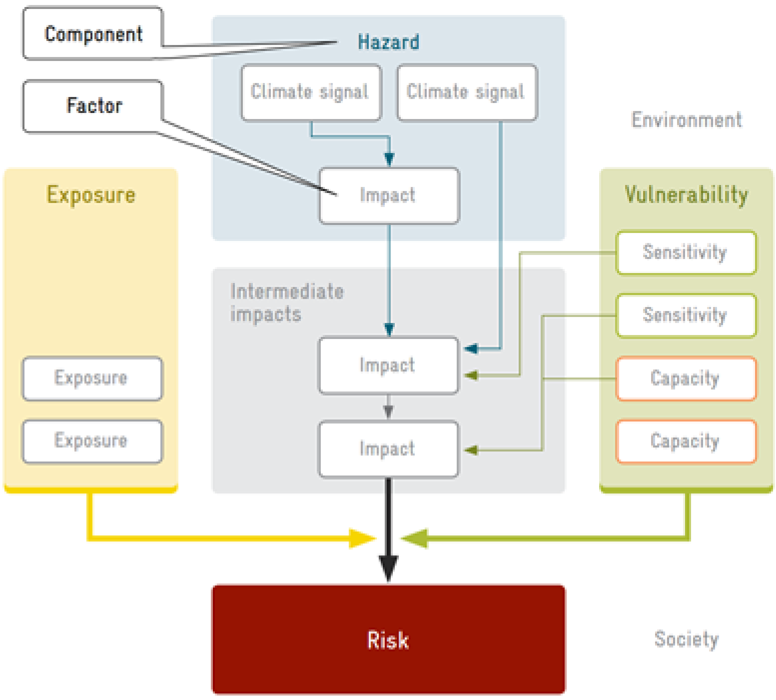

Figure 12: Structure of an impact chain (Source: Risk Supplement GIZ Vulnerability Sourcebook, 2017)

4.1. Use case 1: Adaptation of Agricultural Value Chains to Climate Change in Madagascar

4.1.1. Background

Madagascar faces very high climate change risks. Global adaptation and vulnerability indices such as Notre Dame Global Adaptation Initiative (ND-GAIN) rank the country on position 169 out of 181 countries. Agriculture is one of Madagascar's key economic pillars, accounting for one fourth of its gross domestic product (GDP) and is therefore the most important source of formal and informal employment in the country (78% of the active population) (FAO, 2019). Nonetheless, the agricultural sector is facing numerous challenges such as low productivity, little investments from the private sector and limited market access for farmers. Sector-specific climate risk assessments have shown that many of the underlying barriers resulting in the low performance of Madagascar's agricultural sector are also directly or indirectly linked to the sector's pronounced vulnerability to climate change. The project "Adaptation of agricultural value chains to climate change" (PrAda), implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), mandated by the German Federal Ministry for Economic Cooperation and Development (BMZ) and co-financed by the European Union (EU), has realized climate risk assessments of five agriculture value chains in Madagascar, to increase their climate resilience and thus to improve and sustain the livelihoods of Madagascar's rural population in the long term (GIZ, 2022).

4.1.2. Current approach

In this concrete use case, impact chains have been developed per crop type, in accordance with the type of hazards they are facing and elaborated together with local and national stakeholders. These impact chains allow identifying the complex cause-and-effect relationships between the climate hazards and the vulnerability of the system at risk for value chain actors. Figure 13 shows the summary climate impact chain for the considered crops in the project area in Madagascar (GIZ, 2022).

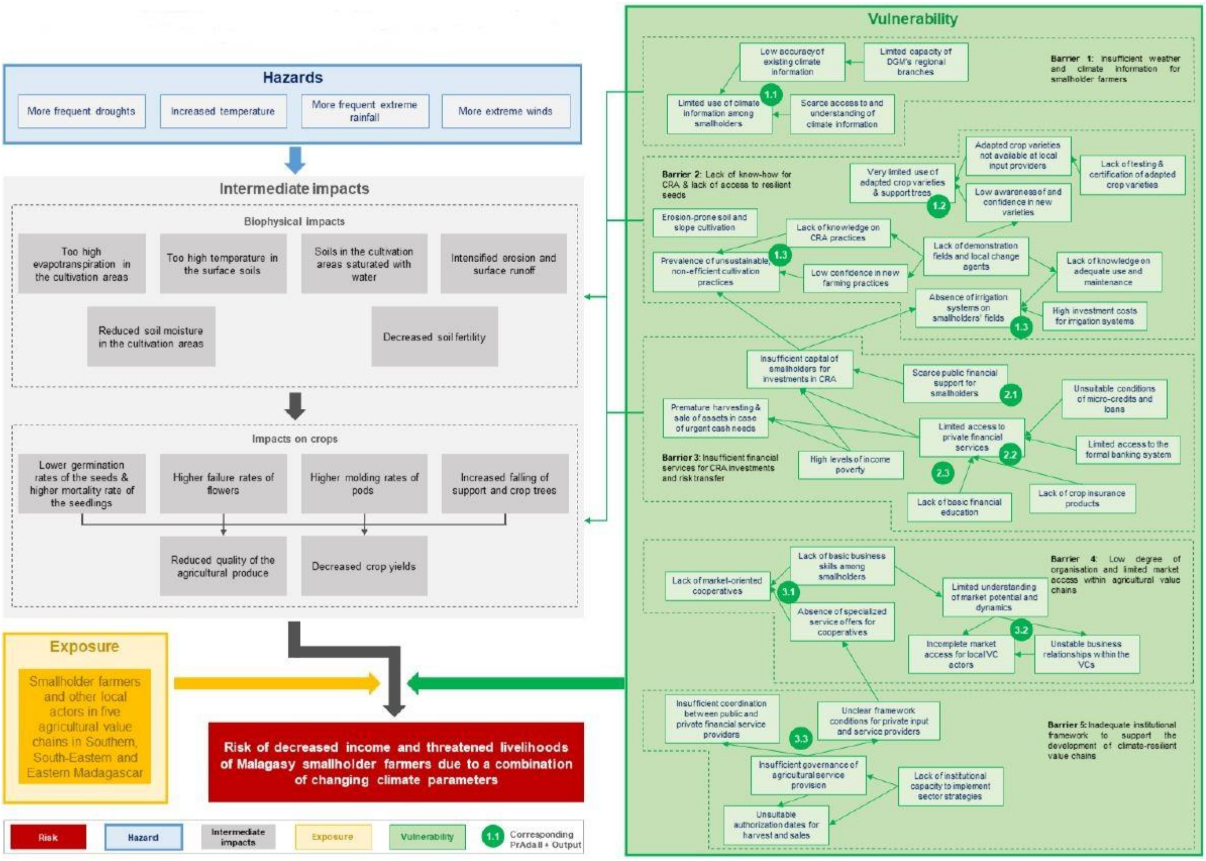

Figure 13: Climate impact chain for agricultural value chains. Source: GIZ 2022

4.1.3. Potential DCSA

Regarding translating this climate impact chain into a digital climate service application, it becomes obvious that the vulnerability assessment has the highest level of complexity in terms of input information and individual consideration of vulnerability criteria. This high level of complexity and the lack of automated data access for the various criteria, are obstacles for an automated assessment via a DCSA. This means that the vulnerability assessment must be either done separately in accordance with the step-by-step modules defined in the GIZ Vulnerability Sourcebook, and/or the vulnerability assessment must be simplified. A simplification of the multiple vulnerability factors seems possible, since they are synthesized and clustered into five key barriers:

- Barrier 1: Insufficient weather and climate information for smallholder farmers
- Barrier 2: Lack of know-how for CRA & lack of access to resilient seeds
- Barrier 3: Insufficient financial services for CRA investments and risk transfer
- Barrier 4: Low degree of organisation and limited market access within agricultural value chains
- Barrier 5: Inadequate institutional framework to support the development of climate resilient value chains

To integrate the vulnerability assessment in the DCSA, such simplification is fundamental, and could be realized via a simplified criteria matrix (e.g., thresholds) that is elaborated by the users and then provided to the DCSA as input. Automatic data access and data processing is necessary for the exposure and hazard assessment, which seems feasible.

To also address the prerequisites of repeatability or scalability of such DCSA, a slight generalization of the approach is beneficial, which allows easy transferability of the DCSA to other areas, countries, or agricultural value chains, and thus to widen its scope. Such a generalized climate impact chain has been conceptualized in this study, which fulfils the requirements of such DCSA. Figure 14shows the impact chain of such climate risk assessment for the specific use case, while also identifying potential globally available data sources for each assessment criteria. Highly automated data access is required to achieve the highest level of automation of the climate risk assessment. For the hazard assessment, data for the baseline are required as well as for the projection of climate scenarios. In case that higher resolution or higher quality input data are available from national sources that can be accessed via APIs, these global data sets can easily be replaced by such.

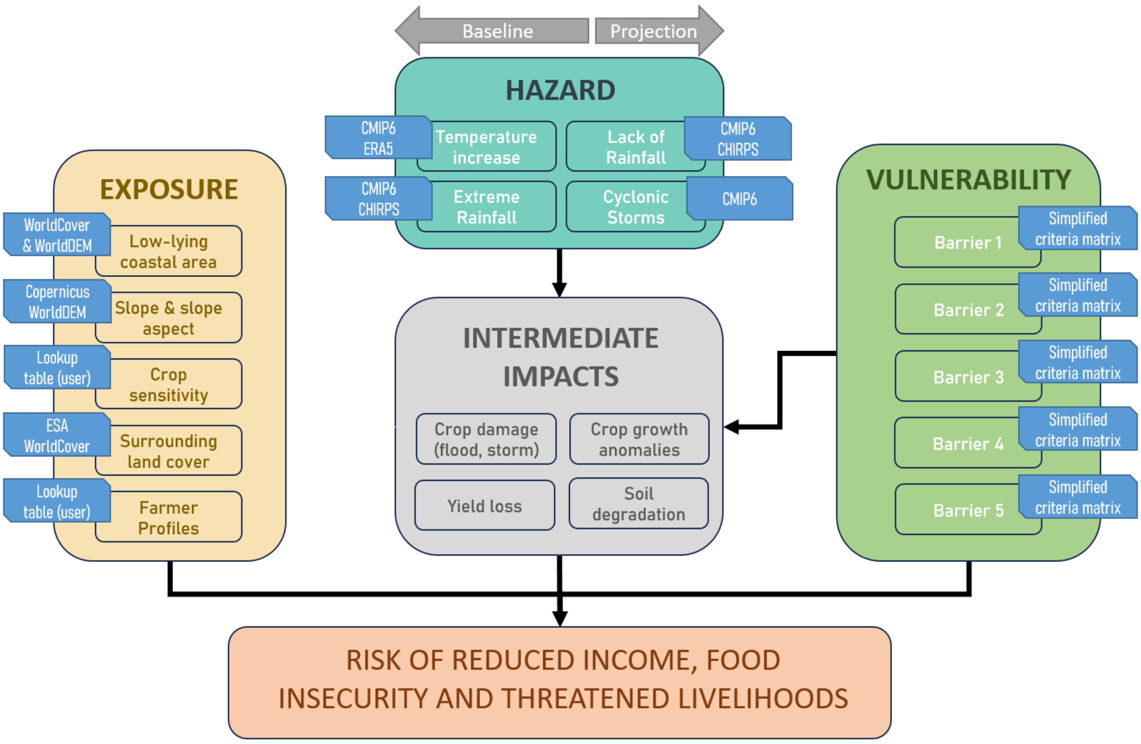

Figure 14: Generalized DCSA-compatible Climate Impact Chain for the described use case. Blue boxes show the potential data sources for the individual criteria assessments.

One potential technical setup for the realization of such DCSA is outlined in Figure 15. In this use case, the DIAS WEkEO is exemplary chosen that runs on the cloud of CloudFerro. WEkEO has the advantage that the services of the Copernicus Climate Change Service are provided, that offers tools and climate data to assess climate risks. The software package provided by climpact could also be partly used to process the climate data to ready-to-use data inputs for the assessment. The various data that are needed for the use case (indicated in Figure 14 above) are accessed from different sources that are processed by the application. In any case, a dedicated frontend and backend must be developed for a DCSA. This technical setup should only be considered as exemplarily for this use case.

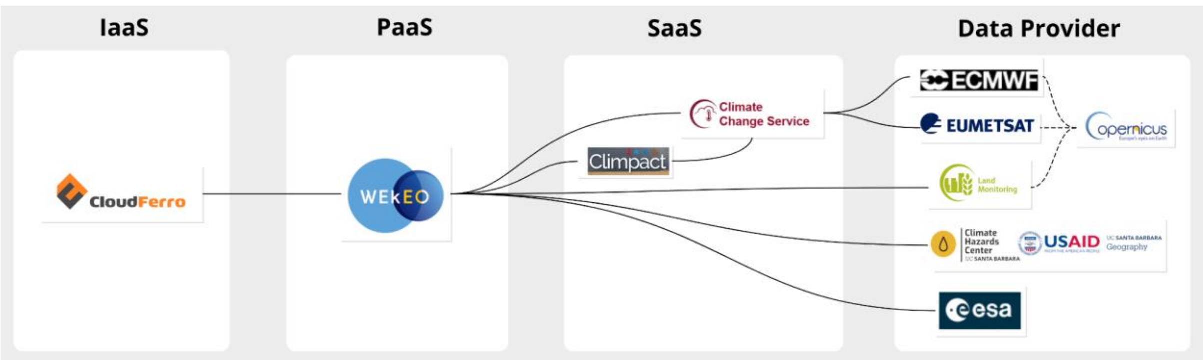

Figure 15: Example structure of a DCSA for the use case of resilient agricultural value chains, with the components IaaS, PaaS, SaaS and data providers.

4.1.4. Summary of the example solution

+ European IaaS, PaaS and SaaS capacities
+ Own algorithms can be implemented
+ Open-source software can be implemented and open data

- Not free of charge
- Full front- and backend development needed
- Multi-source data must be integrated and harmonized

4.2. Use case 2: Impacts and Risks of climate change to Brazilian Coastal public ports

4.2.1. Background

The port sector is among the sectors that can directly face the impacts from climate change, especially because port infrastructure is highly exposed to climatic hazards. Ports are critical infrastructures for global trade, so such negative impacts could result in considerable damages and losses, given that approximately 90% of global trade depends on maritime transport. In Brazil there are 36 public ports within the competence of the Union, called Organized Ports. In this category, there are ports managed by the Brazilian federal government. Given the relevance of the port sector to the Brazilian economy and the sector's high exposure to climate hazards, adaptation becomes fundamental and urgent to ensure port operations and, consequently, the resilience of the logistic sector.

The German Ministry of Environment, Nature Protection and Nuclear Safety (BMU) has been supporting the Brazilian government in actions to increase the country's resilience, through projects aimed at adaptation to climate change. Among these projects, there is the "Supporting Brazil in the implementation of its National Agenda for Climate Change Adaptation – ProAdapta" which aims to enhance climate resilience in Brazil, through the effective implementation of the Brazilian National Adaptation Plan (NAP).

In this context, a study aimed to identify the impacts and risks of climate change to public ports on the Brazilian coast, and to offer a list of general recommendations for possible adaptation measures to increase the resilience of ports to the undesirable effects on the port operation and infrastructure (GIZ, 2021).

4.2.2. Current approach

The climate risk assessment for Brazilian public ports was carried out in six major steps:

1. Review of methods to assess climate risks
2. Assessment of impacts
3. Assessment of climate hazards indicators and definition of scenarios and time horizons
4. Assessment of vulnerability and exposure

5. Assessment of climate risks
6. Assessment of adaptation measures

Individual risk indices (values between 0 and 1) were defined for thunderstorms, strong winds and sea level rise, for which individual risk assessments were carried out. Figure 16 shows an example for a hierarchical structure of the risk index assessment for thunderstorms. These risk index assessments were realized for all ports considered in this study and then each port was ranked according to the individual indices for the three risks covered.

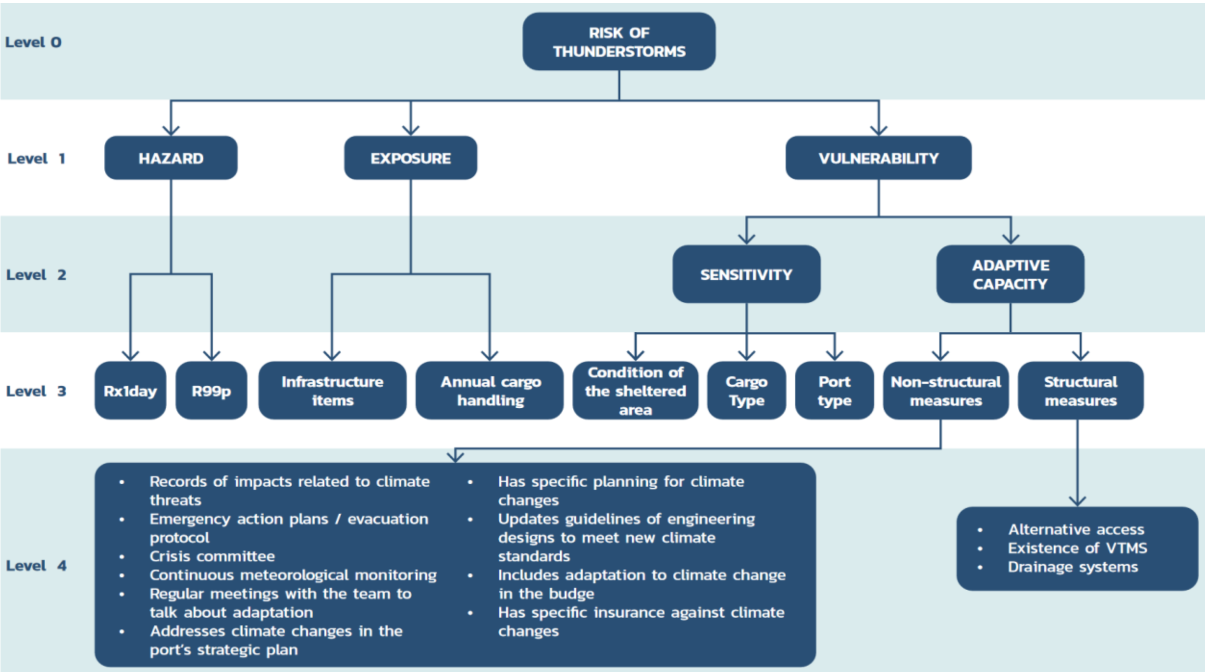

Figure 16: Hierarchical Structure of the Risk Index for Thunderstorms (Source: GIZ 2021)

4.2.3. Potential DCSA

Regarding the major steps realized for the climate risk assessment for Brazilian public coastal ports, steps 3 to 5 (hazard, vulnerability, exposure, and risk) are feasible for a DCSA development, since most parts can be automated. Step 1 can be considered as a fundamental step for any risk assessment, while step 2 (Assessment of impacts) is a prerequisite to define indicators and thresholds for each individual region of assessment. For the vulnerability assessment, user data and information about the individual port's infrastructure are required and can thus not be fully automated within a DCSA but could be realized via an input interface which allows user entries to be made to the database (since this is a rather threshold-based approach in this use case).

In contrast to the current climate risk assessment of the project described above, a DCSA could cover more hazards than the three hazards covered so far, to widen its scope and thus to significantly increase scalability of the service. This would improve the applicability of the DCSA and thus increase its transferability to other countries globally. In the DCSA that was here conceptualized for the use case of climate risk assessments of public ports, extreme rainfall (flood impacts) and waves (impact on operations and coastal morphology) are additionally incorporated. In addition, an advantage of a DCSA could be that not only each hazard is considered separately, but all at once. Figure shows the climate risk assessment framework for the specific use case, while also identifying potential globally available data sources for each assessment criteria. In case that higher resolution or higher quality input data are available from national sources that can be accessed via APIs, these global data sets can easily be replaced by such. Highly automated data access is required to achieve the highest level of automation. For the hazard assessment, data for the baseline are required as well as for the projection through climate scenarios.

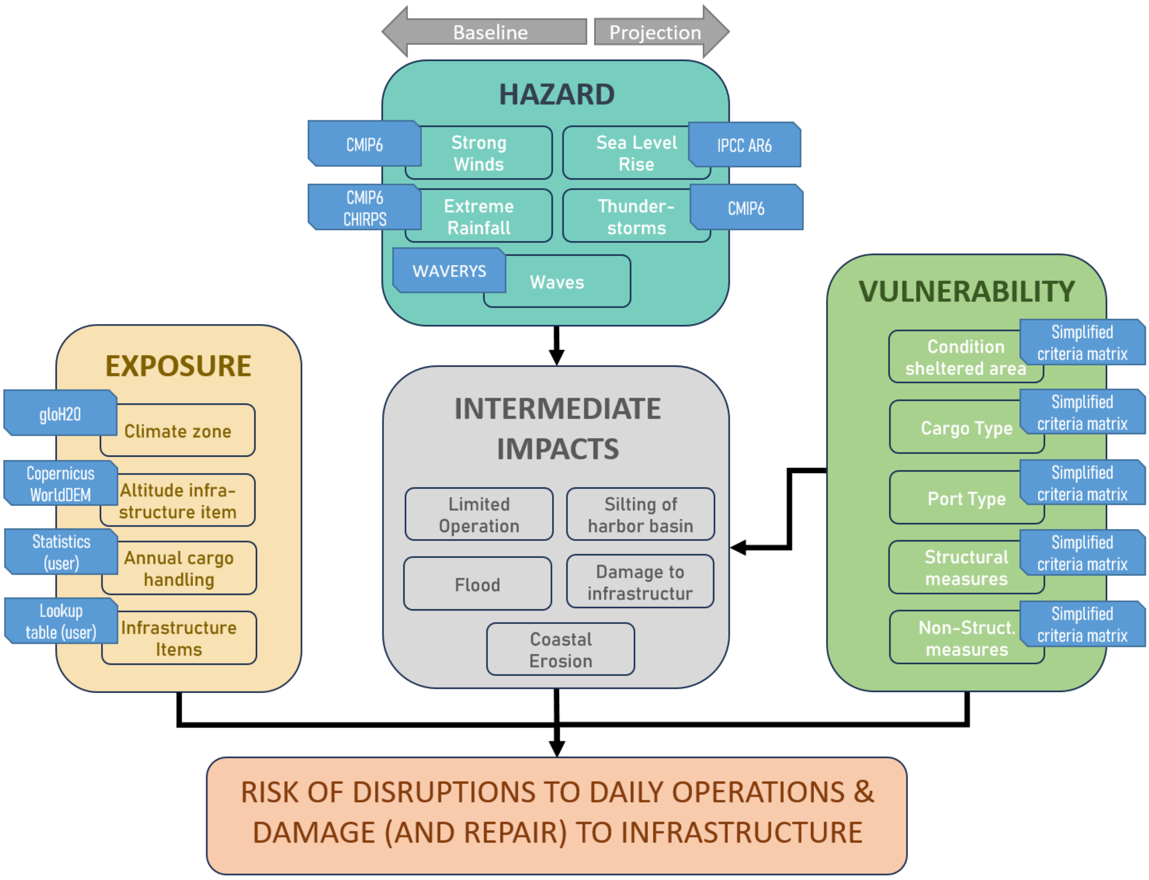

Figure 17: Generalized DCSA-compatible climate risk assessment framework for the described use case. Blue boxes show the potential data sources for the individual criteria assessments.

Two potential technical setups for the realization of such DCSA are outlined in Figure 18. In this use case, either the DIAS sobloo could be used as PaaS that runs on the cloud of Orange, or alternatively the Microsoft Planetary Computer. sobloo has the advantage that the services of the Copernicus Climate Change Service and from the Copernicus Marine Service are provided, that offers tools and relevant data to assess climate risks of ports. The Microsoft Planetary Computer has the advantage that it is a very powerful platform, which allows the integration of almost any data and software. The various data that are needed for the use case (indicated in Figure above) are accessed from different sources that are processed by the application. In both cases, a dedicated frontend and backend must be developed for a DCSA. This technical setup should only be considered as exemplarily for this use case.

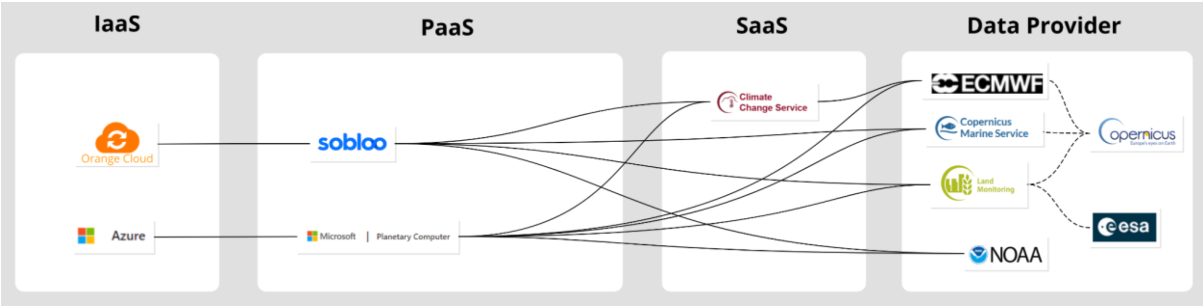

Figure 18: Example structure of a DCSA framework for the use case of climate risk assessments of ports, with the components IaaS, PaaS, SaaS and data providers.

4.2.4. Summary of the example solution

+ European IaaS, PaaS and SaaS capacities in case of sobloo
+ Very powerful computing capacities in the case of MS Planetary Computer
+ Own algorithms can be implemented
+ Open-source software can be implemented as well as open data

- Not free of charge in case of sobloo
- Risk that the so far free service of MS Planetary Computer turns into a paid service
- Full front- and backend development needed
- Multi-source data must be integrated and harmonized

5. Recommendations

Based on the findings from the online survey and the related in-depth interviews with available experts, and based on the DCSA use cases, the following recommendations for future developments of DCSA in the context of activities of the German development cooperation are provided, along the following three points.

5.1. Advisory for DCSA development and implementation (opportunities and challenges)

- **Assess user needs and opportunities through co-creation and co-development:** The user needs and their information demand for decisions in the context of climate change adaptation are key to be understood. Therefore, besides traditional instruments of conducting a comprehensive needs assessment to understand the specific requirements of the target regions, countries, and the actors, it is recommended to build on a co-design and co-creation process jointly together with the user, the donor and the developer. As one expert stated: "Fundamentally we need to get better in living in the shoes of the decision makers and policymakers who are dealing with climate adaptation". Finally, redundancies of existing tools should be avoided.
- **During the conceptual design, a political dialogue** should be initiated to anchor the necessary political acceptance in the context of digital solutions in the development cooperation sector.
- **Evaluate if there is an added value of an DCSA for specific use cases**, or if the effort to develop such service exceeds the resources needed for a classical approach. DCSA are specifically beneficial, if use cases can be scaled or require repeated assessments, which is for instance supported using standardised approaches for CRAs.
- **Data Management, integration and sharing:** DCSAs supporting climate risk assessments rely on vast amounts of data from various sources, including data on the climate, environment, physical aspects as well as a large amount of socio-economic information. It is required to support the relevant policy framing which allows access to and the sharing of relevant data especially on the national and sub-national level. This also includes the documentation of metadata as well as procedures to ensure the quality of data. In cases where data sharing agreements are required, these agreements should clarify data ownership, usage rights, and any confidentiality requirements.
- **Follow standards and guidelines for climate risk assessments:** It is recommended to build on established standards and guidelines for climate risk assessments. This includes for instance ISO14091, the GIZ Climate Risk Sourcebook or for instance the PIEVC protocol. This secures issues around the quality, relevance as well as comparability of results achieved. In addition, and highly relevant for cloud-based solutions is the possibility to automatise routines where possible. This might include the case where parts of the assessment cannot be done within an automated DCSA, but rather need to be done in an external module. Standards and guidelines provide an important basis for

that. It needs to be acknowledged that climate risk assessments need to be seen as processes, therefore a right balance between automation and the integration of heuristic approaches should be maintained.

- **Follow standards for data formats:** It is recommended to follow as best as possible standards for data and document metadata to ensure seamless integration and interoperability between different systems and datasets.
- **DCSAs for sectors:** In general, DCSAs for climate risk assessment should follow a sector-based (or problem-based) approach. However, as risk management is a transversal agenda it needs to be recognized that different user groups have diverse needs and knowledge levels. Therefore, it is also recommended to develop standard service products, that can then be used as input to tailor the DCSAs to cater to specific user groups, such as farmers, policymakers, urban planners, or humanitarian agencies etc.
- **Climate Risk assessments can partly be highly complex** regarding required input information for the sub-assessments of the criteria to be considered for the assessments of hazards, exposure and vulnerability. This high level of complexity can partly be a showstopper for an automated DCSA approach, since automated data and information access is needed. In such cases, it is important to evaluate if a generalization of a use case is technically and thematically feasible. Such generalization could then remove obstacles of complexity and make a DCSA easier to scale.
- **User-friendly interfaces and communication:** It is strongly recommended to create user-friendly interfaces that allow stakeholders to access and understand climate and risk related information easily. Intuitive visualization tools, interactive maps, and customizable dashboards can help users make informed decisions based on the available information (at various levels from experts to decision-makers that have different information requirements). Users should be guided through the portal to find answers to their questions which in the end will support the decision to be taken. Besides the communication of quantitative information and data - which is the main aim of cloud-based tools - the identification of key messages and recommendations should be integrated in the process when developing DCSAs for climate risk assessment.
- **Translation of results vs. expert-based tools:** The need for DCSAs to support climate change adaptation exists on both ends - supporting the end of the value chain, such as decision makers with easy-to-use tools and the distillation of key insights, as well as platforms and tools, which target the expert level, for instance through the customisation of scripting tools or similar. The decision often depends on the context of the application, and it is recommended to be defined during the phase where requirements are developed. If the DCSA is not able to break the assessment down to simple numbers used for recommendations, it will lose decision makers as users. If the DCSA is not able to allow complex analytics, it will use the expert users. If the DCSA is too complex in its handling, it will lose both.

5.2. Cooperation with identified DCSA providers

- **Collaboration and Partnerships**: Foster collaboration with relevant stakeholders, including governments, NGOs, research institutions, service providers and international organizations. Collaborative efforts can enhance data sharing, improve the accuracy of risk models, and increase the impact of DCSAs.
- **Demonstration projects:** A stepwise approach to develop DCSAs is recommended which builds on demonstration projects to showcase the benefits and applications of cloud-based climate risk services. These projects can serve as real-world examples for potential users and hosts, encouraging wider adoption. However, at the end of the development phase, the solution should have reached a high level of technical maturity before its release.
- **Sustainability of portals and platforms:** A challenge when developing technical systems are its sustainability after donor and/or project funding ends. Therefore, it is highly recommended to secure ownership of the relevant tools by target actors, as well as have a long-term perspective in mind which can support the DCSA in the future.
- **Select appropriate cloud platform:** Choose a cloud service provider that meets the specific needs of climate services, ensuring reliability, data security, and scalability. Evaluate different IaaS, PaaS and SaaS solutions to identify the most suitable option for hosting and delivering climate data and services.
- **Diversity of Cooperation:** A one-stop-solution that meets all the requirements of a DCSA does not yet exist, but a potential solution could be based on existing technologies that could be put together in a modular way.
- **Cross sectional use through central steering:** A central control/steering of a cloud-based DCSA by the German development cooperation is necessary. With such central management role, existing structures could be used to the maximum and long-term cooperation with science and industry should be concluded, which is particularly relevant for sector-relevant SaaS developments and their implementation. The steering structure of a platform solution (who manages the service in the long-term) should be clearly defined within development cooperation to institutionalize its global use.
- **Cooperation for sustainable financing of a DCSA**: The "pay-per-use" scenario of most service providers enables an efficient cost-benefit ratio, but can lead to very volatile costs, which requires a flexible financing structure of the DCSA. Such a new financing structure must be ensured through financial cooperation.

5.3. Development of capacity

- **Support the understanding of climate risk across disciplines and stakeholders:** An important challenge observed from the survey and interview results is the lacking awareness and purpose of climate risk assessment. There is a strong tendency to have a view from one's own perspective and discipline; there is currently still a strong shift only to understand hazards and partly exposures. While this is valid, it is of utmost importance when developing DCSAs for climate risk assessment that the need, the purpose as well as the concept and related methods of climate risk assessments are understood. Besides a capacity building component this relates to an adequate policy framing which aims to reduce risks and has a clear governance structure for dealing with hazard, exposure, and vulnerability.

- **Support institutional capacities to allow the development as well as uptake of DCSAs:** There is a strong need to support institutions to develop DCSAs regarding policy framing and awareness of such services. This includes for instance data sharing agreements across different institutions, clarity on the mandate and sharing of expertise in the context of CRAs. CRAs are by nature a horizontal activity and may include a variety of different institutions as well as stakeholders. To allow the technical potentials of DCSA to unfold clarity, commitment together with relevant policy framings are key, so that DCSAs together with CRAs contribute to the management and reduction of risks.
- **Build technical capacities:** While also in partner countries technical capacities are continuously increasing, it is recommended to build technical capacities, specifically to develop or use DCSA platforms and its tools, such as inherent climate risk models. Especially if tools are initially developed by consulting firms, to use and uptake of such results should be evaluated from the very beginning.
- **User training and support:** The lack of necessary geo/climate-expertise on the user side can limit the use of the platform and therefore requires a clear capacity development strategy which includes training workshops (on concepts, methods, and data interpretation) and webinars to familiarize users with the cloud-based climate services. Provide guidance on accessing, interpreting, and utilizing the climate information effectively for climate risk assessment and decision-making.
- **Partnership with Educational Institutions:** It is recommended to collaborate with educational institutions to integrate DCSAs for climate risk assessment into their curricula. This can help build a pipeline of skilled professionals who can leverage these services for sustainable development.
- **Continuous feedback and improvement:** Encourage users to provide feedback on the usability and effectiveness of the climate services. Use this feedback to continuously improve the services and address any shortcomings.

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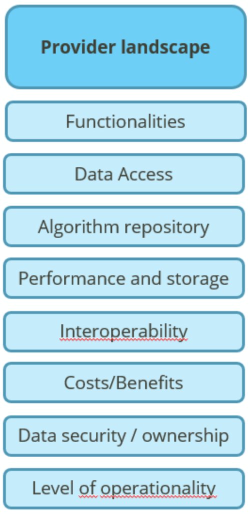
ANNEX 1 - Guiding questions for the Semi-structured interviews

<table>
<tr>
<td>
</td>
<td>Purpose: How can a DCSA support a CRA, beyond current approaches? What could be the main application domain?

Sectors - Survey: Does a DCSA for a CRA need to be sector specific? Which could be main application contexts.

Spatial Scope: Which challenges do you see for DCSA providing meaningful data for DCSA?

Methods: Does a DCSA need to follow standards/guidelines (procedures?

Data/Indicators: Thinking on the risk domain, which domain would benefit the most in the context of a DCSA for CRA?</td>
</tr>
<tr>
<td>
</td>
<td>Functionalities: Which functionalities of a DCSA are the most fundamental and which are the most wanted?

Data access: What are requirements for a DCSA in regard to data access?

Algorithms/Performance/Interoperability: Are you interested in an expert platform, which allows own scripting, or a non-expert platform that provides a user interface with predefined processing procedures?

Costs/Benefits: Are you able/willing to pay for a DCSA?</td>
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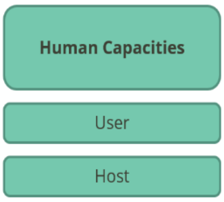
<td>
</td>
<td>User: Which human capacities need to be developed/available on the user side to make the best use of DCSA in CRAs?

Host: Which human capacities need to be available on the host side?</td>
</tr>
<tr>
<td>General questions:</td>
<td>- Follow up on opportunities
- Follow up on challenges
- Who are users?
- What are trends in the context of CRA?
- Which technology trends do you see around DSCAs?
- What are your recommendations for DCSAs in general?</td>
</tr>
</table>

ANNEX 2 - Questions of the online survey

Survey on Digital Climate Service Applications for Climate Risk Assessment

Thank you very much for your willingness to fill out this survey. This is very short, and will be finished in a few minutes

1. Your Name

___

2. Your institution:

___

3. Your e-mail:

___

4. Please select the sector or type of institution that best matches your entity:

Markieren Sie nur ein Oval.

- ◯ Private Sector
- ◯ Science
- ◯ Governmental Organization
- ◯ Inter-Governmental Organization
- ◯ Financial Sector
- ◯ Donor
- ◯ **Sonstiges:** ___

Are you a user of climate services or are you/have you been a provider/developer?

5. Please select the option:

Markieren Sie nur ein Oval.

- User *Fahren Sie mit Frage 6 fort*
- Provider/Developer *Fahren Sie mit Frage 9 fort*

Your experience as a user:

6. How often are you using climate data or climate services?

Markieren Sie nur ein Oval.

- On a daily basis
- Once a week
- Few times per month
- Few times per year

7. Have you already used cloud-based platforms (e.g. data on Copernicus Climate Data Store or similar) to use/analyse climate data? ***Markieren Sie nur ein Oval.***

- Yes *Fahren Sie mit Frage 8 fort*
- No *Fahren Sie mit Frage 12 fort*

YES - Your experience with cloud-based platforms

8. Please specify the platform

Fahren Sie mit Frage 12 fort

Your experience as a provider/developer:

9. Please specify the climate service (e.g. downscaled climate variables, climate indices, historical climate data etc.):

10. Is that climate service created via internal tools/software, or is it provided as a cloudbased service that can be accessed by users?

Markieren Sie nur ein Oval.

- via non-open tools via a
- cloud-based platform

11. Please specify the software/tool or platform

Climate Risk Assessments

12. Have you been using climate data and other datasets for climate risk assessments, in general?

Markieren Sie nur ein Oval.

- ◯ Yes *Fahren Sie mit Frage 13 fort*
- ◯ No *Fahren Sie mit Frage 14 fort*

YES - You have been using data for climate risk assessments

13. Please select the domain of climate risk assessment

Wählen Sie alle zutreffenden Antworten aus.

- ☐ Infrastructure
- ☐ Transportation
- ☐ Health
- ☐ Agriculture
- ☐ Natural Resources
- ☐ **Sonstiges:**

Fahren Sie mit Frage 15 fort

NO - You have not been using data for climate risk assessments

14. Please specify the purpose, other than climate risk assessments

On opportunities

15. What is the main opportunity/benefit for digital climate service applications in the context of climate risk assessments and climate change adaptation?

On limitations and obstacles

16. What are the major limitations/obstacles of existing cloud-based climate service applications (in general and/or for climate risk assessments particularly)?

Please indicate your level of agreement or disagreement for the following statements

17. At their current development stage, digital climate service applications provide a substantial benefit to climate risk assessments.

Markieren Sie nur ein Oval.

	1	2	3	4	5	
not a	◯	◯	◯	◯	◯	totally agree

18. The provision of digital climate services for climate risk assessments, will be of great potential to execute a sound and data driven risk assessment tailored to the identification of viable adaptation options! ***Markieren Sie nur ein Oval.***

	1	2	3	4	5	
not a	◯	◯	◯	◯	◯	totally agree

19. The development of digital climate services for climate risk assessment, will be accompanied by a number of challenges, which can be solved… ***Markieren Sie nur ein Oval.***

	1	2	3	4	5	
easil	◯	◯	◯	◯	◯	with a lots of effort

20. The main capacity to be improved in regard to the use of digital climate services for climate risk assessment is within the following fields (multiple choices possible)

Wählen Sie alle zutreffenden Antworten aus.

- [ ] technical - to be able to use such services
- [ ] technical - to build such services institutional
- [ ] framing and setup governance issues,
- [ ] independent of such services customization for
- [ ] the wide range of purposes **Sonstiges:**
- [ ] ______________________

We hope for your support

21. Would you be interested to take part in an online 30 minutes interview, in which we can further discuss the potential of DCSAs?

Markieren Sie nur ein Oval.

- ( ) Yes
- ( ) No

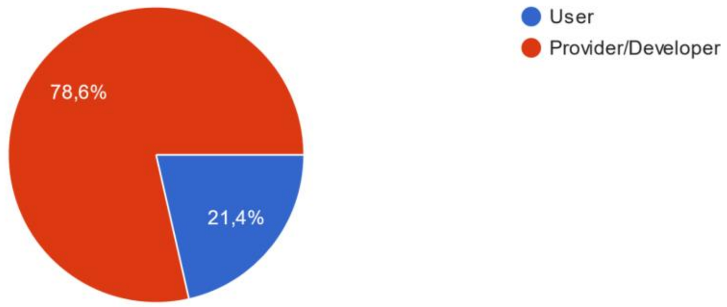
ANNEX 3 - Overview of results of the online survey

Please select the sector or type of institution that best matches your entity:

15 Antworten

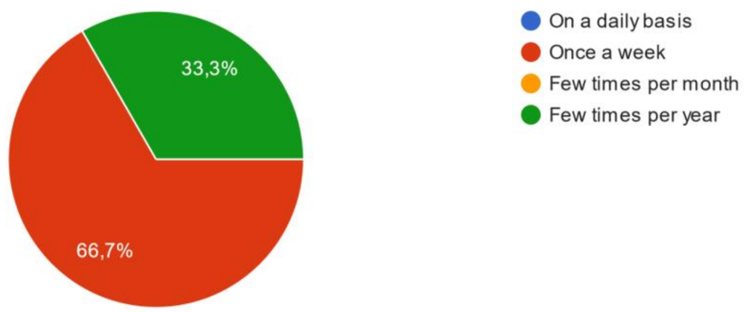
Please select the option:

14 Antworten



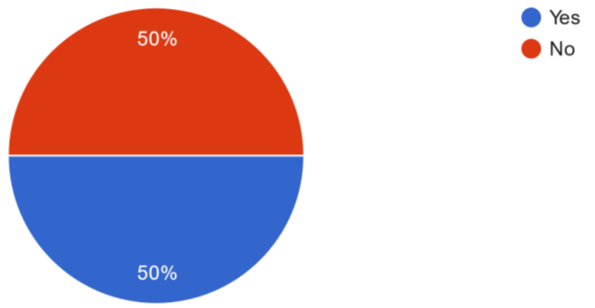
How often are you using climate data or climate services?

3 Antworten



Have you already used cloud-based platforms (e.g. data on Copernicus Climate Data Store or similar) to use/analyse climate data?

4 Antworten



YES - Your experience with cloud-based platforms. Please specify the platform

2 Antworten

- ➔ Climate Change Knowledge Portal - World Bank (https://climateknowledgeportal.worldbank.org/), Copernicus Climate Data Store and https://climateinformation.org/
- ➔ ClimateData.ca, WorldBank, CCHIP (Climate Risk Institute proprietary tool), Copernicus

Your experience as a provider/developer: Please specify the climate service (e.g. downscaled climate variables, climate indices, historical climate data etc.):

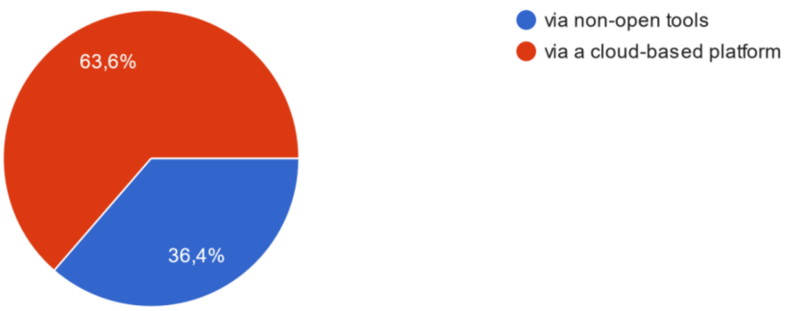
11 Antworten

- ➔ The Climate Change Initiative of ESA covers R&D for a vast range of climate services
- ➔ climate indices, historical climate
- ➔ Environmental data management dashboards for Local Governments
- ➔ historical and modelled climate data and indices
- ➔ downscaled seasonal climate forecasts, monthly and weekly forecasts, climate indices such SPI forecast, early warning systems
- ➔ Yield forecasts, partly based on climate forecasts
- ➔ I worked for 3 years and a half at ICPAC supporting climate service delivery, developing watch systems and improving products and dissemination channels
- ➔ All of the above
- ➔ Seasonal outlooks (climate variables), climate drivers
- ➔ open data provider

- ➔ Integrator of quality assured, open and free data products and applications of past, present and future climate at a global and European scale, including toolbox and services such as user support, documentation and training.

Is that climate service created via internal tools/software, or is it provided as a cloud-based service that can be accessed by users?

11 Antworten

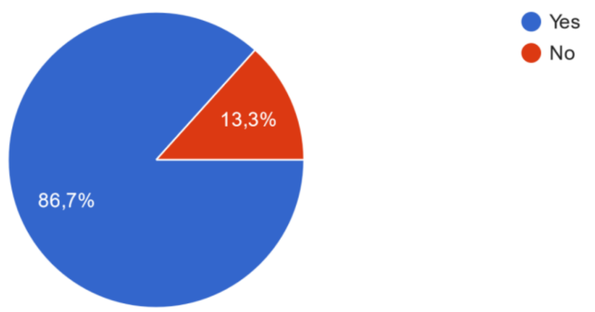


Please specify the software/tool or platform

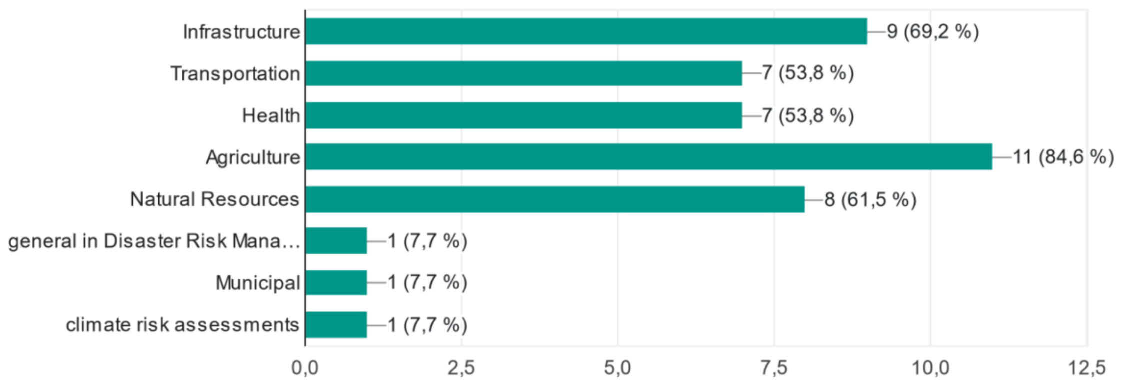
11 Antworten

- ➔ CEDA Archive
- ➔ ArcGIS plus a collection of open-source tools. The processing scripts to generate climate indices are provided as open source via GitHub. Computation is done in cloud platform and provided as download and OGC web services from cloud platform.
- ➔ google environmental insights explorer
- ➔ Agriculture Risk Metrics
- ➔ We use WRF and statistical models to generate forecasts, the forecasts are made available to the public through various online web-systems, these web systems are hosted in the cloud; several early warning systems have been developed
- ➔ Self-developed crop models
- ➔ East Africa Hazards Watch, email marketing, social media, website
- ➔ In-house python-based tool
- ➔ mostly python
- ➔ AWS
- ➔ Copernicus Climate Change Service (C3S) Climate Data Store (CDS)

Have you been using climate data and other datasets for climate risk assessments, in general?
15 Antworten



Please select the domain of climate risk assessment
13 Antworten



NO - You have not been using data for climate risk assessments

Please specify the purpose, other than climate risk assessments

2 Antworten

- ➔ I have only accessed data to get a broad overview on potential climate impacts under different scenarios
- ➔ To support regional National Meteorological and Hydrological Services, some users (although not explicitly in risk assessments)

On opportunities

What is the main opportunity/benefit for digital climate service applications in the context of climate risk assessments and climate change adaptation?

14 Antworten

- ➔ Better prepare / assess planned operations

- ➔ To better inform planners and policy makers so they can incorporate climate risk into their decision making.
- ➔ Informed decision making
- ➔ information delivery for risk management
- ➔ Digital Climate Services Applications provide an opportunity for automated continuous monitoring allowing for timely early warning dissemination and hopefully action. DCSA also provide intelligence on what is working, what is not, what's coming therefore what's the best adaptation practices to implement
- ➔ Better and earlier decision making, even under uncertainty
- ➔ To gather and synthesize all sources of climate information and customize it to the decision-makers.
- ➔ assessments: easier to access, less data collection needed, cheaper, / further digital processing possible
- ➔ Building next-generation tools informed by end-user needs, integrating societal and behavioural considerations in DCSA tools, and developing metrics for measuring uptake. Emphasis on institutionalization is required. Less emphasis should be placed on advances in tools development and the paradigm should shift towards end-user priorities.
- ➔ one stop platform for different sources and types of information
- ➔ Expediting vulnerability and risk assessments by providing pre-processed historical and future-projected data for and statistics aligned with indices that support analyses ranging from "high level" / general to potentially far more specific (e.g., aligned with known sensitivities or design thresholds of particular natural or built infrastructure components and systems).
- ➔ With Open Data specifically, we can provide a variety of users the ability to assess their climate risk in a variety of use cases, from sea level rise - will this building be under water in 10 years before I build- to wildfire monitoring from space. Armed with this data and analysis, users can act on their climate risk - move that building inland and prepare/respond to wildfires faster.
- ➔ Better data availability to a broader range of users
- ➔ Accessibility and operability // Ability to work close to the data**.**

On limitations and obstacles

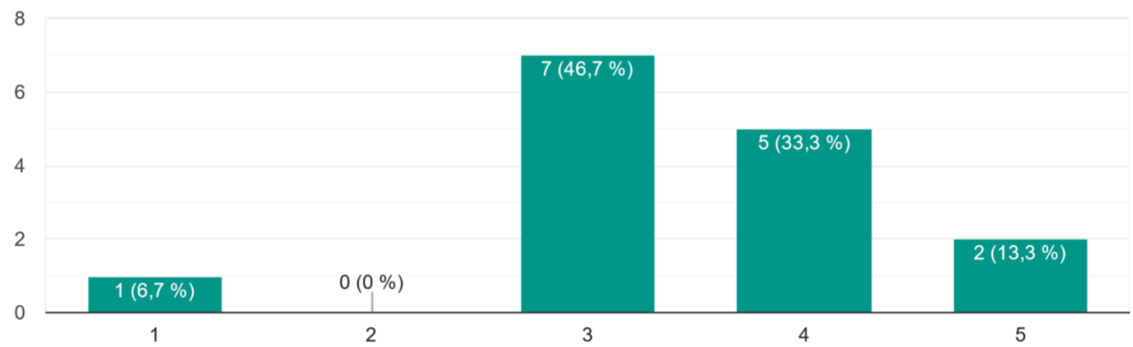
What are the major limitations/obstacles of existing cloud-based climate service applications (in general and/or for climate risk assessments particularly)?

14 Antworten

- ➔ Having all the data available in one place as well as all the tool necessary to process them seamlessly
- ➔ End users often have limited understanding of assumptions. Rigorous regional downscaling not available in most parts of the world. Most cloud services provide overwhelming amounts of data and detail that policy makers and planners cannot effectively use.
- ➔ Awareness, poor data quality & models

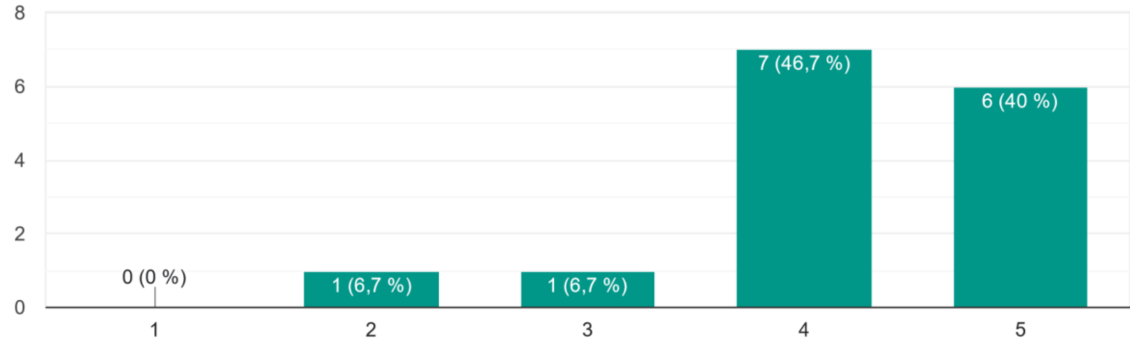
- ➔ user-specific interface/information delivery that directly addresses the information needs of the user (e.g. farmer, insurer)
- ➔ Could perpetuate existing digital divide. Other limitations include: access and skills to interpret the products;
- ➔ complexity for users, interpretability, costs
- ➔ The decision makers are not familiar with the format in which climate information is delivered. Moreover, there is a need to inform the uncertainties related to the climate projections in a way that is understandable by the decision makers
- ➔ not sure but often not country specific /
- ➔ Too generic for any kind of application. And not regionally relevant.
- ➔ using climate data effectively (or making sure underpinning data is appropriate for the application)
- ➔ Overly course spatial and/or temporal resolutions; overly "generic" / not specifically tailored indices for the assessment of likelihoods of exceedance of thresholds particular to and consequential for specific system components etc.
- ➔ Researchers aren't (necessarily) cloud experts and it's hard to get started. THere's a bit of a learning curve - how do I get data? how do I get data at scale (seasonal changes, year over year changes)? how do I process this data in an efficient manner?
- ➔ Missing contact persons for consultancy
- ➔ Depends on the data proficiency and domain background of the expert which you aim to reach: general knowledge of their existence (pros/cons), slow operational and download speed, API issues, documentation and user guidance, UX and user journey issues, standardisation (FAIR principle) incl. scalability and interoperability with other data and information which is essential for risk assessments. Depending on need: accreditation (e.g. banking, insurance)

At their current development stage, digital climate service applications provide a substantial benefit to climate risk assessments.
15 Antworten



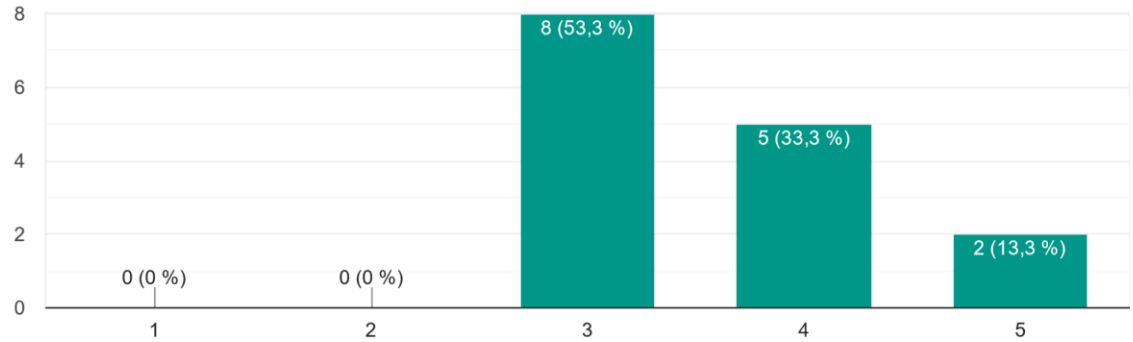
The provision of digital climate services for climate risk assessments, will be of great potential to execute a sound and data driven risk assessment tail...to the identification of viable adaptation options!

15 Antworten



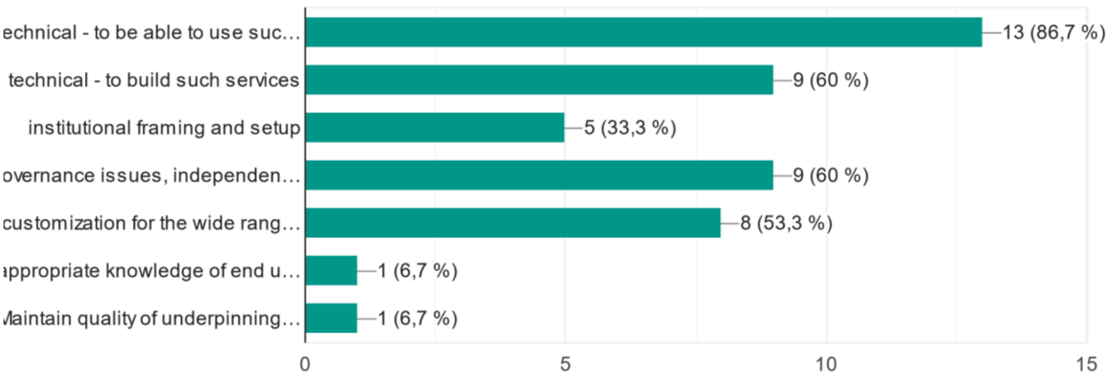
The development of digital climate services for climate risk assessment, will be accompanied by a number of challenges, which can be solved...

15 Antworten

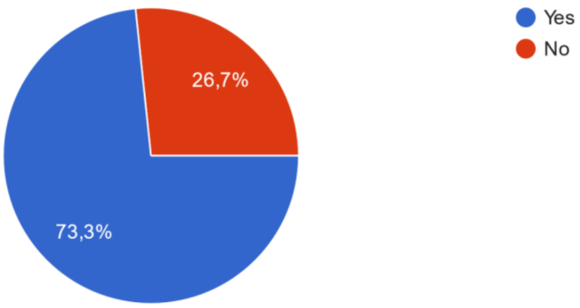


The main capacity to be improved in regard to the use of digital climate services for climate risk assessment is within the following fields (multiple choices possible)

15 Antworten



Would you be interested to take part in an online 30 minutes interview, in which we can further discuss the potential of DCSAs?
15 Antworten



ANNEX 4 – Institutions interviewed

Institution
World Meteorological Organization (WMO)
GIZ Brazil
ESRI
Intergovernmental Authority on Development (IGAD)
Google
GeoSphere Austria
Climate Risk Institute
Amazon Web Services
ECMWF/Copernicus C3S
PIK
answr
Genillard

Annex 5 - Short Description of climate data and web service providers (in alphabetical order); Information was mainly compiled from the respective websites

answr:

answr is a commercial platform that leverages API-based global climatic and risk data layers to build new or enhance your existing risk models and improve your decision-making and asset management. It offers highly distributed and modular application architectures and use case-based API endpoints for maximized application flexibility and scalability. Answr provides real-time access to climatic and risk data layers to directly integrate into workflows.

Arbol:

Arbol settles contracts leveraging climate data and models from dClimate, a leading decentralized climate information ecosystem. The dClimate ecosystem provides data, forecasts, and models on important variables like rainfall, temperature, soil moisture, carbon sequestration, and much more. Arbol leverages dClimate to retrieve industry-leading, institutional-grade climate data and models sourced from both public and government sources like NOAA, NASA, and the European Space Agency (ESA) as well as industry-leading commercial and private sources for underwriting our parametric coverage products. Data gets run through our proprietary AI underwriter, where thousands of variables are analyzed.

Cervest (EarthScan):

EarthScan is a commercial platform mainly to assess physical risks to assets from multiple hazards. Through combining earth science, data modeling, and machine learning, EarthScan™ provides on-demand climate intelligence to confidently de-risk decisions, meet financial disclosure needs, and make assets more resilient. It allows for historical, current and predictive climate risk assessments on physical assets, and to baseline, monitor and forecast risk across entire portfolios (https://cervest.earth/earthscan).

Climate Explorer:

The KNMI (Royal Netherlands Meteorological Institute) Climate Explorer is a web application to analyze climate data statistically. It contains more than 10 TB of climate data and dozens of analysis tools. It is part of the WMO Regional Climate Centre at KNMI. The KNMI Climate Explorer is a scientific tool to investigate the climate. By selecting a class of climate data from the menu it allows to investigate it, correlate it to other data, and generate derived data from it. Much of the observational data is updated monthly, part of the daily data is updated every day (https://climexp.knmi.nl/start.cgi).

CMRA (Climate Mapping For Resilience and Adaptation):

Climate Mapping for Resilience and Adaptation (CMRA) helps people assess their local exposure to climate-related hazards. Understanding exposure is the first step in determining which people, property, and infrastructure could be injured or damaged by climate-related hazards, and what options might be available to protect these assets. CMRA is intended to serve as a high-level screening tool for exposure to climate-related hazards. The US Federal data and tools offered on the site serve as helpful inputs into local communities' and government offices' assessments of vulnerability and risk. CMRA was developed in August 2022 as part of an interagency partnership working under the auspices of the U.S. Global Change

Research Program (USGCRP) and with guidance from the U.S. Federal Geographic Data Committee (FGDC). The project was funded by the Department of the Interior (DOI) and National Oceanic and Atmospheric Administration (NOAA). The site was developed by Esri, working under contract to NOAA. NOAA hosts and manages CMRA (https://resilience.climate.gov).

Copernicus Atmosphere Monitoring Service (CAMS):

CAMS is one of six services that form Copernicus. CAMS is implemented by the European Centre for Medium-Range Weather Forecasts (ECMWF) on behalf of the European Commission. At the core of our service is direct access to reliable data and expertise related to air quality, solar energy, and the role atmospheric gases and particles play in climate change. We use satellite and ground-based observations with forecast models to support businesses, policy makers and scientists dealing with the challenges and opportunities related to the composition of the atmosphere. To acquire all the observations that are needed to produce the CAMS services, ECMWF collaborates with the European Space Agency (ESA) and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) as well as many other organisations providing satellite and in-situ observations. The current portfolio of mature operational products was designed in close consultation with the (potential) users and developed through a series of EU-funded precursor projects starting in 2005.

Copernicus Climate Change Service (C3S):

The C3S mission is to support adaptation and mitigation policies of the European Union by providing consistent and authoritative information about climate change. C3S offers free and open access to climate data and tools based on the best available science. C3S is one of six thematic information services provided by the Copernicus Earth Observation Programme of the European Union. Copernicus is an operational programme building on existing research infrastructures and knowledge available in Europe and elsewhere. C3S relies on climate research carried out within the World Climate Research Programme (WCRP) and responds to user requirements defined by the Global Climate Observing System (GCOS). C3S provides an important resource to the Global Framework for Climate Services (GFCS). C3S offers access to data and also provides a suite of software tools to allow scientists and consultants to make use of climate datasets to support planning and decision-making.

Copernicus Emergency Management Service (CEMS):

The Copernicus Emergency Management Service mainly provides three service levels such as 1) on demand mapping for selected emergency situations that arise from natural or man-made disasters anywhere in the world, 2) exposure mapping that provides highly accurate and continuously updated information on the presence of human settlements and population with the Global Human Settlement Layer (GHSL) and 3) Early Warning and Monitoring offers critical geospatial information at European and global level through continuous observations and forecasts for floods, droughts and forest fires.

Copernicus Land Monitoring Service (CLMS):

The Copernicus Land Monitoring Service (CLMS) provides geospatial information on land cover and its changes, land use, vegetation state, water cycle and Earth's surface energy variables to a broad range of users in Europe and across the World in the field of environmental terrestrial applications. It supports applications in a variety of domains such as spatial and urban planning, forest management, water management, agriculture and food security, nature conservation and restoration, rural development, ecosystem accounting and mitigation/adaptation to climate change. CLMS is jointly implemented by the

European Environment Agency and the European Commission DG Joint Research Centre (JRC) and has been operational since 2012.

Copernicus Marine Environment Monitoring Service (CMEMS):

The CMEMS provides free, regular and systematic authoritative information on the state of the Blue (physical), White (sea ice) and Green (biogeochemical) ocean, on a global and regional scale. It is funded by the European Commission (EC) and implemented by Mercator Ocean International. It is designed to serve EU policies and International legal Commitments related to Ocean Governance, to cater for the needs of society at large for global ocean knowledge and to boost the Blue Economy across all maritime sectors by providing free-of-charge state-of-the-art ocean data and information. It provides key inputs that support major EU and international policies and initiatives and can contribute to: combating pollution, marine protection, maritime safety and routing, sustainable use of ocean resources, developing renewable marine energy resources, supporting blue growth, climate monitoring, forecasting, and more.

CREODIAS (DIAS):

As part of the DIAS initiative, CREODIAS provides an environment for processing earth observation data. The platform contains online most data and services from the Copernicus Sentinel satellites, Envisat and ESA/Landsat data and other EO data. The design of the platform allows third-party users to create prototypes and develop their own value-added services and products. A set of tools enables simplicity, scalability and repeatability of the service value chain. CREODIAS offers a big data-ready OpenStack cloud platform for processing over 18PB of earth observation data with instant and local access. In addition, access to a range of platform-as-a-service applications is enabled.

dClimate:

dClimate is a chain-agnostic decentralized climate information ecosystem. dClimate makes it easy for businesses and builders to find, access, and utilize essential information about our planet to better understand how weather and climate impacts our communities and build data-driven technology solutions for helping communities achieve climate resilience in the 21st century. The dClimate network solves key issues around access, availability, and accountability in the climate data ecosystem with the world's first decentralized, open marketplace for participants to get and share climate data. The network then enables an open ecosystem of climate resilience applications like parametric insurance, advanced analytics and models, and tooling to be built on top of the data layer. dClimate is pioneering data infrastructure solutions for scaling global carbon markets, incentivizing regenerative agriculture practices, and bringing increased efficiency to industries affected by climate risk.

Early Warning eXplorer (EWX):

The Early Warning eXplorer (EWX) is a web-based single-page application for exploration of geospatial data related to drought monitoring and famine early warning. The EWX enables scientists, analysts, and policymakers to view diverse data sets side-by-side in the same spatial bounding box, while also stepping through sequences of multiple time-series data sets. The EWX also allows users to view summary statistics and plots for user-selected regions by administrative zone, crop zone, hydrologic zones, or country. The objective of the EWX is to provide the famine early warning community with a lightweight, customizable web-based GIS client focused on the needs of food security analysts and decision-makers. Key features are listed below, however, new user-friendly features and data sets are being added as the user community and analytical requirements of that community expand. EWX instances are hosted by several different agencies, including USGS, Climate Hazard Center and RCMRD.

European Centre for Medium-Range Weather Forecasts (ECMWF):

ECMWF is an independent intergovernmental organisation supported by 35 states. It is both a research institute and a 24/7 operational service, producing and disseminating numerical weather predictions to its member states. The Centre has one of the largest supercomputer facilities and meteorological data archives in the world. Other strategic activities include delivering advanced training and assisting the WMO in implementing its programmes. It provides information on climate change (Copernicus Climate Change Service), atmospheric composition (Copernicus Atmosphere Monitoring Service) and flooding and fire danger (Copernicus Emergency Management Service). ECMWF's core mission is to:

1. produce numerical weather forecasts and monitor the Earth system;
2. carry out scientific and technical research to improve forecast skill;
3. maintain an archive of meteorological data.

European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT):

EUMETSAT is an intergovernmental organisation, currently with 30 Member States. EUMETSAT operates the geostationary satellites Meteosat -10, and -11 over Europe and Africa, and Meteosat-9 over the Indian Ocean, two Metop polar-orbiting satellites as part of the Initial Joint Polar System (IJPS) shared with the US National Oceanic and Atmospheric Administration (NOAA) and is partner in the cooperative sea level monitoring Jason missions (Jason-3 and Jason-CS/Sentinel-6). The service provided by EUMETSAT helps to enhance and safeguard the daily lives of European citizens. They aid meteorologists in identifying and monitoring the development of potentially dangerous weather situations and in issuing timely forecasts and warnings to emergency services and local authorities, helping to mitigate the effects of severe weather and protecting human life and property. This information is also critical to the safety of air travel, shipping and road traffic, and to the daily business of farming, construction and many other industries.

Google Earth Engine:

Google Earth Engine (GEE) is a geospatial data processing service. Geospatial processing can be performed at scale and in real-time with Earth Engine, powered by Google Cloud. GEE offers an interactive platform for the development of spatial algorithms on a large scale. By providing a variety of data, APIs, and GUIs, it's easy to get started. Algorithms provided can be applied directly to datasets. The service is currently free for private use and for research and commercial evaluation.

IS-ENES:

Infrastructure for the European Network for Earth System Modelling (IS-ENES3), is a Horizon 2020 project, is the third phase of the distributed e-infrastructure of the European Network for Earth System Modelling (ENES). IS-ENES delivers the research infrastructure providing access to climate model data and tools to boost the understanding of past, present and future climate variability and changes. It contributes to speeding up the development and use of models of the Earth's complex climate system in Europe by sharing models, tools and expertise and it supports the international standards and data services of the World Climate Research Program coordinated experiments for global and regional climate models CMIP (Coupled Model Intercomparison Project), with a focus on CMIP6, and CORDEX (Coordinated Regional Climate Downscaling Experiments) (https://is.enes.org/). The Climate4Impact portal from IS_ENES is a user interface and a collection of services dedicated to climate change impact modellers, impact and adaptation consultants, and other experts using climate change data (https://www.climate4impact.eu/c4i-frontend/).

KNMI Climate Explorer (WMO Regional Climate Centre at KNMI):

The KNMI Climate Explorer is a web application to analysis climate data statistically. It contains more than 10 TB of climate data and dozens of analysis tools. It is part of the WMO Regional Climate Centre at KNMI. Much of the observational data is updated monthly, part of the daily data is updated every day. Other data is updated when needed. The code of the Climate Explorer itself is freely available on GitLab.

Microsoft Planetary Computer:

The Planetary Computer (PC) combines a multi-petabyte catalogue of global environmental data. These are provided via various APIs with efficient search functions. In addition, the "Planetary Computer Hub" offers a development environment with access to various open-source tools. The Azure cloud infrastructure is used for this. On the home page (https://planetarycomputer.microsoft.com/) there are many applications built on the PC.

NOAA's Climate Data Online (CDO):

Climate Data Online (CDO) provides free access to NCDC's archive of global historical weather and climate data in addition to station history information. These data include quality controlled daily, monthly, seasonal, and yearly measurements of temperature, precipitation, wind, and degree days as well as radar data and 30-year Climate Normals. Customers can also order most of these data as certified hard copies for legal use. Climate Data Online (CDO) offers web services that provide access to current data. This API is for developers looking to create their own scripts or programs that use the CDO database of weather and climate data. An access token is required to use the API, and each token will be limited to five requests per second and 10,000 requests per day.

OASIS Hub:

Oasis Hub was launched in June 2017, as an aggregator for catastrophe, extreme weather and environmental risk data, tools & services, as well to provide data set enhancement, development and data aggregation services. The key driver & focus was to create an open, transparent, data platform that would inevitably help provide environmental, climate change and catastrophe risk information to business and wider society, whilst providing everyone with a platform that encourages collaboration and crossover around data and services (https://oasishub.co/about/about-us/). The Climate Change Risk Explorer (CCRE) by Oasis Hub provides access to climate change data produced and distributed by leading institutions and frameworks.

Onda (DIAS):

Like all other DIAS services, ONDA offers access to the Copernicus data and partly services. The data and several processing options are offered free of charge, and a paid cloud environment is provided. Depending on the requirements, the user can choose between different virtual machines. For example, there are machines with performance-intensive GPUs or fast IOPS.

Sobloo (DIAS):

sobloo is operated by Airbus, Orange, Capgemini, CLS and Vito with the aim of providing open access to Copernicus data, creating a "one-stop shop" for geospatial data in general, generating new ways of using data to promote new communities for the use, processing and evaluation of geospatial information and to offer a universal docking station for any application. Through its cloud computing architecture, sobloo enables access to Copernicus data and provides APIs, tools and services for processing data According to the website, sobloo aims to provide "near real-time" access to all Copernicus data (satellite imagery and Copernicus Services), while currently data is made available for the last month. It is also possible to save own data on the sobloo Object Storage. Sharing Data and applications is possible via the sobloo Marketplace, where further information on available data, services and applications is also available. In addition, it is possible to run AI models on virtual machines with GPU access using sobloo's ModelArts feature. With ModelArts, AI models can be created via a graphical interface or with Python in Jupyter Notebooks.

USGS (The United States Geological Survey):

Created by an act of Congress in 1879, the USGS provides science for a changing world, which reflects and responds to society's continuously evolving needs. As the science arm of the Department of the Interior, the USGS brings an array of earth, water, biological, and mapping data and expertise to bear in support of decision-making on environmental, resource, and public safety issues. USGS' scientists develop new methods and tools to enable timely, relevant, and useful information about the Earth and its processes. USGS provides a range of data and maps also from Earth Observation sources such as the Landsat satellites (https://www.usgs.gov)

WCRP CORDEX:

The CORDEX vision is to advance and coordinate the science and application of regional climate downscaling through global partnerships. An initial focus of the CORDEX initiative was to establish a central CORDEX archive supplemented by regional data portals. However, it soon became clear that a geographically distributed archiving system such as the Earth System Grid Federation (ESGF) would offer much greater flexibility for the provision of numerous CORDEX RCM simulations produced by many modelling groups across the globe, analogous to the Coupled Model Intercomparison Project Phase 5 (CMIP5). ESGF is an up-to date scientific infrastructure for distributing climate data and will now become WCRP's main tool for providing global and regional climate simulations together with observations and reanalyses over the next decade. CORDEX output can be accessed using the following: 1) The federative ESGF infrastructure; 2) Impact Portals (only ESGF segment); 3) Regional Data Portals; and additionally, 4) Services provided by individual institutions (https://cordex.org/data-access/how-to-access-the-data/).

WEkEO (DIAS):

WEkEO is an EU Copernicus DIAS (Data and Information Access Service) provided by EUMETSAT, ECMWF, EEA and MERCATOR OCEAN for satellite and environmental data, virtual processing environments and customer support. Currently, WEkEO provides more than 235 datasets with data from Copernicus satellites and Copernicus Services via the WEkEO data catalogue, which can be accessed via the Harmonized Data Access API (HDA). In addition to data access, WEkEO offers a cloud-based infrastructure for data processing and data transformation using processing and big data tools. This includes offering ready-to-use virtual machines pre-configured for data access, Software-as-a-Service and the ability to use Jupyter Notebooks, standard tools such as SNAP and QGIS, and development tools for Python or R.

WMO Catalogue for Climate Data:

The WMO Catalogue for Climate Data is a trustworthy source for climate data. The datasets have been assessed through an internationally agreed maturity evaluation process. An initial 18 global climate datasets have been so far submitted by international domain Subject Matter Experts (SMEs) and assessed. The content of the catalogue is expected to expand quickly in the future with the addition of other global datasets as well as regional and national climate datasets.

Selected Research activities & Frameworks:

CLIMPACT:

The Climpact open source package for R reads in meteorological data (daily minimum and maximum temperatures, as well as daily precipitation) and delivers the frequency, duration and magnitude of various climate extremes that are directly relevant to each sector. Indices calculated by Climpact are available at both monthly and annual timescales. The climate extremes indices calculated by Climpact have been recommended by the World Meteorological Organization's Expert Team on Sector-Specific Climate Indices (ET-SCI) in conjunction with sector experts. The ET-SCI is an international team of climate scientists dedicated to improving the availability and consistency of sector-specific climate indices through the creation of software, regional workshops, research, and training materials (https://climpact-sci.org/).

GERICS:

The Climate Service Center Germany (GERICS) was initiated by the German Federal Government in 2009 as a fundamental part of the German high-tech strategy for climate protection. Since June 2014, GERICS has been an independent scientific organizational entity of the Helmholtz-Zentrum Hereon. The interdisciplinary team at GERICS develops scientifically based prototype products and services to support decision-makers in politics, business and public administration in adapting to climate change. GERICS functions as a think tank for climate services in order to meet these information needs. GERICS develops prototype products in the area of climate services and works in close cooperation with science and practice partners from politics, economy and administration.

Potsdam Institute for Climate Impact Research (PIK):

The Potsdam Institute for Climate Impact Research (PIK) is a member of the Leibniz Association. PIK integrates the latest understanding of the Earth system with the assessment of climate risks, and with the exploration of policies and pathways towards a manageable climate future. A guiding framework for PIK's research is therefore the integration of Planetary Boundaries and Global Commons. The institute in a unique way combines research across disciplines and scales with solution orientation, emphasizing that societal relevance is based on scientific excellence. PIK contributes knowledge to the global scientific community by way of publications in high-ranking peer-reviewed international journals and engagement in numerous partnerships and networks. Its main methods are integrated and complex systems analysis and data integration; numerical simulations are run on our own super computer. The institute also actively provides insights to decision-makers in policy, business, and society as a whole.

Global Framework for Climate Services Office (GFCS):

GFCS provides a worldwide mechanism for coordinated actions to enhance the quality, quantity and application of climate services. The principles of GFCS are:

- High priority for the needs of climate-vulnerable developing countries
- Primary focus is the better access and use of climate information by users
- Framework will address needs at three spatial scales: global, regional and national
- Climate services must be operational and continuously updated
- Climate information is primarily an international public good and governments will have a central role in the Framework
- The Framework will encourage global, free and open exchange of climate-relevant data
- The Framework will facilitate and strengthen - not duplicate
- The Framework will be built through partnerships