Deliverable – 3.3

Feasibility study of local climate services

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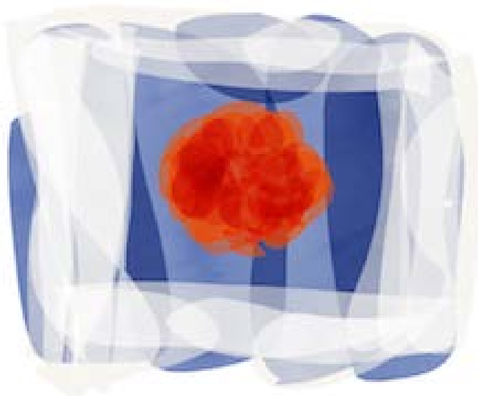

European Research Area for Climate Services

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1 Executive summary

In this deliverable, the feasibility of local climate services is analysed. Based on the results of D3.2, knowledge gaps and missing formats are localised. Moreover, it is analysed to what extend raised information demands can be catered with the existing related research results, which are relevant for the found issues. Challenges for communicating climate change on local scales are addressed and limitations from scientific, providers' and stakeholders' perspectives are identified. Options for the (co-) development or improvement of sustainable local climate services are discussed and documented.

2 Introduction

2.1 Goal/Purpose of the document

The purpose of this document is to define promising scopes for additional climate service formats in the local case study sites. The status of the respective climate related issue (content or format) is documented. Moreover, the options for realization, the challenges and limitations are discussed.

Knowledge gaps may represent limited understanding or constrains (large uncertainties) of the future climate (e.g. storms or heat waves) or of social-economic developments, at the regional or local scale. Hence, this knowledge is also not available (but might be needed) for regional and local decision-making processes (e.g. territory planning). This knowledge gap implies research efforts from the scientific community and communication efforts from the climate service community to make the needed information adoptable for decision-making processes. Tailoring formats to users' needs are another task in situations where the scientific knowledge exists in the scientific literature but not in the form of a service for decision-makers or stakeholders. When these tailored formats exist, climate information becomes available for users but challenges can remain since missing climate related action may not correspond to the availability of climate information and its communication but to other dominant social, economic and political interests and constrains. Based on all previous challenges and limitations identified, options for the improvement of existing services or co-development of new services can be discussed.

2.2 Relationship to the Description of Work (DOW)

This report is part of Co-Cli-Serv WP 3, Task 3.3. of feasibility analysis of local climate services and contributes to the overarching Co-Cli-Serv aim to transform climate science into action-oriented place-based climate services to engage, enable and empower local communities to act locally. This aim is to be reached by identifying future information needs and the nature of the climate science needed to address the local communities' concerns, aspirations and goals in view of climate variability and climate change, and through the co-construction of climate services to support local planning and adaptation decision-making (Vanderlinden et al., 2016). Based on the results of D3.2, climate related information needs are identified to address the local communities' concerns. Subsequently, ways to transform climate science into action-oriented information and formats are illustrated with respect to the state of the art and by considering local circumstances.

The report meets the requirements of deliverable D3.3 (Feasibility study of local climate services).

3 Dordrecht (Birgit Gerkensmeier)

The feasibility discussion for the Dordrecht case study is based on the evaluation presented in D3.2. It includes insights on knowledge needs deduced from the WP2 scenario activity (provided by Arjan Wardekker) and the comparative analysis of perceived issues (deduced from the narratives) and the presented knowledge needs with available climate services. Building on that basis, in the following section the need and room for improvement and development of enhanced local climate services will be discussed for the most relevant thematic issues.

3.1 Changes in the seasons

Following the WP1 material and the related analysis in D3.2, changes in the seasons are recognized by the interviewees through changes in precipitation (more rain in summer and particularly winter) and temperature ("winter isn't as cold any more as it used to be", D1.2, p. 47). This issue was not addressed in the discussions about knowledge needs in the WP2 scenario workshop. Building on the evaluation of existing local climate service components (D3.2) it became clear that missing information (e.g. absence of information of adequate spatial and temporal resolution for major parameters) is not an urgent issue here. Available services (evaluated in D3.2) sometimes show a very high spatial resolution. However, beside the highly adaptive visualization of available data for different spatial scales, a problem is seen with the presentation of the findings: existing services are designed to be applicable to a wide spatial area. You can zoom in the maps (compare here the Climate Impact Atlas[1]) up to a very local scale. However, the explanation, especially the texts of the additionally presented format of story maps[2], do not offer the desired "translation" of the visualized, local information into a description on local effects and impact in the accompanying text. In this situation, it is striking that the existing text-based climate service is inflexible at this point. One example for text-based information, which is flexible with regard to the chosen region are the web tools of the Northern German Climate Office (www.norddeutscher-klimamonitor.de, Meinke et al. 2014 and www.norddeutscher-klimaatlas.de, Meinke et al. 2009). Both tools are providing climate information for predefined sub-regions of Northern Germany while the interpreting text is changing with the chosen region.

If the presented scenarios actually contain a very high spatial resolution, it should be elaborated, how the descriptive texts could also be adjusted to this level of detail in order to enable the user to best explain and interpret the visually displayed data. However, before expanding the corresponding (text-based) climate services, however, it is important to check which level of detail actually exists methodologically in the model / data. Further activities should only be started if it can be excluded that the zoom function does not only suggest a high spatial resolution, but is based on local data and information. In order to be able to expand or adapt the text-based climate service tools and products accompanying dynamic web tools, in addition to the climate scenarios, scenarios and information on local social and cultural

[1] http://www.klimaateffectatlas.nl/en/
[2] http://www.klimaateffectatlas.nl/en/story-maps

geographic developments are required. At present, these type of local social scenarios are often much rarer (especially for the local level) and, due to the direct and diverse interactions between climatic, ecosystem and social systems, are significantly less reliable. At this point improvement of knowledge is still needed.

In the case that there is sufficient information available to allow the text-based components of dynamic web tools to be expanded and adapted, the major challenge here is either to adapt existing services (mostly web tools), or to change the format of climate services entirely in order to better address and include additional information.

Looking at the CoCliServ portfolio on already used climate services (D3.1) we found indications that, adapting the text-based components of a climate service accordingly to a dynamic visual zoom function in a map (showing spatially interpolated datasets) is a unsolved challenge in many web tools. For this situation, we suggest to follow the example of the web-tools developed at the Northern German Coastal- and Climate Office. Moreover, web tools could be expanded with additional text-based products. These small texts or brochures should contain information on specific, small-scale regions and provide an explanation of the local data and local impacts visualized in the web tool. Examples of such short brochures are already available in the European climate service landscape, for example the fact sheets on the usage of regional climate scenarios in practice – the example of the metropolitan region of Hamburg, designed by the Northern German Coastal- and Climate Office (https://www.hzg.de/imperia/md/content/klimabuero/publikationen/180110_factsheet_hamburg_rz_bildschirm.pdf) and the "Klimaprofiler" in the portfolio of the Norwegian Climate Service Center[3]. A print format in addition to the existing web tool is certainly conceivable; but it also implies additional work - on the one hand, by creating the brochures and, on the other hand, by constantly updating and adapting it based on new available knowledge. Another and far more serious disadvantage of this addition to the dynamic web tools (dynamic because the user decides where to zoom in and out by him-/herself) is that brochures could only be designed for a specific area right from the start (so they are static in its resolution). This means that

[3] https://klimaservicesenter.no/faces/mobile/article.xhtml?uri=klimaservicesenteret/klimaprofiler

small-scale considerations and information can be offered - but this only applies to areas previously defined by the provider (= a loss of the zoom function in relation to the text). Thus, the proposed additional brochures do not entirely solve the problem; but form a supplement to further adapt the climate services already available to the information needs of local stakeholders.

3.2 Being surrounded by water

With regard to the thematic discussions in Dordrecht on water-related issues, two major issues became apparent from the WP2 workshop results (D2.2) and the D3.2 analysis: a) need for information with regard to local probabilities and local impacts of extreme events. Moreover, not only extreme disasters are of interest but also information about small disasters on the local level are requested. b) (For decision-makers). A need for information about the sensitivity of the affected neighbourhood to water-related risks. Both are discussed individually in the following paragraphs.

3.2.1 Climate extremes (including hot summers / heat and flooding)

The aspect of climate extremes was highlighted as a perceived issue in the WP1 narratives, mainly referring to the weather parameter precipitation (extremes are more intense). Furthermore, the WP2 scenario workshop results underline a knowledge need in terms of information about probabilities and local impacts from extreme events; as well as information about small disasters. The analysis in D3.2 showed that the required information, in particular for local impact and probabilities of impacts from extreme events, is only partially available in the existing climate services. However, extracting this information from the currently available climate services is difficult and sometimes, large-scale information is not usable to appropriately answer questions at local scale.

This demand shows that information from an assessment at the local level seems to be an important criterion for successful decision-making processes making the consequences of extreme events more tangible for the stakeholders. Thus, a major challenge in this context is about the possibility (and cost) of a practical implementation of local climate change impact assessments of extremes as well as for small disasters.

Regarding the possibility of local impact assessments, an appropriate local impact assessment could include monetary assessments as well as other forms of damage information. Climate science as well as the risk management community have achieved considerable improvement with regard to damage- and risk analyses in the last decade; impact assessments are already available for many regions and sectors. Within the scientific literature on risk assessment analysis, frameworks and large-, meso-, small- and micro-scale analysis are available. Thus, from a methodological point of view, relevant frameworks and approaches are already available (= no knowledge gap).

With regard to the challenging effort of a practical implementation of local climate change impact assessments, we can highlight an already available climate service and show how it already addresses the required claims – and where improvement is needed:

The most important and most suitable available climate service for Dordrecht in this context is the climate impact atlas (klimaateffectatlas[4]). Probabilistic estimates for events are already included in the tool, e.g. for flooding in the form of information about return intervals. It is possible to zoom into the map (visualization of the data) and thus view the results for a local area. However, potential damage assessments are not included.

Improvement of this service can be relatively easy provided. The knowledge needed to produce the requested information is already available in the scientific literature, or can be produced using appropriate, already existing methods. Therefore, it is, from our perspective (which is limited by the fact that we are not sufficiently familiar with the local level of knowledge about local risk assessment results), a particular need to make information about local effects and damage, which is already available in the scientific debate and literature, available and more visible via a local climate service. The situation here is that the existing knowledge needs to be better and more effectively converted and used for climate services.

However, such increased use also poses some challenges: limitations from the scientific and provider's perspective in this context include methodological and

[4] http://www.klimaateffectatlas.nl/en/

structural challenges related to very local assessments. Local assessments require very precise and extensive data; and their provision can be problematic. Monetary valuations in particular are often associated with assumptions and estimates if exact values are missing or are not available. These estimates cannot be objective per se. If information and values are missing, it is often useful and desirable to incorporate local partners' assessments and knowledge in order to fill the gaps with regard to tangible and intangible values. This implies an opportunity for improved co-development processes for sustainable local climate services. If the values are not discussed with the local actors, there is a high risk that the decision-makers will not accept the result of the assessment and they might not be used in practice. Further difficulties can arise from the fact that uncertainties and assumptions, which are included in the calculations, requires a sufficiently transparent discussion. This aspect can make it difficult to present the results in a simple, understandable way (which is often one of the goals of a climate service).

The newly developed climate service tool from the Dordrecht case study team in cooperation with CAS, which is based on the Climate Impact Atlas, already accepted the challenge and provide a more detailed view on the Vogelbruut about impact information (height difference, flooding, heat, soil subsidence and pile rot). The scaling of the impacts is represented by a colour scheme; however, there is no more detailed description of the expected damage.

3.2.2 Sensitivity of affected neighbourhood to water-related issues

In the WP2 workshop, policymakers highlighted the need of enhanced insights about the sensitivity of the local community (Vogelbruut neighbourhood) to water-related issues today and in the future. Questions included among others: What do people find acceptable and not acceptable (information on acceptation and perception of risks (but also of options))? For instance, how long should streets be allowed to remain flooded? (cf. D3.2, p. 25).

The question of a community's sensitivity to risks is an important factor in the assessment and decision-making process in many fields, including risk governance and risk management. However, determining the sensitivity of individuals and communities often involve comprehensive quantitative and qualitative methods.

Furthermore, it is essential to consider that sensitivity towards risks is not static, but constantly changing. This constant change requires, above all, regular recording and a continuous survey and continuous analysis of the data. Perception and awareness are not only shaped by personal experiences and values (which can also change constantly), but above all, collective sensitivity can change quickly, for example through sudden events or social debates. These characteristics alone pose a conceptual and practical challenge for its implementation in a (local) climate service. Thus, from our perspective and based on our previous studies on climate information and climate services (D3.1, D3.2, M3.2), this knowledge need highlights a claim for a new or at least an additional aspect of climate services. Nearly all climate services available at the moment focus on the objective presentation and description of the physical changes; but most of them neglect the discussion and presentation of available knowledge about perceptions and awareness of different changes and risks.

Insights and discussions about the sensitivity of the population to climate change (adaptation, perception and awareness) including the impacts and potential action measures are available in particular in social science and climate science. In both, the findings and methodological approaches and experience about these topics, are available in a comprehensive manner. It becomes clear at this point, that already available knowledge from social and climate science should be more prominently and more comprehensively included in the climate service development. Social as well as political science already provide a broad range of methods and experiences with regard to develop and discuss social future scenarios, which explicitly goes beyond the description of the aspects of physical climate change effect and impacts. Since a lot of knowledge and experiences are already available in these fields, there is no knowledge gap here, but there is currently a limitation in the composition of the current climate service community. The provider side (climate service community) needs to become more diverse and interdisciplinary. There seem to be a need of supplementing and expanding the climate service community with experts from the areas of political and social science as an important structural step. In practice, this could be realized e.g. by enhanced funding and increased requirements asking for interdisciplinary climate service projects, like CoCliServ. In addition, expanding the climate service community with experts from the areas of political and social climate science will be essential to be able to adequately address complex, local questions and needs.

The WP2 activity in Dordrecht already showed how such question might look like. What do people find acceptable and not acceptable (information on acceptation and perception of risks (but also of options))? E.g., how long should streets be allowed to remain flooded? (cf. D3-2, p. 25)).

Consequently, the next question is: can this be done by using existing climate service formats? Or do we need additional formats? One of the few available climate services that could be used as a guide is the web tool 'Klimanavigator[5] ' (climate navigator, a German climate service), in which the topic 'perception of climate change' is taken up and prepared for the user. The climate navigator addresses the topic with a thematic dossier. It contains various short sub-chapters explaining how climate change is perceived in Germany and Europe, how it is perceived in different social environments and how perceptions have changed over time. On the one hand, this service represents an example of how this topic can be implemented in a ‘classic’ climate service format[6]. On the other hand, the last category about changes in climate change perception in recent years refers to a methodological approach that is promising for an implementation of new local climate service about the sensitivity of the local population to climate change and climate change adaptation. This methodological approach has also been incorporated in the Hamburg climate report (climate change assessment report for the Metropolitan Region of Hamburg[7]). The approach includes a long-term, annual survey series among citizens in Hamburg (available from 2008-2019), providing a unique long-term assessment perception (Ratter 2017, Ratter et al. 2012). Following this methodological example, setting up and processing the data of a continuous, long-term survey to record perception and awareness and, above all, to monitor changes in the public perception can be a helpful tool to provide information that local stakeholders ask for. Questions that

[5] The 'Klimanavigator' is a web portal, which brings together actors from the research landscape in the field of climate research and provides guidance. The portal is sustained currently by more than 50 partner institutions from climate research in Germany – across all institutional and professional borders.
[6] In the context of the "climate navigator", the topic of 'climate change perception' is one of many topics within a climate service that provides comprehensive information on the topic of climate change
[7] Storch et al. 2018; https://www.springerprofessional.de/en/hamburger-klimabericht-wissen-ueber-klima-klimawandel-und-auswir/15142188

could be answered might include those questions we are referring to at beginning of this subsection (results from the WP2 workshop): e.g. what do people find acceptable and not acceptable (regarding flooding events)).

With regard to practical implementation of a (new) climate service, including such kind of long-term surveys, the studies by Ratter et al. show that they are applicable for local climate services, as they showed as a practical example application that works in small and very local areas (e.g. city of Hamburg).

From our perspective, looking at the climate service formats available so far, it does not seem necessary to develop a new climate service format to communicate information from such a kind of long-term survey. At this point, web tools in particular offer an effective format, as they enable a continuous update of the available data in a timely manner as well as it offers the opportunity to provide a corresponding description of the data.

With regard to potential limitations from the provider's perspective, for the implementation of this methodology and a related climate service (format) it is important to take into account that such activities require continuous support and regular collection and processing of data in terms of work force and budget.

3.3 Information need on political and social trends

During the WP2 workshop in Dordrecht stakeholders highlighted the need for information about political trends, social sensitivity concerning options / activities and legal issues, related directly and indirectly to climate change. This demand includes essential information about the social and political boundary conditions within which climate change adaptation and mitigation measures and activities will be implemented. These aspects (social and political) are essentially overlooked in the available climate services portfolio of the CoCliServ research areas. No climate service was found that addresses these information needs, nor serves them extensively. This can be explained partially by the fact that in most cases these indirect, non-climate aspects are not even addressed by most of the current definitions of climate services (for a more detailed discussion about the role and definition of climate services see introduction in D3.1). However, considering the CoCliServ aim to develop local climate services at this point it here becomes legitimate to ask whether political trends and social sensitivity can and should be addressed by local climate services (in the future). The latter would result in an expansion of the current scope of climate services, in particular on a local level. This expansion will only be possible with the above-mentioned necessary diversification of the climate service community by social scientists working at the interface between science and society. In terms of feasibility of these extended climate service (topics), the broad spectrum of methodologies and approaches, knowledge, and findings already available in social and political climate science represent a pro-argument for enhanced (local) climate services. There is no typical knowledge gap, since the knowledge already exists (at least partly) in other parts of the climate science community. It is rather seen as missing aspect in the conception of climate services (extension of climate services) and as a gap in transfer of information from different parts of the climate science community to (local) climate services. One very important precondition that has to be implemented in order to overcome these gaps is to (better) involve social and political climate science communities in the development of climate services. As already discussed for different aspects in the previous paragraphs, cooperation between physical, social and political climate science is important, in order to jointly answer local information needs, which often go beyond the pure information from the physical system (e.g. about society's sensitivity of affected neighbourhood to water-related issues). The social and political climate science are particularly important due to their knowledge and insights about perceived changes in the social, ecological and political system, analysis of risk awareness, about working out the willingness to take risks, but also insights into changes that can be expected in the social and economic system in future (social and political scenarios). (The latter are partly induced / triggered by changes in the climatic conditions; but also other, non-climatic external and internal drivers can also cause them). Social and political science provide important knowledge with regard to the methodical recording and discussion of the recorded information and knowledge to answer these aspects.

In the specific case of Dordrecht, beside the general challenge of enlarging the climate service community, another practical limitation is the available description of the information need that is currently still broad and general. It appears essential to jointly discuss between scientists, provider and stakeholders (decision makers and users) which specific aspects and information stakeholders have in mind by mentioning the keywords ‘political trends’ and ‘social sensitivity’: the questions and demands available so far from the WP2 workshop are still relatively vague. A more precise definition is needed, ideally as a joint discussion. A joint discussion about how these more precise research questions should look like provides an opportunity and need of co-development process including scientists, providers and local stakeholders and users. If we are able to deal with the challenge of a more precise research question, how could such a climate service look like? Classic, available climate service formats already offer several options: Text-based products are certainly a good option, since the situation can be explained in detail. Moreover, various types of web tools can also be considered. In addition, communicative and capacity building measures seem to be a promising climate service format here, since this format supports and facilitates a direct exchange between the stakeholders, providers and scientists. However, political trends and social sensitivity can change very quickly (legal issues are less dynamic), which represents a restriction for all these formats (as well as for the processes of collecting and processing information), which represents a restriction for all these formats (as well as for the processes of collecting and processing information). Text-based products in particular are often ‘sluggish’ in their response, since revising and adapting them is usually time-consuming. Therefore, formats based on direct and constant exchange and communication (e.g. continuous expert dialogue, stakeholder forums, stakeholder partnerships) between stakeholders and scientists represent the most promising to reduce and overcome these this limitations. Anyhow, attention must be paid to the fact that the communicative and interactive climate service formats are very time-consuming and labour intensive for both sides.

4 Jade Bay (Insa Meinke)

As the D3.2 analysis for the Jade Bay region clearly showed, the reason for missing climate change related action in the Jade Bay region is not due to a gap of knowledge on climate change or missing place based climate information. Nevertheless, several climate related issues were identified which reflect either certain interest for information or particular relevance to local stakeholders. Furthermore, the climate-related topics that we discuss below are wide-ranging and might be interesting for other case studies considering similar or the same topics.

4.1 Uncertainties of future climate scenarios

According to D3.2, direct questions of the stakeholders were related to the tipping points of the climate system and the uncertainty of greenhouse gas emission scenarios with respect to possible uncertainties of the existing worst-case scenarios (D3.2, chapter 5.2.2). For both topics, the IPCC reports are the main basis for answering these questions and for discussing possible additional information and service formats (IPCC 2013).

4.1.1 Tipping points

General overviews on tipping points in the climate system in German language are provided by the environmental agency / Umweltbundesamt (2008) and PIK / Potsdam Institut für Klimafolgenforschung (2020), however, there is no information on time scales. According to IPCC, tipping points are defined as hypothesized critical threshold when global or regional climate changes from one stable state to another stable state. The tipping point event may be irreversible. While there is evidence for threshold behaviour in certain aspects of the climate system, such as ocean circulation and ice sheets, on multi-centennial-to-millennial timescales, there is, however, no evidence for global-scale tipping points in any of the most comprehensive models evaluated to date in studies of climate evolution in the 21st century. IPCC (2013) describes nine changes in climate system components as potential tipping points (IPCC 2017, Tab 12.3, p.1115). According to the IPCC AR5 definition, seven of them are potentially abrupt and three of them are irreversible. The only component in the climate system, which is potentially abrupt *and* irreversible are clathrate methane releases. However, according to the IPCC (2013) there is high confidence that it is very unlikely that methane from clathrates will undergo catastrophic release within the 21. Century. Moreover, according to tipping points with impact within the 21. Century there is high confidence that it is very unlikely that the AMOC will undergo a rapid transition. Furthermore, it is exceptionally unlikely that either Greenland or West Antarctic Ice sheets will suffer near-complete disintegration. The only plausible change, which is according to IPCC AR5 “likely” to happen in the 21. Century is that the Arctic Ocean becomes nearly ice-free in September. This is expected with medium confidence before mid-century under high forcing scenarios such as RCP8.5. However, none of these studies assessed in IPCC (2013) show evidence of irreversible changes in Arctic sea ice. In conclusion, tipping points are not expected to contribute substantially or to impact in a large way on the range of existing IPCC future climate projections over the 21st century. Thus, according to the role of tipping points for future climate changes and their impact on worst-case scenario of climate change in the 21. Century, there is no need for additional climate service formats other than explaining the assessed agreement of scientific knowledge described above.

4.1.2 Emission scenarios and worst case future climate projections

Another aspect in D3.3, chapter 5.2.2 was referring to the generation of future greenhouse gas emission scenarios and their inherent uncertainties. It was questioned if the future development of society has been accounted, in particular against the backdrop that China, India and Africa are not (completely) industrialized, yet. These thoughts were referring to a plausible enlargement of the range of future climate changes in order to estimate their worst-case scenario. Again, the IPCC reports are the main source for reflecting this issue (Nakicenovic et al. 2000). The IPCC process has resulted in four generations of emissions scenarios: Scientific Assessment 1990 (SA90), IPCC Scenarios 1992 (IS92), Special Report on Emissions Scenarios (SRES), and the Representative Concentration Pathways (RCPs) used in AR5 IPCC (2013) Fifth Assessment Report. The IPCC has developed various emission scenarios since 1990.

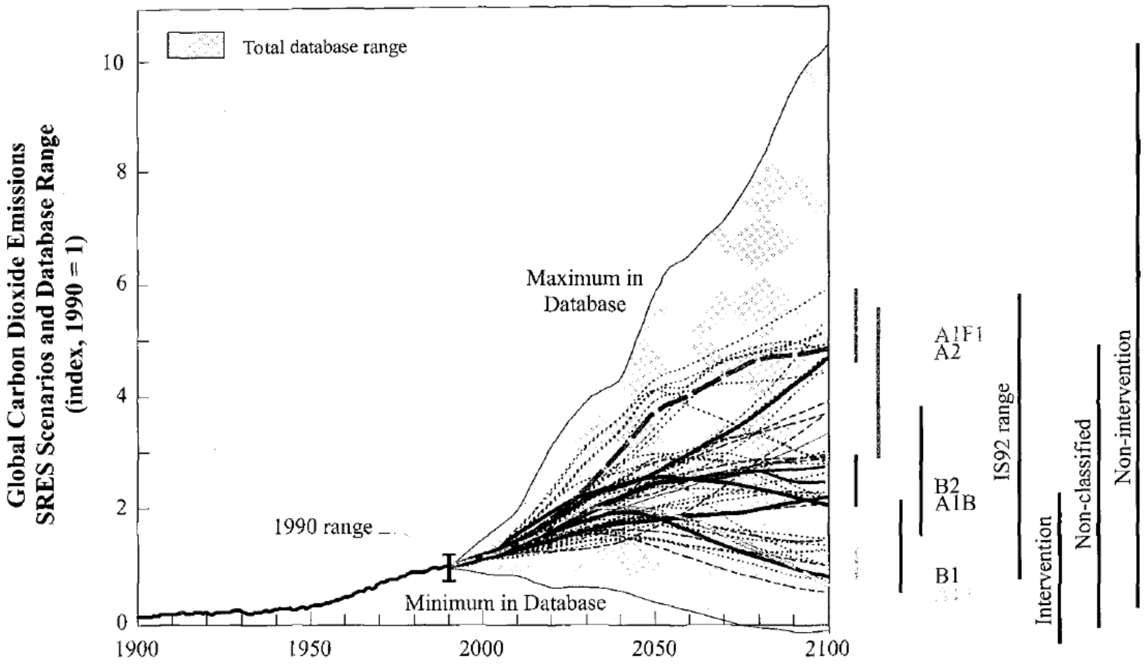

Fig. 1 Global CO2 emissions related to energy, industry and land-use changes from 1900 to 1990, and for the 40 SRES scenarios from 1990 to 2100, shown as an index (1990 = 1) Nakicenovic et al. 2000

Beside the emission scenarios developed by the IPCC (2000), other so-called non-intervention scenarios (Fig. 1) existed in the literature, but they have not been further accounted in the generation of global climate scenarios. Moreover, the SRES-A1FI, which is representing the strongest future greenhouse-gas emission scenario, has not been regionalized over Europe (e.g. Christensen et al. 2002). The most recent concept is based on representative concentration pathways (RCP, Moss et al. 2010) which are defined by the radiative forcing. The four RCP scenarios used in CMIP5 lead to radiative forcing values that span a range larger than that of the three SRES scenarios used in the coupled model intercomparison project CMIP3 (Fig. 2.). RCP8.5 represents somewhat higher emissions than A2 in 2100 and is close to the SRES A1FI scenario (Fig. 2). Nevertheless, as Fig. 3 shows, future temperature projections of the SRES A1FI produce still highest values.

Summarising, worst-case scenarios of possible future climate changes due to anthropogenic greenhouse gas emissions are not covered by the available regional climate change scenarios, so far.

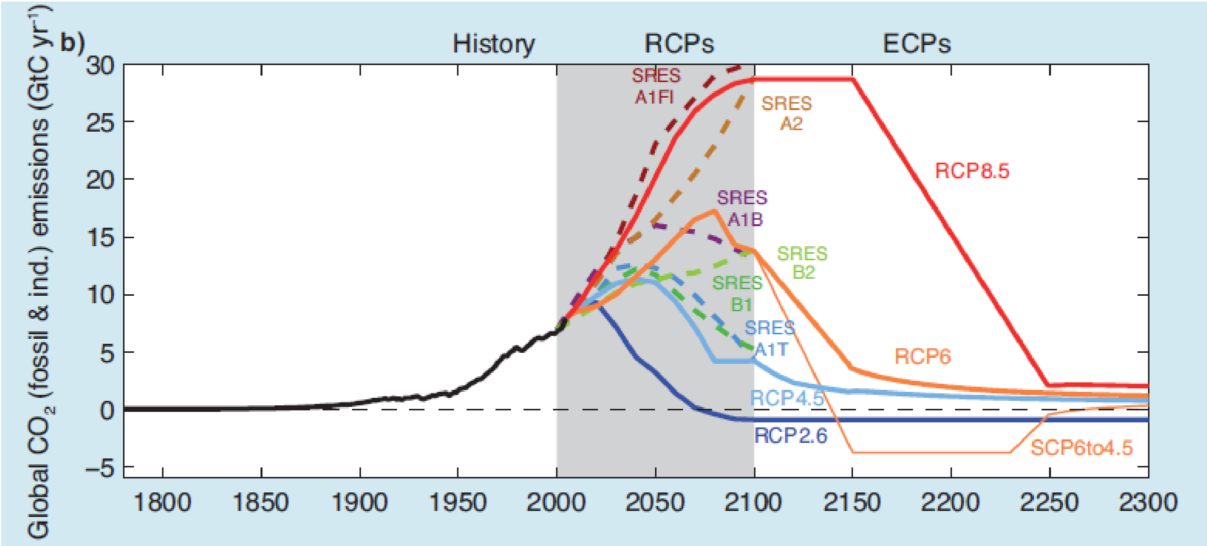

Fig. 2: CO2 emissions (except land use emissions) for the four RCPs and their ECPs as well as some SRES scenarios

Therefore, it should be considered to include the available worse and worst case emission scenarios e.g. A1FI and non-intervention scenarios in future international model inter-comparison and regionalization projects. Notwithstanding this, it is not possible to reliably predict social development over long periods. By anticipating a broad spectrum of possible socio-economic scenarios, the IPCC has attempted to counter this uncertainty to a certain degree. The main problem here is that it is unclear if and to what extent the storyboards actually reflect the entire range of possible future social developments. The problem becomes apparent when one considers that only a handful of selected scenarios from the entire spectrum of socio-economic scenarios described in the SRES report and in Moss et al. 2010, are usually used as input parameters for climate models. The resulting range of possible future developments is inevitably limited. The ranges that usually arise should, therefore, be interpreted as a lower limit of the uncertainties.

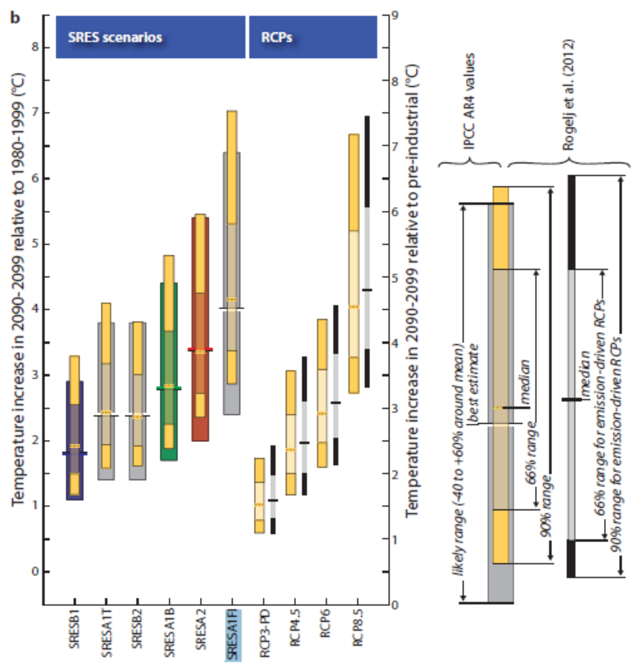

Fig. 3: Temperature projections for SRES scenarios and the RCPs. Ranges of estimated average temperature increase between 2090 and 2099 for SRES scenarios and the RCPs respectively.

Thus, an ongoing careful monitoring of anthropogenic greenhouse gas emission in reference to the IPCC emission scenario as suggested by Peters et al. (2013) is needed, in order to assess if the currently available future greenhouse gas emission scenarios cover their real development (see Fig 4).

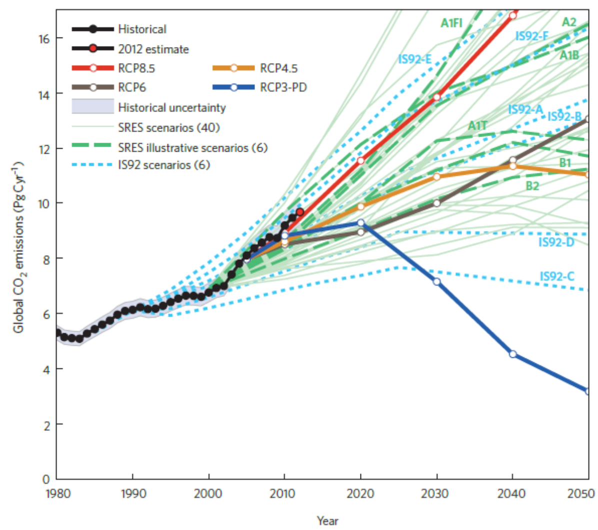

Figure 1 | Estimated CO_2 emissions over the past three decades compared with the IS92, SRES and the RCPs. The SA90 data are not shown, but the most relevant (SA90-A) is similar to IS92-A and IS92-F. The uncertainty in historical emissions is ±5% (one standard deviation). Scenario data is generally reported at decadal intervals and we use linear interpolation for intermediate years.

Fig. 4: Estimated CO2 emissions over the past three decades compared with the IPCC emission scenarios (Peters et al. 2013)

According to Peters et al. 2013, the observed growth rates of CO2 emissions are at the top end of all four generations of emission scenarios. This indicates that the space of possible pathways could be extended above the top-end scenarios to accommodate the possibility of even higher emission rates in the future.

In case the real development of future greenhouse gas emission exceeds the range of the emission scenarios permanently, a new set of adjusted emission scenarios needs to be developed (Peters et al 2012).

4.2 Anthropogenic contribution to climate change

Two contrary perspectives of the anthropogenic contribution were elucidated: one was referring to the climate deniers, assuming that the observed global warming is within the range of natural variability. The other was the contrary assumption, that there is and will be no extreme season or weather, which is not impacted by anthropogenic greenhouse gas emissions.

4.2.1 Climate deniers

It was supposed that climate deniers are conducting own analyses, which is based on the same data as used in climate research. Thus, it was questioned why they come to different results (D3.2). There are several information platforms referring to the arguments of climate change deniers and how they are disproved by climate scientists, e.g. https://skepticalscience.com/, https://www.klimafakten.de/. About 200 arguments of climate deniers are assessed on: https://skepticalscience.com/argument.php none of them is representing own research. Instead, the arguments refer to scientific results by highlighting single aspects in order to raise contradicting statements. Mostly, they follow an easy to understand line of argumentation, while the scientifically proved interrelations are much more complex. Both platforms (Scepticalscience and Klimafakten) also summarize the research on the consensus according whether humans are causing global warming. A key finding of the meta-study is that the degree of consensus reached is strongly dependent on the competence of the respondents: among climate researchers who are actually active in the field (i.e. who can refer to peer-reviewed publications in specialist journals), the degree of consensus is close to one hundred percent. On the other hand, there is a much lower level of agreement on the causes of climate change among the scientists (or laypersons) questioned who are not active in the climate research field.

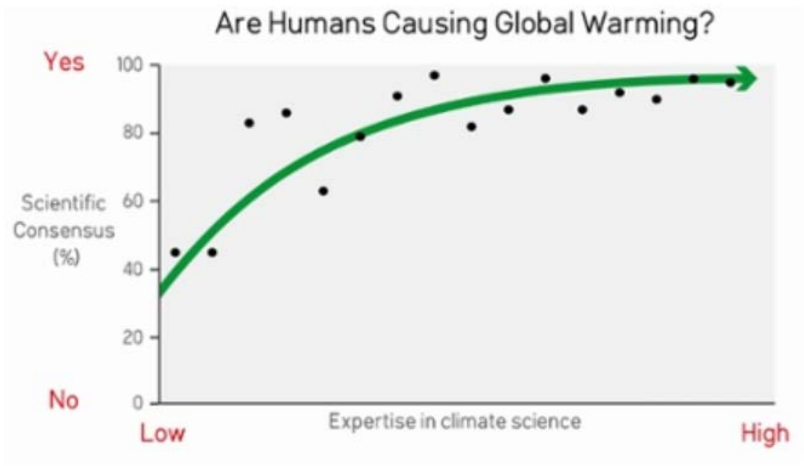

Fig. 5: Level of scientific agreement on human-caused global warming versus the level of scientific expertise in climate science, across a range of studies https://www.klimafakten.de/meldung/die-ursachen-des-klimawandels-es-herrscht-konsens-ueber-den-konsens (accessed on 06.02.2020)

Summarising, as the expertise increases, so does the consensus. Moreover, none of the climate deniers' arguments is included in the available global and regional climate assessment reports, since these are not scientific analyses, published in peer-reviewed journals. Although the denial arguments are not based on science, they need to be considered in climate services, since they are mainly used to make people insecure about climate change and the underlying science. Within a science stakeholder dialogue process, it is possible to localize the arguments, which are most frequently perceived in the public. The climate service needs 1) to show that these arguments are not science-based information, since own analyses and peer review process is missing and 2) to address each single argument by explaining the complex scientific background.

4.2.2 Detection and attribution

The other perspective articulated with regard to the anthropogenic contribution to climate change was the contrary assumption, that there is and will be no extreme season or weather which is not impacted by anthropogenic greenhouse gas emissions (D3.2). In this context, the concept of detection and attribution provides the scientific bases. A whole chapter of the IPCC AR5 2013 is dedicated to research of detecting and attributing human contribution to climate changes. Moreover, there are several EU-projects on extreme event attribution (e.g. EUCLEIA and EUPHEME 2020). While there is high confidence that human activity is contributing to atmospheric temperature changes (surface temperature, warming of the troposphere, lower stratosphere cooling, increased frequency and intensity of temperature extremes), there is only medium confidence that global scale precipitation patterns over land have changed due to anthropogenic forcing. This is also true for the global scale intensification of heavy rainfall events. According to the IPCC (2013), warming trends associated with global change are generally more evident in averages of global temperature than in time series of local temperature. This is because most of the local variability of local climate is averaged away in the global mean. Multi-decadal warming trends detected in many regions are considered to be outside the range of trends one might expect from natural internal variability of the climate system, but such trends will only become obvious when the local mean climate emerges from the 'noise' of year-to-year variability. How quickly this happens depends on both the rate of the warming trend and the amount of local variability (IPCC 2013). Referring to the perspective mentioned above, the IPCC clearly shows, that in particular on local scales natural variability is strong. For example for changes in precipitation, there is only medium confidence according to the human contribution even at a global scale, it might lead to fundamental wrong conclusion, if a measured change in precipitation at a certain weather station is interpreted as consequence of anthropogenic contribution. This could lead to the assumption that adaptation is needed to this supposed systematic change. However, as result of natural variability there might be large changes into the opposite direction and thus, adaptation measures would not be effective. To distinguish between natural variability and systematic climate change, a simple trend test can be applied in combination with a consistency test between the measured trend and the range of future trends projected by the regional climate scenarios. Figure 6 shows the spring precipitation trend in Lower Saxony since 1980. The yellow line is dashed, which indicates that the decreasing trend is not significant, since variability is strong.

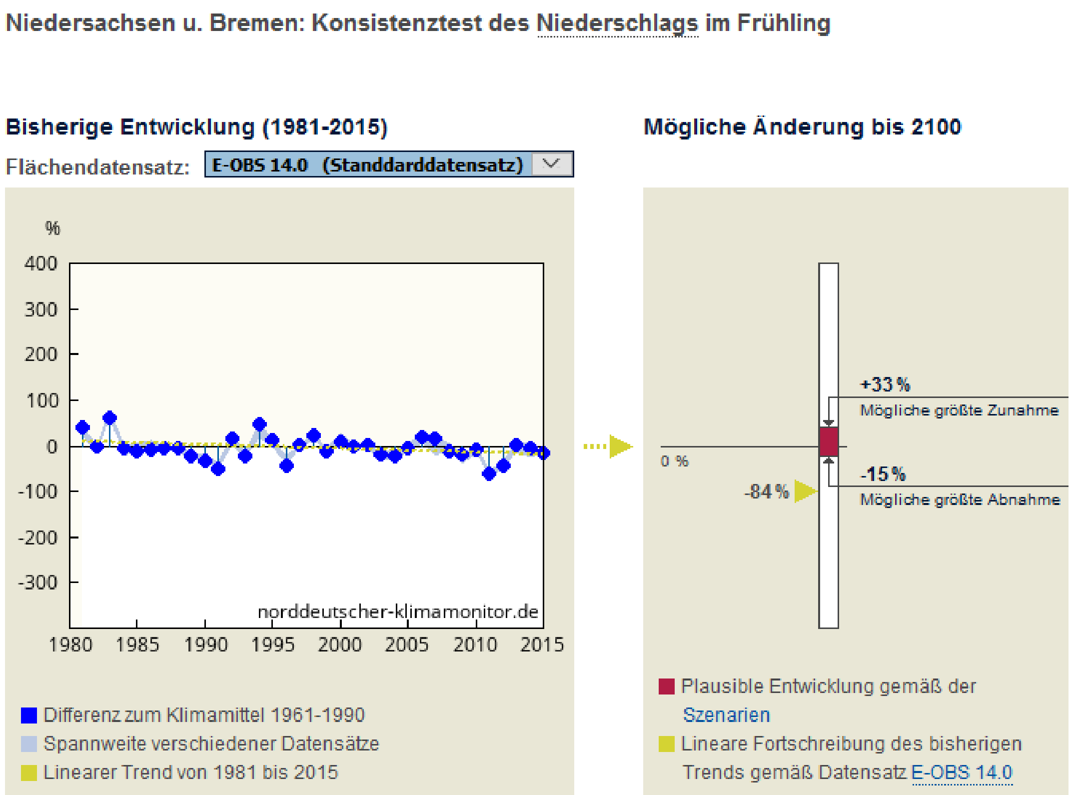

Fig. 6: Consistency test between measured trends and the range of possible future change projected by regional climate change scenarios, here spring precipitation in Lower Saxony www.nordeutscher-klimamonitor.de, Meinke et al. 2014

The observed trend since 1981 is linearly extrapolated until 2100. According to this extrapolation, the change in precipitation in spring would be minus 84 % by the end of the 21st century compared to the reference period (1961-1990). This shows that the recent climate trend for 1981-2015 is much larger than the projected by the regional climate scenarios. The discrepancy between the recent trend and the trends of the regional climate scenarios indicates that human greenhouse gas emissions are not a dominant driver for the past change. Thus, the recent trend may largely be a consequence of natural variability. Other anthropogenic factors such as land-use changes may have additionally influenced the recent local change. Based on this knowledge, long-term decisions can take into account that the future development of spring precipitation may substantially differ from the recent trend since it is not dominantly driven by human contribution and thus not essentially a systematic long term change.

4.2.3 The role of peatlands

Another question was related to present anthropogenic greenhouse gas sources, in particular the peat bogs as greenhouse gas sources due to drainage. According to IPCC 2013, anthropogenic greenhouse gas emissions from peatlands are included in the AFOLU (agriculture, forest and land use) sector which is contribution with 24% to the total anthropogenic GHG emissions. The accounted processes here are peat fires and peat decay.

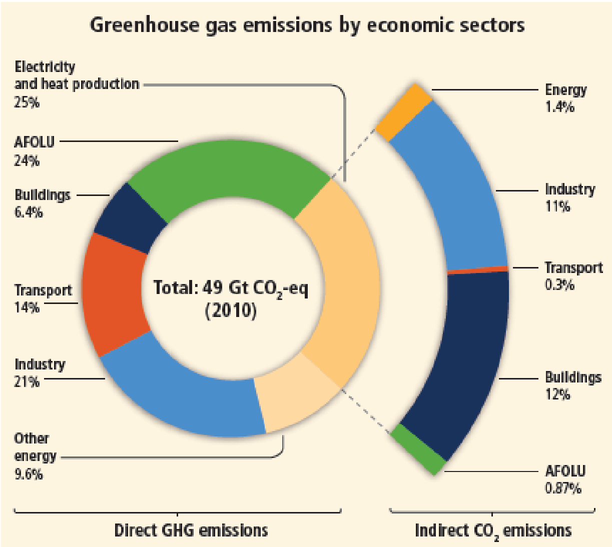

Fig.7: Total anthropogenic greenhouse gas emissions from economic sectors in 2010. IPCC 2014

According to IPCC 2013, peatlands are also a significant natural source of methane. The above question was referring to the assumption that nature conservation areas are the same areas where peatlands could be rewetted. Thus, it was assumed, that here nature conservation instruments could also be used to pursue climate protection goals. However, as Freibauer et al. (2009) show, rewetting projects only lead to a reduction in greenhouse gas emissions if water levels are raised over the long-term. In the case of a heavily degraded and heavily drained bog soil, rewetting leads to a strong change in the current redox conditions in the soil. This initially leads to an increased emission. Besides carbon dioxide, the emissions include the much more effective greenhouse gases methane and nitrous oxide. (N_2O). These greenhouse gases are increasingly emitted, particularly, when the water level cannot be optimally adjusted and the bog surface is flooded. A water level of about 10 cm below the soil surface is usually regarded as optimal. For a successful rewetting with reinstated peat accumulation, it is essential to prevent renewed drainage. On the backdrop of regional climate change, however, temperature increase and a strong future decrease of summer precipitation is plausible (www.norddeutscher-klimaatlas.de, Meinke et al. 2009). Thus, to prevent anew peat decay, a technical long-term management would be required.

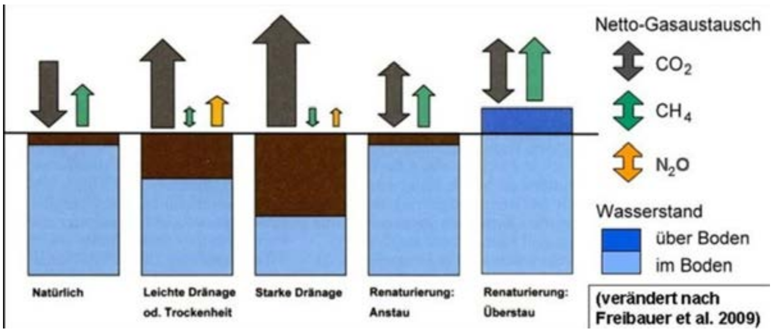

Fig. 8: Impact of rewetting peatlands on greenhouse gas emissions (Freibauer et al. 2009)

The peatland had a considerable extension in North-West Germany. Due to extensive conversion to agricultural use and intensive peat use, peatland areas of about 50,000 ha have disappeared since 1950. There are some approaches in the Jade Bay region to protect or rewet peatlands (Administrative district of Friesland and https://www.moor-land.de/). Both are projects, mainly financed by the EU regional development fund (ERDF). The aim of the administrative district Friesland is the combination of emission reduction, water management and land use. More water is aimed to be retained in the peat body through optimized regulation of the trench water level. This way the decomposition of the peat body should be counteracted. At the same time, the drainage necessary for land use is to be guaranteed. Since the success of the project would benefit not only the peatland but also water management and sustainable land use, a long-term management by the administrative district Friesland is probable.

The moor-land.de is also inviting civil society to participate by donating money. It is said:

> *By opting for a "Moorland® Climate Donation", you are enabling the rewetting of so-called "climate peatlands" in Lower Saxony, thus preventing the progressive emission of climate-damaging gases from our peatlands. At the same time, your donation will help to protect species, nature, soil and water.*

Further on:

> *"Moorland®" offers you the opportunity to offset greenhouse gases caused by your own actions with a "Moorland® Climate Donation", as a result of which selected moors in our region can be rewetted."*

According to the scientific aspects discussed above, it is, however, questionable whether a compensation by rewetting peatlands is possible. Besides the fact that greenhouse gas emission could proceed although the peatland has been rewetted, a long-term management beyond 25 year is not guaranteed by Moorland® Climate Donation. In this context, the scientific plausibility of GHG compensation projects is localized as highly relevant information need. Each mitigation and compensation measure should be assessed according to its efficiency to compensate or mitigate GHG emission.

4.3 Personal impairment due to climate change in other regions

Due to (so far) missing direct personal impairment of local climate change in the Jade Bay region, it was discussed if and how these changes would impair inhabitants of other regions in the world. Here, mainly two aspects of local climate change were discussed: the seal level rise and increasing heat (D3.2, Meinke et al. 2019).

4.3.1 Sea level rise

Due to efficient coastal protection measures, sea level rise is currently not perceived as a threat in the Jade Bay region. However, it was assumed that in many regions of the world adequate coastal protection measures do not exist and, thus, there are tens of millions of people living in coastal megacities, which do not have any comparable protection against rising sea levels (D3.2, Meinke et al. 2019). In fact, many web tools exist showing flooded areas at varying amounts of sea level rise (e.g.: https://www.floodmap.net/, https://ss2.climatecentral.org, https://www.climate.gov/maps-data/dataset/sea-level-rise-map-viewer). These exposure estimates, however, give an incomplete picture of coastal risks to human settlements because they do not consider existing or future adaptation measures that protect the exposed population and assets against coastal hazard (IPCC 2014). Although the global potential impacts of coastal flood damage and land loss on human settlements in the 21st century are substantial, these impacts can be reduced considerably through coastal protection (IPCC 2014). However, none of the above web-tools is accounting for the existing coastal protection measures or future coastal adaptation strategies of the respective areas.

For Northern Germany a web tool has been developed, showing the present and possible future coastal protection need (www.kuestenschutzbedarf.de, Weisse et al. 2015, Fig. 9). It shows that many regions would be flooded twice a day by the normal tide high water (Fig. 9, yellow areas). However, due to efficient coastal protection measures, these areas are protected. Moreover, protected areas are marked in case of storm surges (Fig. 9, light green areas). For this analysis, information is needed on the local design water levels. With this information, the areas, which are currently protected against high water levels, can be localized.

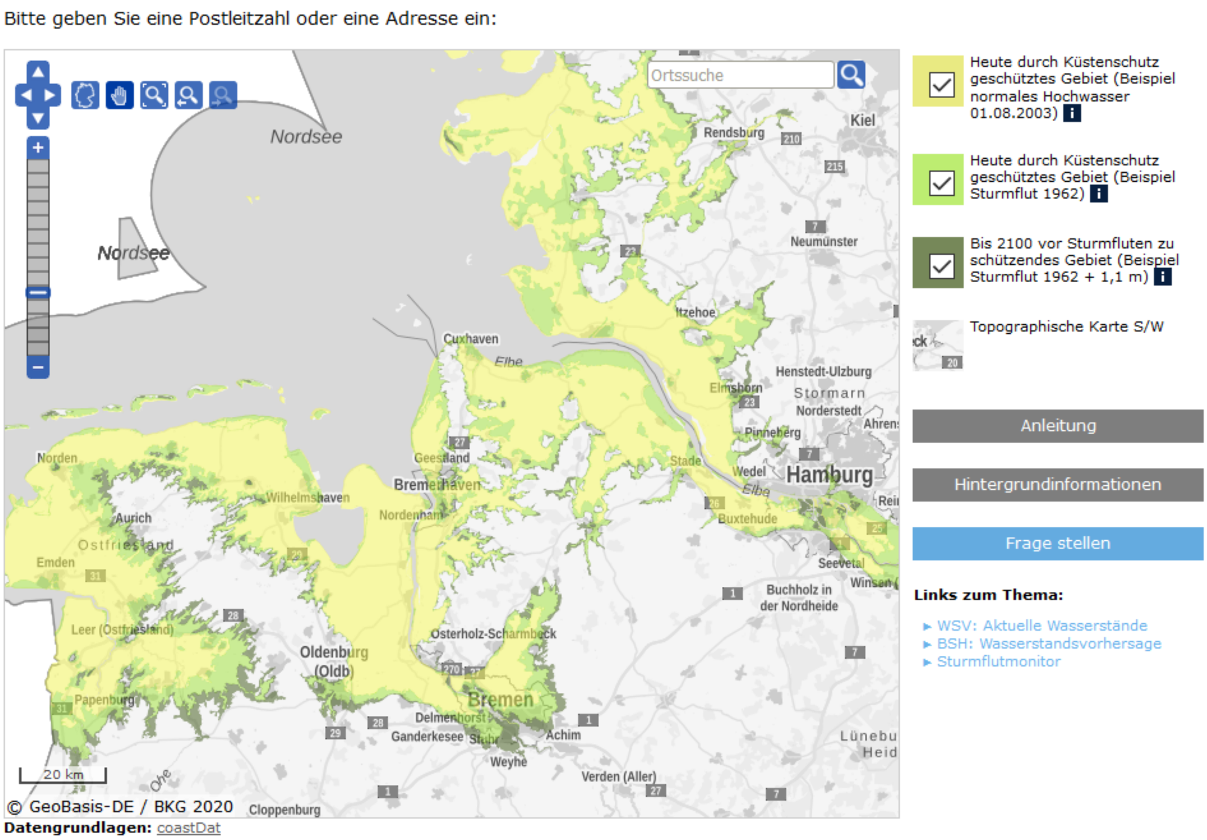

Fig. 9: coastal protection need today and in future (www.kuestenschutzbedarf.de)

Additionally, www.kuestenschutzbedarf.de shows areas with possible future protection need (Fig. 9 dark green area). For this analysis, besides information on future regional sea level rise, information on changes in the relevant wind climate and its impact on the highest water levels is needed. In order to estimate realistic coastal protection need, this information needs to be combined with future coastal adaptation and planning strategies. IPCC 2014 is referring to another approach accounting for future coastal protection need (Fig.10), the minimum height that coastal protection structures would need to be raised in a future period so that the number of exceedances of that height remains the same as under present climate conditions (Fig. 10).

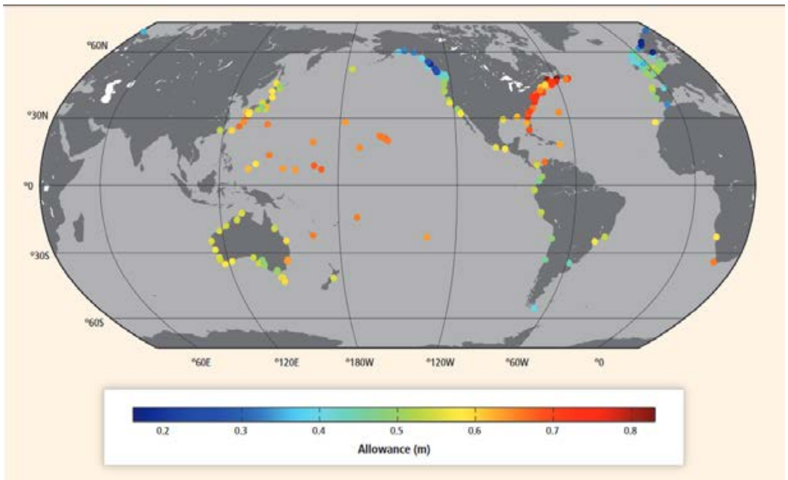

Fig. 10: Estimated increase in height (m) that flood protection structures would need to be raised in the 2081–2100 period to preserve the same frequency of exceedances that was experienced for the 1986–2005 period under a Representative Concentration Pathway 4.5 (RCP4.5) scenario (IPCC 2014).

However, the major driver of increasing risks to human settlements in the next decades is socioeconomic development. When upgrading flood defences to maintain a constant probability of flooding, as suggested in Fig. 10, average annual losses in the 136 largest coastal cities are expected to increase nine fold from 2005 to 2050 due to socioeconomic development. Only another 12% due to subsidence and 2 to 8% due to global mean seal level rise of 0.2 to 0.4 m (IPCC 2014; Fig. 11).

Fig. 11: The 20 coastal cities where average annual losses (AALs) increase most (in relative terms in 2050 compared with 2005) in the case of optimistic sea level rise, if adaptation maintains only current defence standards or flood probability (IPCC 2014).

IPCC 2014 B also shows that the estimated costs of adaptation are far below the estimate of losses in the absence of adaptation. Moreover, the differences in the cities most at risk are highlighted, depending on whether the ranking is by economic average annual losses or by such losses as a proportion of each city's GDP. In the first, it is mainly cities in high-income nations, in the second (Fig.11), mainly prosperous cities in middle-income nations. Summarising, various aspects need to be included for assessing to which extend people living in coastal megacities are directly impaired by sea level rise. Beside the mean global seal level rise, these are, as described above, the currently existing regional coastal protection, future regional coastal protection strategies and their local design water levels. Moreover, a multi model, multi scenario ensemble of regional sea level rise projections is needed, as well as their impact in combination with possible changes in wind climate on local extreme water levels. In addition, the described socioeconomic development needs to be accounted and future scenarios need to be estimated. Only combining and accounting all this information allows for a more profound quantification of future risks of sea level rise on local scales.

Another example, which was mentioned with regard to sea level rise, was the situation in Kiribati and Tuvalu (D3.2, Meinke et al. 2019). It was assumed that they would disappear when sea level rises about one meter. As stated in the IPCC (2014 B) the costs of protection works to combat sea level rise would be extremely high for small island nations, in particular in relation to the size of their economies. Vulnerability and adaptation analysis gave insights into the socioeconomic implications of sea level rise for small islands including: negative impacts on virtually all sectors including tourism, freshwater resources, fisheries and agriculture, human settlements, financial services, and human health (IPCC 2014, B). According to IPCC, for those unable to afford protection, accommodation or advance measures, or when such measures are no longer viable or effective, retreat becomes inevitable. The resultant impacts on distinctive cultures and ways of life could be devastating (Oppenheimer et al., 2019). Thus, the situation on these small island states are an example of direct personal impairment due to sea level rise as a consequence of anthropogenic climate change. Therefore, it might be suited to localise strong personal impairment. However, since these personally impaired persons do not belong to the group of the main GHG emitters, it is questionable if these matters of concern would induce the needed action, namely a significant reduction of GHG emission.

4.3.2 Heat waves

The other aspect, which was discussed as source of strong impairment due to climate change in other regions of the world, was heat and its impact on health (D3.2, Meinke et al. 2019).

According to IPCC (2014), the health of human populations is sensitive to shifts in weather patterns and other aspects of climate change. Beside general changes in temperature and precipitation, the occurrence of heat waves is mentioned. Morbidity and mortality due to heat stress is now common all over the world. Elderly people and people with circulatory and respiratory diseases are also vulnerable even in developed countries; they can become victims even inside their own houses. People in physical work are at particular risk as such work produces substantial heat within the body, which cannot be released if the outside temperature and humidity is above certain limits. The risk of non-melanoma skin cancer from exposure to UV radiation during summer months increases with temperature. High temperatures are also associated with an increase in air-borne allergens acting as triggers for respiratory illnesses such as asthma, allergic rhinitis, conjunctivitis, and dermatitis. With respect to sub-regional vulnerability, populations in Southern Europe appear to be most sensitive to hot weather. Moreover, they will experience the highest heat wave exposures. Extreme events (heat waves and droughts) have had significant impacts on populations as well as multiple economic sectors. Summarizing, the impact of heat on health is one of the few aspects of anthropogenic climate change, which causes strong personal impairment all over the world (poor and developed countries alike). Thus, it is assumed that focussing on health related impacts of heat might enable a strong contextualization of climate change.

4.4 Seasonal predictability

Another discussed issue referring to the impact of climate change on local weather, and seasons was their predictability. It was assumed, that changing global atmospheric processes are leading to increased atmospheric dynamics, more variability and less predictability (D3.2, Meinke et al. 2019). The impact of the Jet stream on extreme seasons, their predictability, in particular of summer precipitation and its significance for agriculture were of certain interest.

4.4.1 Jet Stream

It was assumed that the possible weakening of the Jet stream would be the reason for opposed extreme characters of a specific season, like the wet summer 2017 and the hot and dry summer 2018 in the Jade Bay region.
IPCC (2013) is documenting a poleward displacement of Atlantic front jet streams from the 1960s to at least the mid-1990s and over the last three decades, however, trends in the jet speed are uncertain. Poleward shifts in the mid-latitude jets of about 1 to 2 degrees latitude are likely at the end of the 21st century. The shifts are associated with a strengthening in the upper tropospheric meridional temperature gradient. According to IPCC 2019, recent attention has focused on whether Arctic warming is linked to an increase in blocking and mid-latitude weather extremes, such as drought in California due to sea ice changes that cause a reorganisation of tropical convection, cold and snowy winters over Europe and North America, extreme summer weather and Balkan flooding. Arctic warming could influence extreme weather such as through reducing the equator to pole temperature gradient, slowing the jet stream and hence increasing its meandering behaviour or causing it to split. However, the large internal atmospheric variability and the sensitivity to choice of methodology masks the detection of such links in past records, and climate change can lead to opposing effects on the midlatitude jet stream response leading to large uncertainty in future changes. Regardless of the causal relations with a possibly changing jet stream, a detection attribution analysis, as suggested in Fig.6, could be carried out for each extreme weather event. With this analysis, changes caused by anthropogenic climate change are distinguished form natural variability. This enables a first causal attribution of extreme weather events, like heat weaves or droughts. In

case the analysis indicates that the event is mainly caused by anthropogenic climate change, the reasons for the specific occurrence can be further investigated. Regarding the summer precipitation in the Jade Bay region, the analysis shows no significant trend and no consistency with regional climate projection. Thus, the recent long-term evolution of summer precipitation seems to be rather a consequence of natural variability than of human greenhouse gas emissions.

4.4.2 Seasonal precipitation

The perceived decreased predictability of the seasons, in particular of summers, was mainly related to the summer precipitation in 2017 and 2018. In both summers, the precipitation was perceived as unprecedented. This was addressed with respect to the planning of livestock farming. The uncertainty of a possible dry summer makes the management of food supply difficult. As described above, the long-term trend of summer precipitation in the Jade Bay region could not be attributed to anthropogenic climate change. Moreover, the regional climate projections show contradicting trends in future summer precipitation. Thus, according to climate change, the impact on summer precipitation is unclear. In such situations climate services may support stakeholders in developing no regret adaptation strategies. These are adaptation measures, which may flexibly be adjusted in order to be effective for a broad range of possible future developments. In parallel, the summer precipitation needs to be monitored in order to proof whether the long-term trend is getting statistically significant and to conduct regular consistency tests with the regional climate scenarios. Moreover, seasonal forecasts may support short-term planning in smaller livestock farms. Their most required task should be to reduce uncertainty according to summer precipitation, which still needs some improvement. According to IPCC (2013), a wide range of methods has been explored in seasonal prediction. They include adding random perturbations to initial conditions, using atmospheric states displaced in time, using parallel assimilation runs and perturbing oceanic initial conditions. Some initial conditions might precede more predictable near-term states than other initial conditions, and this has the potential to be reflected in predictive skill assessments (IPCC 2013). One of the central challenges of seasonal forecasting is to communicate its quality and reliability. Although the seasonal forecast system can easily determine how likely its statements are, it is difficult for laypersons to interpret the results. Currently, seasonal forecasts and their communication are mainly hosted by national weather services (e.g. https://www.dwd.de/EN/ourservices/seasonals_forecasts/start.html)

4.4.3 Agroecosystem interactions

Another aspect referring to changing seasons is the impact of climate change on ecosystem interactions, which are relevant for agriculture. It was discussed, if harvest could start earlier or if relevant interactions, e.g. pollination, might be disturbed and, thus, reduce harvest yield. Moreover, it was stated that the impact of climate change on the relevant species are widely uncertain. One example are pollinators as they play a key role on food security globally. Since the response of complex systems is highly context dependent, predicting the effects of climate on pollination services is difficult and uncertain, although there is limited evidence that impacts are occurring already and medium evidence that there will be an effect (IPCC 2019 a). Beside pollination, changes related to pests are highly relevant for agricultural production. Since most insects have relatively high temperature optima, rising temperatures allow higher vitality and higher reproduction rates. Milder winters regularly favour frost-sensitive pests and root parasites (Mosbrugger et al 2012). Moreover, globalization causes the establishment of neobiota. After a short-term increase in the number of species, they cause a displacement of the previously established native species. Besides climate change and globalisation, agricultural relevant ecosystem interactions are impacted by legislations. For example, the renewable energy law makes energy crops much more profitable than traditional field crops. Consequently, monoculture has increased with negative effects on biological diversity and increased vulnerability to pests.

4.5 Discrepancies between climate mitigation goals and society

4.5.1 Policy

According to the needed climate change related action, discrepancies within several societal areas were discussed. In particular, huge discrepancies were seen between political climate targets and actual political decisions (D3.2, Meinke et al. 2019). In this context, analyses of the consequences of these political decisions according to greenhouse gas emissions would increase transparency regarding the extend of the respective contradictory action. In particular, on local scales this would support to set priorities within political decisions by considering overarching climate mitigation targets. To reach this, the particular local measure (e.g. clearing of a forest, building a new highway, open a new brown coal open cast) would need to be quantified with regard to its greenhouse gas emissions.

It was stated that several local short term political decisions are not only contradicting the overarching climate mitigation targets but also harm large parts of the citizenships, i.e. thousands of people, are expropriated in order to make a brown coal open-cast possible (D3.2, Meinke et al. 2019). Thus, a dialogue process with all stakeholder groups involved should be established to negotiate and prioritize potential decisions. Climate change and greenhouse gas emissions of local political decisions would be certainly only one among other drivers for deciding on measures within certain fields of everyday life, e.g. mobility, settlement and energy consumption. However, a quantification of certain local decisions regarding greenhouse gas emission would make this aspect decision relevant, in the first place.

4.5.2 Economy

Moreover, discrepancies were seen between the potential GHG mitigating impact of technical innovation and their actual use to increase performances following the laws of the free market economy. Powerful marketing strategies of the respective companies aiming at maximal profit were seen as source for this discrepancy. This aspect is another example for the circumstance that missing information is not the reason for missing climate change related action. Although information on the implementation of low carbon solutions is available and well known in the respective companies, other decisions are taken. A scientific assessment of barriers, drivers and reasons that hinder the implementation of low carbon options within companies would help to make this circumstance transparent. Companies could be provided with information on how climate change might affect their financial results. The management consultancy Deloitte (2019) has recently published a fact sheet on future viability of the automotive industry. There are warnings that the EU will impose heavy penalties on the car industry for exceeding the CO2 limits. The CO2 limits could only be achieved by selling more e-cars. Beside penalties for exceeding the CO2 limits, companies' reputation according to climate change is increasing in importance. Company strategies, which are not accepting their responsibility regarding greenhouse gas emissions, may harm their reputation, since it can make a company the target of protests and boycotts. Scientific analyses may help to clarify the interaction of companies' climate reputation and financial results. Beside the aspect of reducing greenhouse gas emissions described above, physical risks due to the impact of climate change could reduce profit. A scenario based on business-as-usual greenhouse gas emissions could be used to asses to what extent the profit of certain companies could be affected. If the company is negatively affected, this information could show that climate mitigation and adaptation measures are worthwhile considering.

4.5.3 Individual citizens

Furthermore, the significant gap between existing personal knowledge on climate change and personal action as consequence of this knowledge was discussed. There was agreement among the participants that changes according to climate change related action would only be expected as a consequence of a strong personal impairment and increased suffering pressure. The response to the Coronavirus in Winter/Spring 2020 confirms the correlation between perceived direct personal impairment, personal suffering pressure and related action: respiratory masks are sold out, people in western industrial nations fill their cellars with emergency supplies, handshakes as a greeting are declared undesirable in official letters. There are stronger coughing and sneezing etiquette, distance rules are applied. Each and every individual is called upon to do something to prevent the virus from spreading any further. Needed action has instantaneously been adopted and implemented. Whereas needed action related to climate change is postponed, although it might be even more existential. One approach to explain the discrepancy between coronavirus responses and those to climate change (mitigation and adaptation) is the availability heuristic (Stöcker 2020): people are less willing to change their behaviour the further away the presumed consequences of inaction seem to be, both in time and space. This effect becomes even more extreme, when there is uncertainty about the expected consequences. The availability heuristic replaces question of the frequency of an event or the scope of a category with the simpler question of how easy it is to remember appropriate examples. Such examples are readily available either because of personal experiences or through reports in the mass media and thus lead to a systematic error. This availability error leads to the perception that certain risks cause more personal impairment than others do, although it could be vice versa. Events, which are easy to remember, perceived in a peer-group and which are associated to famous names promote availability heuristic. Moreover, the easiness of information processing and easily imaginable visual content have an impact on the perception in this context. These drivers should be accounted within a climate service. Stöcker (2020) concludes that it would be the task of politicians to draw the necessary conclusions and act against the "climate crisis". However, as described in D3.2 it was assumed, that implementing adequate policy would require a broad acceptance for the needed political decisions and measures within society. Beside the perceived personal impairment, it was discussed that the needed acceptance could only be achieved by meeting the challenge to combine rising prosperity with decreasing CO2 emissions. However, the question of how human society can succeed and live a good life in view of ecological borders is currently unresolved. Against the background of sustainability, the definition of prosperity and its close link to economic growth must be renegotiated.

4.6 Explicit knowledge needs

4.6.1 Mitigation

Two of the three raised issues were related to human greenhouse gas emissions and their mitigation. In both cases, the need for transparency according to the amount of greenhouse gas emission related to mitigation targets was demanded. One aspect was related to the impact of urban development strategies on greenhouse gas emissions, the other to the temporal development of greenhouse gas emission in different sectors. There is a broad range of approaches for accounting greenhouse gas emissions available. Depending on the objective, some approaches are more suitable than others are. If national and international targets are considered, a source balance approach is applied, since it is based on international agreements. The IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) provide methodologies for estimating national inventories of anthropogenic emissions by sources and removals by sinks of greenhouse gases. The IPCC Methodology Report titled the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas

Inventories (IPCC 2019) aims to refine the 2006 IPCC Guidelines in order to provide an updated and sound scientific basis for supporting the preparation and continuous improvement of national greenhouse gas inventories. The source balance describes the CO2 emissions directly resulting from primary energy consumption. In particular, it depicts all major industrial and power generation plants.

However, the aim in the context of regional climate protection plans is to identify local opportunities for action. Thus, a polluter pays balance is more suited. The polluter-pays balance refers to final energy consumption and is, thus, more directly related to the consumption behaviour of industry and private households. This balance approach is more decision relevant for climate protection strategies, as it strongly reflects the cause and thus the factors that can be influenced by climate protection measures in particular regions. Since the climate policy goals and commitments at federal and state level refer to greenhouse gas accounting without emissions from land use and land-use change and forestry (LULUCF), monitoring in the energy system transformation and climate protection reports is currently carried out accordingly. The climate impacts of land use or changes in land use patterns and the climate impacts associated with forestry (LULUCF) have so far only been incompletely included in climate protection goals. Thus, no commitments to reduce greenhouse gas emissions can be quantified for these sectors at present. The EU aims to harmonise and improve reporting in the LULUCF sector in Europe. In close dialogue with Member States' experts, a joint project will produce guidelines on how to overcome critical problems, show best practice examples and - if possible - assess the costs of possible improvements (Thünen 2020).

4.6.2 Personal impairment

The other raised issue was -like several aspects before- linked to the missing personal impairment of climate change. See chapter 4.3 for further discussion.

5 Bergen (Birgit Gerkensmeier)

For the Bergen case study, the work in D3.2 provides the starting point for the feasibility discussion. Building on that basis, we will discuss the need and room for improvement and development of enhanced local climate services for the most relevant thematic issues with regard to the aspects of potential knowledge gaps, missing climate service formats, identifiable challenges for communicating climate change on local scales, and options for the (co-) development and improvement of sustainable local climate services.

5.1 Seasonal changes: Exceptional seasons and shifts in seasons

The narratives of WP1 for Bergen highlighted two different facets determining the discussion about seasonal changes: long-term shifts in seasons and singular, exceptional seasons (summers and winters). The evaluation activity in D3.2 made clear that there is less information available for exceptional seasons than for shifts in seasons. Indeed, the analysis showed that: i) there is no service that exclusively focuses on the topic of seasonal changes, related impacts and adaptation options; ii) with regard to impacts: knowledge about impacts on eco- and economic system are available and translated to climate services in a satisfactory manner. However, there are no links between the information on shifts in seasons and their impacts on health and social life (demand from WP2 scenario activity). Moreover, available climate services do not address the distinction between long-term shifts in seasons and the occurrence of exceptional seasons.

At present, we did not find a climate service dedicated solely to ‘shifts in seasons’ as well as ‘exceptional seasons’ for Bergen (based on the WP3 assessment and evaluation activities). Nevertheless, there are climate services that include information about “changes in seasons” and “extreme in seasons”: the European Environment Agency indicator covers changes within seasons (summer and winter): mean precipitation[8], extreme precipitation[9], temperature and heatwaves[10], etc.[11];

[8] https://www.eea.europa.eu/data-and-maps/indicators/european-precipitation-2/assessment)
[9] https://www.eea.europa.eu/data-and-maps/indicators/precipitation-extremes-in-europe-3/assessment-1
[10] https://www.eea.europa.eu/data-and-maps/indicators/global-and-european-temperature-9/assessment

the Climate Change Knowledge Portal covers monthly changes of climate variables as well as some extremes[12]. The available information for Bergen, mainly about temperature and precipitation, is included partially in the climate service tools that present to the users a general picture about climate change in Norway and Bergen[13]. Some information about long-term shifts in seasons is already provided in available climate services, e.g. in the web tools of the Norwegian Climate Service Center (KSS) providing information amongst others about climate projections[14], and in assessment reports e.g. "Climate of Norway 2100[15]" (Hanssen-Bauer et al. 2017).

However, it might be difficult for a layperson to extract the relevant information about seasonal changes from the massive amount of information e.g. provided by the KSS online or by the climate assessment report for Norway. The establishment of a climate service on the topic of seasonality could be considered to be sensible and necessary in order to do justice to the topic sufficiently. Regarding the implementation of such a local climate service, a major challenge comes from the high level of uncertainty for the projections of these rare events (exceptional seasons), whereas long-term shifts are attached to less uncertainty. About how such a climate service (web-tools focussing on seasonal climate change) could look like, examples are the Klimamonitor (www.norddeutscher-klimamonitor.de Meinke et al. 2014) for recent climate change & variability, and the Klimaatlas (https://www.norddeutscher-klimaatlas.de/ Meinke et al. 2009) for future climate change. In both of these web-tools, users can choose single seasons for Northern Germany and several pre-defined sub-regions. For each choice, related interpretation is provided. From the physical climate perspective, seasonal climate change is localised as far as possible, this way. Since not only information on seasonal shifts but also on extreme events within seasons are provided, the web tools are adoptable

[11] https://www.eea.europa.eu/data-and-maps/indicators/#c0=30&c12-operator=or&b_start=0&c12=climate-change-adaptation
[12] https://climateknowledgeportal.worldbank.org/country/norway/climate-data-projections
[13] Such as the services provided by the KSS: Climate Projections https://klimaservicesenter.no/faces/desktop/scenarios.xhtml, Precipitation intensity https://klimaservicesenter.no/faces/desktop/idf.xhtml, Climate fact sheets https://klimaservicesenter.no/faces/desktop/article.xhtml?uri=klimaservicesenteret/klimaprofiler
[14] https://klimaservicesenter.no/faces/desktop/scenarios.xhtml
[15] https://cms.met.no/site/2/klimaservicesenteret/klima-i-norge-2100/_attachment/11592?_ts=15c10419731

for many stakeholders. Therefore, a key question here is if a similar web-tool with information for the Bergen region could be useful for local stakeholders.

From the D3.2 analysis, two potential entry points were deduced, which could additionally be used in Bergen within a new climate service providing users with easy access on information regarding seasonal changes. i) The discussion of impacts of seasonal changes and exceptional seasons is an essential aspect in the local debates; ii) seasons as cognitive schemes are an essential point in local contextualization. The WP1 narratives showed that the topic ‘seasonal changes’ is mainly addressed in the Bergen community through the lens of societal topics such as health and social activities. Although these topics are not in conflict with the scientific impact assessment, they have not yet been the focus of such analyses. The evaluation activity in D3.2 already showed that current scientific debates and available impact assessments mainly focus on natural systems and economic dimensions rather than on social dimensions. Therefore, scientific information regarding impact assessment focusing on social dimensions seems to be currently lacking. Consequently, enhanced information about impacts of seasonal changes and exceptional seasons on health and social activities are needed to better serve the local request as an entry point to the topic. Since different climate services communicating climate change impacts are already available, existing climate services could be used as an example and basis for developing a new service for Bergen. Examples of the implementation of a climate service focussing on impacts of seasonal changes (for both health and social activities as well as impacts on the natural system and the economic dimension of impacts) include web tools such the Northern German Climate Atlas (www.norddeutscher-klimaatlas.de Meinke et al. 2009), the Dutch climate impact atlas[16], or the Impact2C atlas[17].

With regard to the second entry point, D3.2 refers to the fact that WP1 and WP2 activities highlighted ‘seasons as cognitive schemes’ as an essential point in local contextualization and therefore as an entry point for a (new) climate service.

[16] http://www.klimaateffectatlas.nl/en/

[17] https://www.atlas.impact2c.eu/en/ The Impatc2C web atlas of the (now completed) EU project IMPACT2C (Quantifying projected impacts under 2C warming) assessed climate change impacts due to +2°C global warming for Europe and three particularly vulnerable regions of the world (Bangladesh, Niger, and the Maldives), regarding vulnerabilities, risks and economic costs.

Following essential aspects are identified for a successful new climate service on seasonal changes, building up on the entry point of seasons as cognitive scripts:

- Advanced research activities: gain in-depth knowledge of cognitive scripts in the population in order to achieve proper knowledge of users' requirements. What must be clarified: which activities, routines or processes are shaped and dependent on the seasons and in which way?
- Describing the situation more clearly (today and in the future) in order to increase the understanding of the scope and characteristics of the overlap and discrepancies between physical climate changes and cognitive scripts for seasons. This new in-depth knowledge of cognitive scripts has to be contrasted with the available knowledge about climate changes in the future, focussing on the questions: what are these changes (shift of the season, lengthening or shortening of the season, changes in the seasonal cycle of meteorological variables, etc.)? Which activities or routines can be expected to be impacted by these changes and how?
- Co-development appears particularly important: not only by involving (co-development) scientists from the natural fields and social fields, but also through participation of local experts and the local population. The latter is essential to support the connection to local activities, and thus to ensure the relevance and usability of the climate service.

5.2 Landslides and torrential downpours

The WP1 narratives show that interviewees in Bergen often talk about the topic of landslides and torrential downpours through the standpoint of impacts. The D3.2 evaluation activity about this issue showed that the science provides a comprehensive picture and substantial findings for the observation of events (physical data) and the observation of impacts (damage recording). In addition, impact assessments and related vulnerability analyses are available. Moreover, impact assessments represent an essential part of the current debate within the climate science in this context. Several climate services are already implemented which address the topic of vulnerable areas and recorded landslide events. The available assessment analyses range from information on national and regional scales (that often give a good overview) up to the service of the Norwegian water resources and energy directorate (NVE), which is dedicated only to the topic of landslide events and with a high spatial resolution (up the local level). The NVE atlas provides insights about the areas hit (hazard zone); moreover, the related reports provide comprehensive insights about landslides events (including observations made during the inspection as well as model calculations e.g. used to present different probability levels). Thanks to a high level of detail, the NVE atlas is usable for very local questions and assessments. The maps and report show a very comprehensive picture of the risk situation. However, no information from *impact* assessments, an essential aspect highlighted by the WP1 narratives as an entry point to the topic, are directly involved and provided. This implies that there is still an unanswered need for a service focusing on the *impact* of landslides at the local level.

Analysing the current science about landslides, the assessment of their impacts and the available climate services in this context, we conclude that already a great deal in terms of methodology for impact assessment and evaluation (national and international analysis) is available and potentially applicable to answer this local demand for enhanced information about local impacts from landslides.

However, such local examinations would probably be data- and labour-intensive, despite the existing methodology. Therefore, the questions to answer with these examinations should first be clarified between provider and user. This is also crucial in order to generate information that is usable in practice for local decision-makers and stakeholders. As long as both sides, providers (and scientists) and users, do not have a joint understanding about the limitations and possibilities of such an analysis, expectations can be raised (on both sides) that will ultimately not be met by a local climate service. In our view, some of these questions to clarify the situation and help in the preparation of the local service are:

- *What kind of results or information is useful for the local stakeholders?*
- *What are their expectations vs. what is feasible from the scientific perspective regarding the results of the impact assessment? Contrasting the expectations (potentially different) between provider and user?*

- *Is local assessment feasible according to the available methods (do they allow the consideration of very specific and local elements or conditions)?*

Similar to the discussion about information needs on impact assessments resulting from changes in the seasons (see paragraphs above about 'seasonal changes'), there are already a few services available that can be used as examples with regard to possible formats for sharing and communicating this information. Web tools in the form of an impact atlas provide a handy option, as well as text-based formats such as reports or understandable summaries.

5.3 Physical arenas and meeting places to jointly discuss and develop local adaptation activities

In contrast to the topics discussed above, this issue does not cover a thematic matter of concern or specific knowledge need, but it concerns a demand that was evidenced by the participants in the WP2 stakeholder workshop. When stakeholders in this workshop were asked to identify resource needs and obstacles needed to achieve the scenarios developed jointly for the future, several stakeholders (in different contexts and small working groups) independently called for the need of physical arenas and meeting places to jointly discuss and develop local adaptation activities. Going into more detail, the items on the wish lists (cf. D2.2) linked to the call for physical arenas and meeting places includes the following demands:

- *"An interdisciplinary, research-based arena for climate communication and dissemination"*
- *"Local meeting places, e.g. "Soup and Climate Measures""*
- *"A research arena where the 'kommune' can ask questions"*
- *"Arenas for dialogue and cooperation across a variety of sectors in society"*

Furthermore, these calls for physical meeting spaces are also closely linked to the call for "positive framing of climate projects" (additional item on the wish list) including the demand for increased efforts by climate scientists to communicate their scientific results to the various sectors of society in an understandable way (cf. D2.2, theme 1: Bergen as a 'climate science city').

The claim for local meeting spaces and a physical arena for dialogue and cooperation across sectors in society is related to several of the matters of concern and perceived risks from climate change. Due to the fact, that many stakeholders have identified this need independently, this format appears to be an important (climate) service that is not yet sufficiently available, but is crucial for local communication about climate change and the development of further co-development activities. In our view, this claim both addresses the need for a new type or format of climate service as well as it represents an option for active, local co-development activities. This points to local climate services that would be more participatory and social, and processes that enable the exchange of different actors on climate relevant themes.

Looking at our inventory on available climate services in the CoCliServ research areas (D3.1, p. 69), there are very few climate services for Bergen doing ‘advisory services and products’ and none doing ‘dialogue and educational format’. Although this inventory is not exhaustive, it shows that the local stakeholders actively demand currently lacking communicative and direct exchange-based climate services in Norway. However, a format like the one required here would seem to be absent from all the climate services covering the case study regions so far. Based on this, we broadened our research beyond the D3.1 inventory and looked for existing climate service activities similar to the claim of the Bergen stakeholders (even if these activities were not necessarily established under this name and in this context). The idea behind this is to learn from existing examples and to compile information about which aspects are important for the implementation of a new local climate service on increased participatory and social processes that enable the exchange of different actors on climate relevant themes. It can be noted that our research was limited to the English and German languages, which probably reduced the findings. We found a few activities that include the idea of a ‘climate café’ (as suggested by the stakeholders).

They all share the aim of bringing people together to exchange ideas about climate change and the sustainable use of resources. However, the goals of these services (see Table 1) are different: they range from creating a place for discussions without any further evaluation, through the collection of ideas and wishes, up to the joint discussion and planning of concrete initiatives and measures. These services mostly focus on climate change mitigation rather than adaptation; nevertheless, this orientation should not be an obstacle to the question of transferability to local discussions (as in Bergen) about climate change adaptation.

Table 1 Research findings for local or community activities related to the idea of a climate café / meeting space for joint discussion of climate change (adaptation and mitigation)

What (name, location, source)	Short description	What is helpful or transferable for the Bergen case
Climate Cafés **Oxford, UK** **https://www.meetup.** **com/de-DE/meetup-group-climatecafes/events/** **266004244/**	Started in April 2019 Organised and funded: by Low Carbon Oxford North, a registered charity open for everyone Aim: Talking about climate change is often made more difficult by our feelings of guilt that we are not doing enough, or frustration that others are not doing enough. The climate café will provide a space in which we don't talk about what we or others are doing or should be doing; but just talk about climate change and how it is making us think and feel.	The intention here is to reduce fear of contact and fear of discussion; explicitly not used to discuss or initiate concrete measures; However, this precise call for action is included in the call from Bergen citizens asking for physical meeting spaces; this call also includes willingness to be active
Klimazone Findorff- Global denken, gemeinsam handeln (climate zone Findorff- think global, act jointly) **Bremen, Germany** (Findorff is a district in Bremen) https://klimazone-findorff.de/	Was developed as a neighbourhood project within the framework of the national climate protection initiative Goal: helping to shape a lively, liveable and sustainable district by citizens of Findorff as ambassadors for climate protection and with the help of experienced partners. Klimazone is accompanied by other local projects. Meeting venues / spaces: KlimaCafé (café) in the heart of Findorff as a central meeting point for a mutual exchange. In addition an InfoMobile is available and used on site in many streets, at events, festivals, and a weekly market	Form and structure of the Klimazone Findorff as an established physical meeting space is very similar to the wishes in CoCliServ; it provides a good example how it could be implemented in practice. The second, mobile information stand is also a good suggestion; it can help to raise awareness, visit other events and locations and thus invite other interested parties and citizens. In terms of content, this initiative focuses mainly on climate mitigation. The wishes of the Bergen stakeholders also include discussion and joint development and implementation of measures with regard to adaptive measures. However, adapting the aims and goals seems to be easily

		manageable.
Klimacafé **(climate café)** **Hattingen, Germany** **https://www.hattingen.de/stadt_hattingen/Rathaus/Fachbereiche/Stadtplanun%20und%20Stadtentwicklung/Strategische%20Stadtentwicklung/Klimaschutzkonzept/**	The climate café was installed as a one day event format on 12.03.2019 (held in the town hall) Organised by City administration, which was commissioned to draw up a climate protection concept Open to all interested citizens; methodology used: World café discussions The Klimacafé is part of the development process of a local climate mitigation concept; citizens of Hattingen were invited to discuss and collect ideas, suggestions and suggestions for municipal climate protection	For the CoCliServ context, the use of the world café method is interesting. In terms of handling large groups of participants discussing specific questions, this can be a good opportunity to initially conduct and structure the discussions. Otherwise, this one-day event format does not go in the same direction as the wishes of the Bergen stakeholders. Rather, they want something constant (in the form of a café) or at least something recurring (regular meetings at a certain place). The example also focuses on climate mitigation; the Bergen community is interested in mitigation and adaptation. However, expanding the content in this direction appears to be quite easily doable.
Climate change café **Ojai, California, USA** **http://climate changecafe.org/about/**	Started in 2018 Organiser: not really clear, seems to be an engaged citizen; Motivation: idea emerged from the organisers experience that many have fears, sadness, anger, confusion, despair, and feel very alone in these difficult places also with regard to the topic of climate change. Bring people together to talk about their fears and discover how to overcome these fears and sadness.	This activity has little similarity or overlap with the wishes of the stakeholders in Bergen. Similarity exists in the setting (discussion round between citizens with similar interests). However, the motives in Bergen are much more proactive and more action-oriented (example here first aims to remove hurdles in dealing with the issue of climate change).

This review initially serves as a first point of reference for further statements on a possible new format and its possible design in practice. At this stage, it is not possible to present a profound step-by-step-plan for implementing a physical meeting arena for joint discussion and development of local climate change adaptation in Bergen. However, we can provide some thoughts and findings regarding which basic conditions are needed and which kind of formats are appropriate to establish a service corresponding to the demand of a physical arena for jointly developing local adaptation activities:

- The claim from the stakeholders includes a physical meeting place as a fixed location, therefore the existing cafés, community centres, etc., all represent possible options.
- It is also conceivable to connect or expand the activities of existing environmental initiatives or other community facilities by the additional layer of joint climate change adaptation discussion and activities. This would have the advantage that activities could be built on existing physical structures as well as existing contacts and networks.
- The stakeholders proposed the format of climate cafés, repair cafés, community cafés. Such a facility would have a double use: in addition to a normal café, they would invite you to public discussions about climate change adaptation at regular intervals.

However, such activities also require coordination: who is responsible for this task? Who has the contact e.g. into the scientific scene? If necessary, it makes sense to hold a team responsible, in which, at best, different members from different areas, sectors, or administrations bring contacts to experts and sectors together.

6 Gulf of Morbihan (Florentin Breton)

The discussion of the feasibility of local climate services for the Gulf of Morbihan relies to the previous activities and deliverables from WP1 (D1.1, D1.2, D1.3), WP2 (D2.1) and WP3 (D3.1, D3.2). For each topic of interest from the case study, we present the local issue or question, describe the most relevant climate services addressing it, discuss the gaps, limitations, and challenges that emerge from the situation, and consider options for overcoming these shortcomings. The discussion of these elements corresponds to both, specific and general features of the climate services and literature. Unfortunately, we have access only to the results of the first WP2 workshop (focused on ideas) in the Gulf of Morbihan, since the last workshop (focused on action) will occur in the next months.

6.1 Impact of storms, sea level rise and marine submersion for coastal risk management

Storms and sea level rise are both perceived in the local narratives as threats and linked to climate change (D1.1 and D1.2). The Xynthia storm for example strongly impacted the coast (D1.1), and the shoreline footpath appears to be retreating (D1.3). The vulnerability of the coastal population and economic activities are expected to increase in the future with climate change (D1.2), while local subsidence could also increase the risk from sea submersion (D1.2). Therefore, the climate adaptation of the Gulf could be supported by climate services regarding the evolution of the coastline (D1.3, Meinke et al., 2019).

- **Climate services**

The most relevant climate services that we found are Climat HD[18] and Tempêtes[19] (Météo-France) for storms and Surging Seas[20] (Climate Central) for sea level rise. The specific strengths and limitations of Climat HD and Surging Seas were discussed in the evaluation activity (Meinke et al., 2019), and the following discussion is more general about the current limitations of climate services and of the climate literature, and about options for the improvement or development of local climate services.

- **Knowledge gaps:**

Based on our findings from previous activities, there is no single climate service including all aspects[21] of coastal risks, and while some individual components of coastal hazards are covered by climate services, such as storms (Climat HD; Indicator Assessment[22] (IA) from the European Environment Agency), and sea level rise (Surging Seas, IA[23]), others do not exist outside of the climate literature (e.g. wave height in Collins et al., 2019). Most climate services addressing coastal risk at the regional level, such as the scale of Brittany or Morbihan, focus mostly on

[18] http://www.meteofrance.fr/climat-passe-et-futur/climathd
[19] http://tempetes.meteofrance.fr/
[20] https://sealevel.climatecentral.org/maps/
[21] Hazard, exposure and vulnerability (Cardona et al., 2012)
[22] https://www.eea.europa.eu/data-and-maps/indicators/storms-2/assessment
[23] https://www.eea.europa.eu/data-and-maps/indicators/sea-level-rise-6/assessment

individual coastal hazards[24] but not vulnerability[25] or exposure[26]. Three reports in the literature give a broader perspective, with a focus on impacts (Belleguic et al., 2012; ODEM, 2012) or on vulnerability and adaptation (Roussel, 2012).

The three main knowledge gaps that we can identify in the climate services are:

- The large uncertainty in the future evolution of coastal hazards, such as low confidence in the regional changes of storms (Oppenheimer et al., 2019), or such as the rate of sea level rise especially in the case of high-end scenarios (IPCC[27], 2019). Bridging these gaps is highly relevant for both climate research and society.
- The lack of a climate service, providing an integrative representation of most coastal risks (including hazard, vulnerability and exposure), or even most coastal hazards, at regional or local level. In some cases, these features are addressed in the climate literature (Belleguic et al., 2012; ODEM, 2012; Roussel, 2012), or in climate services for other case studies (e.g. the Northern German Coastal and Climate Office is integrating atmospheric[28] and marine[29] hazards with coastal vulnerability and exposure[30]). Most climate services also do not include local aspects of coastal risks that are subtle to climatology, such as local subsidence (geology) and coastal erosion (sedimentology).
- The lack of a translation of coastal risks for adaptation measures at the regional or local level, such as the consequences implied by these risks for the territory and the diverse sectors of society. This translation exists partially in the three reports listed above.

We note here that although the large uncertainty in future coastal hazards could constitute a large knowledge gap for stakeholders in planning the climate adaptation of the coastal territory, the evaluation activity (Meinke et al., 2019) indicated that including the uncertainty associated to different models and scenarios was rather

[24] possible future occurrence of natural or human-induced physical events that may have adverse effects on vulnerable and exposed elements
[25] propensity of exposed elements such as human beings, their livelihoods, and assets to suffer adverse effects when impacted by hazard events
[26] inventory of elements in an area in which hazard events may occur
[27] Intergovernmental Panel on Climate Change (https://www.ipcc.ch/)
[28] www.norddeutscher-klimamamonitor.de
[29] www.stormsurge-monitor.eu
[30] www.kuestenschutzbedarf.de

beneficial than detrimental for the decision-making. However, the evaluation activity relied on the involvement of the case study leader as an expert of the region, rather than direct involvement of local stakeholders (due to difficult accessibility), limiting the strength of conclusions derived from the evaluation for decision-making. This raises the question of the necessary level of detail of the information (spatial, temporal, uncertainty) that can be used for the local decision-making for coastal risk management in the planning of the territory for adaptation to climate change.

- **Missing formats:**

From the WP3 perspective based on local knowledge needs, the lack of a service, such as an online visualizing tool, providing an integrative representation of coastal risks (possibly considering hazard, vulnerability and exposure) can be regarded as a missing format. Such a service could look similar to the way Surging Seas displays information about the territory in the United States, for example by including social vulnerability[31]. Another example is the web tool[32] developed by the Northern German Coastal and Climate Office, which shows the current coastal protection measures and the areas, which could possibly need coastal protection in the future (2100), when sea level and storm surges would increase. The evaluation activity (Meinke et al., 2019) highlighted that a service showing the characteristics of past storms other than their occurrence, such as their intensity and location (e.g. maps), would be interesting in order to provide context for the present (and future) situation of coastal hazards. This information is covered by the climate service Tempêtes from Météo-France.

- **Challenges for communication of climate change on local scale:**

Generally, the information available from climate services falls in one of two categories: the simple approach with one model and one scenario, and the multi approach with several models and scenarios. The first approach is usually associated with the apparent perception of low uncertainty and the second with the apparent perception of high uncertainty, although the second one can bring better understanding of the causal chains (mechanisms) between the different assumptions

[31] https://ss2.climatecentral.org/#6/33.998/-81.892?show=sovi&projections=0-K14_RCP85-SLR&level=5&unit=feet&pois=hide
[32] https://kuestenschutzbedarf.de/

(model, scenario) and outcomes (system response). A complement to the multi approach is to use all regional projections (multi model and multi scenario) available for a given region as was done in the Klimaatlas (Meinke et al. 2009)[33] web-tool (incuding more than 120 regional climate scenarios). However, the multi approach is more expensive in resources and requires to understand the different assumptions represented by the diversity of models and scenarios, which might be difficult to navigate for non-experts. Therefore, communicating the future projections of a climate variable (e.g. sea level rise) to non-experts in a context of large uncertainty, multi-model and multi-scenario, requires giving them the ability to understand how results differ according to varying assumptions (associated to different types of uncertainty). Providing the interpretation of the results in the web tool (e.g. Klimaatlas, Meinke et al. 2009) is a solution for this. Yet, the multi approach remains scientifically more robust because models and scenarios represent simplified versions of the reality and the trajectory of the system might currently follow one scenario but later switch to follow another. Surging Seas[34] is an example of multi approach with varying assumptions (carbon pollution and cuts, stability of the Antarctic ice sheet) and consequences (resulting sea level rise and marine flood levels), although it does not consider all local factors (such as subsidence, coastal erosion, and coastal protection). Not considering coastal protection can lead in many regions to a wrong idea on what might happen. This general remark about models, scenarios, and climate change communication is very relevant in the case of coastal risks and especially sea level rise because of nonlinear processes that can be triggered by some scenarios (and assumptions) but not others, hence making the multi-model and multi-scenario approach essential to not underestimate or overestimate the impacts to which the coastal territory might adapt. However, this still depends on the good representation of coastal risks, societal scenarios, natural variability, and human forcings in the models, attached to different kinds of uncertainties (Le Cozannet et al., 2017a).

[33] www.norddeutscher-klimaatlas.de
[34] https://ss2.climatecentral.org/#10/47.5775/-2.6903?show=satellite&projections=1-DP16_RCP85-Flood10pct&level=1.5&unit=meters&pois=hide

- **Limitations from scientific, provider's and stakeholder's perspectives:**

A general limitation from provider's perspective is to identify accurately the climate information that is needed when the local needs are not very detailed. However, identifying these local needs in detail is also challenging.

We found three main limitations that constrain the scientific confidence in predicting future shoreline erosion and sea submersion:

- Developing future projections of shoreline changes requires a good understanding of the driving coastal processes (resulting from mean sea level, waves, storm surges, and tides) which are affected by climate change (Toimil et al., 2020).
- The large inter-annual variability of storms and the resulting difficulty to attribute their evolution (e.g. frequency, intensity, trajectory) to climate change, outside the range of natural variability, represent two barriers in the understanding of the future evolution of storms[35]
- Projections of sea level rise are highly dependent on the model and scenario used, and regional rates may differ from the global rate due to local factors such as subsidence (Oppenheimer et al., 2019). Moreover, the current frequencies and intensities of extreme sea level events in many places of the world are not well understood due to a lack of observational data.

Additionally, implemented adaptation responses to coastal impacts are mostly based on current risk or experienced disasters (high confidence; Oppenheimer et al., 2019). However, examples also exist of approaches combining the consideration of uncertainties with a no regret strategy for coastal protection measures[36]. Therefore, the adaptation to future coastal risks represents a large challenge, especially since it requires to first identifying the future impacts, as well as (potentially) the exposure and vulnerability of coastal systems (human and natural). Appropriate adaptation to climate change is essential, even more so in the case of coastal systems, since future extreme sea level events could exceed the threshold of adaptation measures such as

[35] http://www.meteofrance.fr/activites-recherche/mieux-comprendre-les-phenomenes-atmospheriques/tempetes
[36] https://www.adaptationcommunity.net/?wpfb_dl=112

protection from dams if these measures are too conservative, resulting in misadaptation and high damage. This relates to the question of the current trajectory of the Earth system in the next decades for the associated adaptation responses at different time horizons, which is also relevant for other features of climate change such as extreme events inland.

From stakeholder's perspective, different coastal management decisions might require different types of climate information such as probabilistic sea level rise projections or probabilistic knowledge on impacts (Le Cozannet et al., 2017b) which are generally not directly accessible from available climate services. Nevertheless, they can be found in the climate literature up to regional scale although they may not consider all local factors (e.g. Kopp et al., 2014; Vousdoukas et al., 2018).

- **Options for the co-development / improvement of sustainable local climate services**

A limitation from the currently available climate services is linked to barriers in the scientific understanding of the future evolution of sea level rise and storms, requiring further research efforts. Another obstacle is the compounding uncertainties related to the coastal impacts from sea level rise, such as shoreline change and sea submersion (Kettle, 2012). A better scientific understanding of the future evolution of climate variables at a regional or even local scale (e.g. Stephens et al., 2017) could be translated to a climate service in order to facilitate the decision-making in local climate change adaptation of the coast for the next decades. This service could be similar to Breili et al. (2020), but complemented by local physical factors, and assisted (Pidgeon & Fischhoff, 2011) in the design process by principles from social science and decision science for usability in the decision-making under uncertainty.

However, this might not be enough and another limitation might arise in the understanding of coastal risks from knowing the hazards but not the vulnerability or exposure of human infrastructure (and natural systems) to these hazards. Therefore, mapping these three aspects of coastal risks (hazard, vulnerability, exposure; see also chapter 4.3.1 of this report) at the local level in a co-development process could bring to constitute a knowledge breakthrough, and if possible lead to the implementation of relevant local adaptation measures.

6.2 Occurrence of extreme events for agriculture, tourism and territory planning

Local decision-makers in the Gulf need to prepare the territory for future climate change, including extreme events (D1.2). In the Gulf, summer corresponds to strong tourism and freshwater use (D1.1, D1.2 and D1.3), and dry spells could amplify the pressure on the water resource (D1.1). In winter, heavy rainfall events and strong winds might increase the risk of flooding and storms (D1.2). Extreme weather and climate events are a natural part of the climate system (Easterling et al., 2016) but climate change might lead to new extreme weather events (e.g. unprecedented heatwaves).

- **Climate services, knowledge gaps, and missing formats**

Climate services (Climat HD, DRIAS[37], IA[38], CCKP[39] (Climate Change Knowledge portal)) as well as extensive literature (e.g. Kovats et al., 2014) provide information at regional scale about extreme events. Climat HD describes heatwaves, droughts and cold spells at the scale of Brittany in the past and at the scale of France in the future (droughts also at the scale of Brittany). This information includes the year, length (days) and intensity (°C) of heatwaves and cold spells, and the fraction of territory affected by droughts per year. However, there is no information about the spatial distribution of these events or to check whether they would affect the Gulf of Morbihan. This spatial distribution might be partially addressed by IA for heavy precipitation events[40], heatwaves[41], and droughts[42]. DRIAS is more difficult to use but more flexible (annual and seasonal information, multi-model, multi-scenario) and shows maps at different time horizons of many extremes including heatwaves, cold spells, droughts and heavy rainfall. However, limitations are the lack of time series and of local information for the Gulf of Morbihan (12km spatial scale). CCKP shows

[37] http://www.drias-climat.fr/
[38] https://www.eea.europa.eu/data-and-maps/indicators#c0=30&c12-operator=or&b_start=0&c12=climate-change-adaptation
[39] https://climateknowledgeportal.worldbank.org/country/france/climate-data-projections
[40] https://www.eea.europa.eu/data-and-maps/indicators/precipitation-extremes-in-europe-3/assessment-1
[41] https://www.eea.europa.eu/data-and-maps/indicators/global-and-european-temperature-9/assessment
[42] https://www.eea.europa.eu/data-and-maps/indicators/river-flow-drought-2/assessment

maps and time series of many climate indicators (daily, monthly, mean, extremes) of temperature and rainfall, but also climate indicators for society sectors (agriculture, water, energy, health) in past and future (multi-model and multi-scenario) at country and regional (1° or about 110km) scale.

Therefore, these services provide complementary information about future extreme events at a scale finer than Brittany but still coarser than the territory of the Gulf of Morbihan. As in the case of coastal risks, we do not know whether this climate information is precise enough (spatial, temporal, uncertainties) for territorial planning in the Gulf, and therefore if there is a knowledge gap between the available scientific knowledge and the information needed for adaptation decision-making. However, a few assessment reports provide an integrative representation of most extreme events (i.e. heatwaves, cold spells, droughts, heavy rainfall) at the regional scale (Belleguic et al., 2012; Kovats et al., 2014; ODEM, 2012; Roussel, 2012).

- **Limitations from scientific, provider's and stakeholder's perspectives:**

Although there is progress in the assessment and modelling of extreme weather and climate events (Stocker et al., 2013), and despite knowing that some extreme weather events (e.g. droughts and heatwaves) have increased in frequency and intensity in many parts of the world due to global warming (Jia et al., 2019), and are projected to continue increasing, a few scientific limitations in the study of extreme events exist such as:

- The lack of consistent definitions within the scientific community (McPhillips et al., 2018), for example with many studies conflating event and impact in the definition, rather than defining an extreme event based on a statistical threshold which allows to better study resilience to its effects. There also are limitations in the tools (statistical and others) used for analysing observed changes in extremes (Zwiers et al., 2013).
- The lack of high-quality, long-term data to detect and attribute extreme events outside the range of natural variability (Easterling et al., 2000; Rummukainen, 2012), since they are intrinsically rare (Stocker et al., 2013), and especially since there is low confidence in how large-scale modes of

variability will respond to a warming climate (Jia et al., 2019). This also corresponds to limitations in the ability to describe the natural variability of extremes with models and other tools (Zwiers et al., 2013).

- Their large variability, the diversity of triggering mechanisms (Roussel, 2012), and limitations in the understanding of the underlying processes leading to their occurrence (Zwiers et al., 2013). Weather and climate extremes are influenced by small- and large-scale weather patterns, modes of variability, thermodynamic processes, land-atmosphere feedbacks, and antecedent conditions (Stocker et al., 2013)

These hurdles impede a better understanding of the influence of climate change on these events, and therefore impede future projections of extreme events based on model simulations, since climate models are commonly evaluated based on their ability to reproduce the past climate variability from the observational record.

From a stakeholder's perspective, most climate services give information on extreme events at regional or larger scale, although information at local scale is more interesting. Indeed, the evaluation activity (Meinke et al., 2019) suggested that the current formats of climate information are supportive of action but may not be precise enough to know what to do locally. For example, Climat HD describes future heatwaves and cold spells at the scale of France but it is unknown whether these extreme events will also hit Brittany and the Gulf. It is possible to access more local information but requires to do data analysis (extraction, plotting of maps and time series, etc.) on free online platforms such as the Copernicus Climate Data Store[43] or DRIAS.

- **Options for co-development / improvement of sustainable local climate services**

Research efforts could strive to overcome scientific limitations (Zwiers et al., 2013; Jia et al., 2019) and lead to improved projections of future extreme events, and if possible to derive the impacts at local scale. This could lead to a climate service aggregating the variability (spatial and temporal) of the impacts from the different extreme events at regional or even local level, including if possible the uncertainty

[43] https://cds.climate.copernicus.eu/toolbox-editor/30964

associated to models and scenarios. However, a co-development process with decision-makers might be preferable to ensure that the produced information is usable for action measures in adaptation of the territory.

6.3 Seasonal changes for primary activities and tourism

Inhabitants of the Gulf are reporting changes within the seasons, such as rainfall more frequent in winter or summers that are getting drier (D1.1), but also changes of the phenological seasons themselves. Indeed, hay and wheat harvests in the Gulf are perceived to happen typically 1 month earlier now than 50 years ago (D1.1). There could be a link with climate change since the phenology of plants is intimately related to climate (Cleland et al., 2007), although there are also many non-climatic factors at play in the development of a plant. Therefore, seasonal changes of the weather as well as changes in the weather seasonality (i.e. structure of seasons) are both perceived and questioned by inhabitants of the Gulf. These are important questions since seasons play a large role in agriculture and tourism in the Gulf (D1.1, D1.2 and D1.3).

- **Climate services, knowledge gaps, missing formats, challenges for communication of climate change on local scale, and options for co-development / improvement of sustainable local climate services**

For complementary details on the topic of seasonal predictability (jet stream, seasonal precipitation, agroecosystem interactions), refer to chapter 4.4. The topic of the impact of climate change on local weather, seasons, and their predictability is already developed is chapter 4.4. Climate services (Climat HD, CCKP, DRIAS, IA,) largely cover climatological changes (e.g. temperature, rainfall) within the meteorological seasons (e.g. winter from December to January) but essentially do not cover possible changes of seasons themselves, such as a shortening of the winter season and lengthening of the summer season (Cassou & Cattiaux, 2016; Vrac et al., 2014). Of course, examining the structure of seasons and its possible changes essentially depends on the definition of seasonality. Here we essentially consider seasonality in terms of the structure (and its possible changes) of the seasons of a given climate variable or associated indicator in the year. We found a few climate services about changes of the seasonality:

- IA about phenology[44] and growing season[45]. These indicate changes in the timing of phenological events across Europe, with an earlier onset of crop growth in spring and later senescence in autumn, due to changing climate conditions.
- CCKP and DRIAS about the seasonal and monthly changes (mean, minimum, maximum, extremes) in temperature and precipitation at regional scale, and changes in their distribution in the year. Based on RCP8.5 over 2020-2039, the projections from CCKP indicate for the region of the Gulf of Morbihan that the July-August-September period undergoes the most warming and May shows the most decrease in precipitation. Rainfall is also projected to become more variable[46] across the year by being less evenly distributed across the seasonal cycle.

A large body of the literature suggests (with high confidence) that the seasonal activities of many plant and animal species have changed as a result of recent climate changes (Jia et al., 2019). These recent climate changes might include surface warming and changes in the seasonal cycle of tropospheric temperature (Chen et al., 2019; Santer et al., 2018; Yettella et al., 2018). Other effects of global warming on crop growth and development in temperate regions include an increase in heat stress (Teixeira et al., 2013), and in crop water demand (due to increased evapo-transpiration), acceleration of crop development (i.e. shortening of crop cycles), and an increase in night respiration (Tubiello et al., 2007). Regarding the phenology of wheat crops, the findings from Teixeira et al. (2013) suggest that the selection of different crop types and sowing dates in response to a changing seasonal climate can reduce heat stress impact, since the choice of crop calendars (i.e. time of sowing and harvesting) and the rate of crop development influence the exposure to extreme temperatures during critical phenological phases. Regarding hay crops, Lough et al. (1983) indicate that despite a climate change increasing the duration of the growing season, warmer summers, drier springs and wetter autumns would lead to a decrease in hay yield. In Western France, the main impacts of

[44] https://www.eea.europa.eu/data-and-maps/indicators/plant-phenology-2/assessment
[45] https://www.eea.europa.eu/data-and-maps/indicators/growing-season-for-agricultural-crops-2/assessment
[46] standard deviation of monthly rainfall against the mean rainfall

climate change on agriculture and forestry should be less water resource availability (Brisson & Levrault, 2010), a change in the productivity of crops, the evolution of production (species, varieties) as well as dates of sowing and harvesting (Massu & Landmann, 2011). This evidence appears consistent with the testimony from agricultural workers in the Gulf, which suggests that in their work, and based on empirical experience, they already achieved a climate adaptation to changing climate conditions. However, a counterargument to this conclusion is the difficulty to attribute the evolution of the crops between effects of climate change, changing agricultural practices due to climate change, and changing agricultural practices not due to climate change (Roussel, 2012).

As described above, there are many elements of scientific evidence suggesting that seasons are changing. However, most of the current climate services addressing seasonality focus on phenology, and those regarding climatic conditions (such as temperature and rainfall) consider static meteorological seasons in the year (e.g. Orlowsky & Seneviratne, 2012), assuming the annual structure of seasons doesn't change (until proof of the contrary). In the case of phenology, it seems that climate change is shifting the lifecycle of plants due to warming, since warming results in a shift of a given temperature in the year, although this warming is not homogenous in the year. In the case of meteorological seasons, they mostly result from the features of the Earth's orbit and associated variability in the distribution of energy at the surface, but people mostly experience them through the seasonality of surface weather conditions (e.g. temperature, rainfall, wind). Therefore, whether the seasonality of weather conditions might change due to climate change could change the paradigm of seasons for societal sectors largely dependent on the seasons, such as tourism (Amelung et al., 2007), agriculture, energy, transportation, and health (Naumova, 2006).

Accordingly, a climate service investigating how the seasonality of different indicators or climatic variables might be changing in the year, possibly due to climate change, could be interesting for these sectors. This was also emphasized by the evaluation activity (Meinke et al., 2019). The CCKP and DRIAS climate services partially cover this interest, by showing the future variability of climate variables by month[47]. Additionally, the seasonality of extreme events[48] might also be changing (e.g. Marengo & Espinoza, 2016; Mendez et al., 2008), and the local-scale seasonality might differ from the large-scale seasonality depending on the indicator or climatic variable. Based on our current understanding, some of these questions are already partially addressed by research but others remain open. Therefore, they possible constitute scientific knowledge gaps that could drive climate research to new directions. Regarding the possible climate service that could emerge from this new scientific knowledge, a co-development process could improve the development of this service in choosing the relevant indicator or climatic variable for actionable decision-making towards sectorial adaptation. Involving stakeholders from the different sectors that are sensitive to seasonal changes, especially agriculture and tourism, in the process seems essential since they are key actors in the local implementation of adaptation.

6.4 Temperature rise (air and water) for primary activities, tourism and, to some extent, territorial planning

In the Gulf, agriculture is perceived to be impacted by climate change both inland through the effect on the timing of crop harvest (D1.1), and in seawater through the effect of warming that is damaging the production of oysters (D1.2). Since tourism benefits from the local production of oysters (D1.2), climate change may also indirectly affect tourism in this way, as well as directly with rising air temperatures[49].

- **Climate services, knowledge gaps, missing formats, challenges for communication of climate change on local scale, and options for co-development / improvement of sustainable local climate services**

Many climate services address changes in surface air temperature annually and by season (Climat HD, IA[50]), some even monthly (CCKP, DRIAS), but fewer address the

[47] e.g. http://www.drias-climat.fr/decouverte/carte/experience/vignettes?domaine=SAFRAN&isDonneesImpact=false&generation=rcp
[48] Such as (not exhaustive list): heatwaves, cold spells, dry spells, heavy rainfall events, storms, floods
[49] As well as an increase in heatwaves and dry spells in summer
[50] https://www.eea.europa.eu/data-and-maps/indicators/global-and-european-temperature-9/assessment

warming of surface water. For instance, IA gives information about the water temperature of European seas[51], rivers and lakes[52], so does Copernicus about lakes[53], but this is not very relevant for the information need at the scale of the Gulf since inhabitants are interested in the warming of the local bodies of water, especially the natural harbour. Regarding the surface air warming, the evaluation activity indicated that Climat HD and DRIAS might provide sufficient information (scale, temporal, spatial, multi-model and multi-scenario uncertainty), and this information is also largely complemented by CCKP and IA.

Therefore, we focus here on the warming of surface water in the Gulf, for which we did not find a climate service. We found five sources of information in the literature examining the evolution of surface water temperature in the proximity (off the coast) of the Gulf: a paper (L'Hévéder et al., 2017), two regional assessment reports, and two IPCC reports. The IPCC AR5[54] (Stocker et al., 2013) indicates an observed past warming in the coastal region near the Gulf[55], which is projected to continue in the future[56], as does the paper from L'Hévéder. The IPCC SROCC[57] (Collins et al., 2019) indicates that marines heatwaves will become more probable in the future for that region[58]. The assessment report for climate change in Morbihan (ODEM, 2012) suggests that the warming of marine seawater might damage the quality of the coastal environment, with more frequent eutrophication events. Taken together, this scientific knowledge about the warming of surface waters is interesting but might not be sufficient to address the social question focusing on the natural harbour, corresponding to very local scale information. This conclusion is also supported by the lack of long observation time series that are local (Roussel, 2012).

All these elements suggest that climate services (and the literature) sufficiently cover the topic of surface air warming but not of surface water warming for the Gulf of Morbihan. Therefore, the lack (or near absence) of information about surface water

[51] https://www.eea.europa.eu/data-and-maps/indicators/sea-surface-temperature-3/assessment
[52] https://www.eea.europa.eu/data-and-maps/indicators/water-temperature-2/assessment
[53] https://climate.copernicus.eu/lake-surface-temperatures
[54] Fifth assessment report
[55] Figure SPM.1 (page 22/1552)
[56] Figure SPM.8 (page 38/1552)
[57] Special Report on the Ocean and Cryosphere in a Changing Climate
[58] Figure 6.4 (page 21/68)

warming might constitute a scientific knowledge gap, a missing format of climate service (unavailable information), and a challenge for communication of climate change at local scale (unavailable knowledge). However, this might also constitute an opportunity for research and for a new climate service, where a co-development process (including detailed information need) with decision-makers such as workers in aquaculture (oyster farming is directly impacted by the warming of the water in the natural harbour; D1.2), could essentially guide the relevant studies in support of adaptation.

6.5 Rainfall changes for agriculture

Tourism is a key activity in the Gulf but it can compete with agriculture for the use of water resource in summer such as between drinking and irrigation (D1.3). This increases the importance of rainfall for agriculture in summer to avoid a high risk of freshwater shortage (D1.3). However, too much summer rainfall is detrimental for salt production since it reduces crystallization shortly before the time of harvest (D1.2).

- **Climate services, knowledge gaps, missing formats, challenges for communication of climate change on local scale, and options for co-development / improvement of sustainable local climate services**

Climate services cover information about annual and seasonal rainfall (Climat HD, IA[59]), some even monthly (CCKP, DRIAS), as well as droughts[60], soil moisture[61], crop water demand[62], and river flow[63]. For Brittany, Climat HD indicates that cumulated summer rainfall increased a little in the last decades (low confidence) and will not change much in the next decades, combined with a decrease of soil humidity in the future. DRIAS and IA give information at the scale of the Gulf. DRIAS indicates that cumulated summer rainfall will decrease, and the number of consecutive dry days will increase, over the long-term future. IA indicates that droughts are happening

[59] https://www.eea.europa.eu/data-and-maps/indicators/european-precipitation-2/assessment and https://www.eea.europa.eu/data-and-maps/indicators/precipitation-extremes-in-europe-3/assessment-1
[60] https://www.eea.europa.eu/data-and-maps/indicators/river-flow-drought-2/assessment
[61] https://www.eea.europa.eu/data-and-maps/indicators/water-retention-4/assessment
[62] https://www.eea.europa.eu/data-and-maps/indicators/water-requirement-2/assessment
[63] https://www.eea.europa.eu/data-and-maps/indicators/river-flow-3/assessment

more frequently and becoming more severe in the recent past, and their future frequency is projected to increase. IA also indicates that the annual river flow increased in the recent past, but that the minimum flow level is projected to decrease while the water volume deficit is projected to increase. IA shows an increase in summer heavy precipitation in the recent past, which is projected to continue in the future. CCKP indicates drier conditions for the region of the Gulf, an increase in the probability of droughts, a decrease in precipitation from April to June, and an increase in maximum daily rainfall from November to February.

Overall, the information suggests that summers in the Gulf will become drier (air, soil), with less cumulated rainfall over the season, although extreme rainfall will slightly increase. The different climate services provide more quantification. In conclusion, for the topic of rainfall changes for agriculture, the information from the climate services could be sufficient to answer the questions from local stakeholders, and we do not identify evident knowledge gaps, missing formats, or challenges for communication of climate change on local scale. This conclusion is also supported by the results from the evaluation activity (Meinke et al., 2019). Nevertheless, we emphasize here that the projection of future seasonal precipitation in climate models is attached to large uncertainties, and even contradicting trends sometimes between different projections (see chapter 4.4.2 for more details). From a WP3 perspective we see one possible option for improvement through the integration of the information presented above in a single service targeted for decision-makers, including a co-development process to identify the vulnerability and exposure of their activities (agriculture in this case) to these changes in climate for adaptation. However, it is not clear if the scattering of climate information is a limitation for decision-makers, and hence whether this option of improvement would benefit action towards adaptation.

6.6 Attribution of weather changes to climate change (outside natural variability)

Inhabitants of the Gulf are noticing changes in the weather but in many cases the link to climate change is not clear (D1.1, D1.2, D1.3). This is especially the case with coastal destruction from storms (D1.1, D1.2), but also for drier summers, more frequent winter rains, and agriculture (D1.1, D1.2, D1.3). Understanding the local effects of climate change on the weather of the Gulf is important for adaptation, since the range of variability of the changing local climate might exceed that of natural variability for which human (and natural) systems are (mostly) prepared.

- **Climate services, knowledge gaps, missing formats, challenges for communication of climate change on local scale, and options for co-development / improvement of sustainable local climate services**

There are two different ways to do detection and attribution (D&A) of climate change: on long-term trends and on individual extreme events (Otto, 2017). Long-term trends can be found in any climate variable (e.g. surface temperature) but their attribution to climate change is when natural (modes of) variability alone cannot explain these trends, and human factors[64] are shown to play a role, usually by comparing simulations of a model representing the real world (factual: natural and human factors) to simulations of a model representing the natural world (counterfactual; Stocker et al., 2013). This is also one of the three ways extreme event D&A is done, called the risk-based approach, by comparing the probability of occurrence (or magnitude, or length) of a given event in both worlds (Otto, 2017). The two other ways are the analysis of causal factors leading to the occurrence of the event, and circulation-based approaches. The first aims to determine the individual contribution of causal factors by how much they can predict the occurrence of the event in simulations of different counterfactual worlds. The second aims to assess whether a change in the likelihood of an event occurring is due to warming (thermodynamics) or to changes in the atmospheric circulation (dynamics), such as through analogues (i.e. similar atmospheric situations of the past) by using the method of factual and counterfactual worlds (Otto, 2017). More details about D&A methodologies and results are available in Bindoff et al. (2013).

The climate services that we found for D&A are:

- Climat HD, CCKP, DRIAS, and IA, in a broad sense of a multi-scenario D&A rather than according to the strict definition (and usual methodology) of D&A

[64] Such as (not exhaustive list): anthropogenic greenhouse gases, land-use change, aerosols

- the World Weather Attribution[65] from Climate Central which covers 2014-2016
- the Attribution[66] platform from CarbonBrief which covers 2011-2018
- the Extremoscope[67] platform on Drias which covers 2013-2017
- the Flyingpigeon[68] tool (Hempelmann et al., 2018) which targets expert users (involving coding).
- extensive literature (Allen et al., 2018 ; Chen et al., 2018 ; Cramer et al., 2014 ; Jia et al., 2019 ; Sippel et al., 2020 ; Stocker et al., 2013)

Although these services essentially do not cover extreme events since 2018, the development of operational D&A is a challenging but ongoing project in the community of climate science and services (Stott et al., 2016). As a result, for some extreme events D&A findings become available in the following weeks or months through research papers (e.g. van Oldenborgh et al., 2020) and then sometimes become disseminated more broadly through the media. For complementary details about D&A of climate change, refer to chapter 4.2.2.

Based on the current situation and on the evaluation activity (Meinke et al., 2019), we do not identify supplementary knowledge gaps or missing formats in addition to those discussed earlier (storms, drier summers, more frequent winter rain, phenology). However, from a WP3 perspective, we see a possible challenge in the communication of climate change on local scale regarding D&A since both local-scale and large-scale factors influence long-term trends and extreme weather events.

7 Kerourien in Brest (Florentin Breton)

The discussion of the feasibility of local climate services for the case study of Kerourien in Brest relies on the previous activities and deliverables from WP1 (D1.1, D1.2, D1.3), WP2 (D2.1) and WP3 (D3.1, D3.2). . For each topic of interest from the case study, we present the local issue or question, describe the most relevant climate services addressing it, discuss the gaps, limitations, and challenges that emerge from the situation, and consider options for overcoming these shortcomings.

[65] https://www.climatecentral.org/go/wwa
[66] https://www.carbonbrief.org/mapped-how-climate-change-affects-extreme-weather-around-the-world
[67] http://www.drias-climat.fr/accompagnement/section/213
[68] https://github.com/bird-house/flyingpigeon

We emphasize here that for most of the topics, as the details of the local issue are very limited, it is often unclear whether the available knowledge from the services and literature are sufficient to address the local issue, which restricts our ability to deduce limitations of the current knowledge and options for improvement. Additionally, we do not yet have access to the results of the WP2 scenario activities for Kerourien. Nevertheless, the description (in D2.1) of climate-related and non-related things than can be controlled or not controlled locally is very useful here.

7.1 Housing, urbanization, and physical safety in a changing climate context

Climate change was not considered when building the local infrastructure, including homes, and could contribute to squalor in the buildings that are inappropriately insulated (D1.1, D1.2, D1.3, Meinke et al., 2019).

- **Climate services, knowledge gaps, missing formats, challenges for communication of climate change on local scale, and options for co-development / improvement of sustainable local climate services**

Future weather conditions are addressed by both weather services and climate services on different time scales. Météo-France[69] and Météo-Bretagne[70] give forecasts of the weather situation from today to the next two weeks. Copernicus provides forecasts of weather conditions ranging from the next weeks[71] to the next months[72], and the ECMWF[73,74] for the next 15 days[75], 30 days[76], and 3 months[77]. Other climate services inform about future longer-term (next years and decades) changes in the climate (Climat HD[78], DRIAS[79], IA[80]). While these sources represent a

[69] http://www.meteofrance.com/previsions-meteo-france/brest/29200
[70] https://www.meteo.bzh/previsions/ville/Brest-29200
[71] https://effis.jrc.ec.europa.eu/applications/monthly-forecast/
[72] https://effis.jrc.ec.europa.eu/applications/seasonal-forecast/ and https://climate.copernicus.eu/charts/c3s_seasonal/
[73] European Center for Medium Range Forecasts
[74] https://www.ecmwf.int/en/forecasts
[75] https://www.ecmwf.int/en/forecasts/charts/catalogue/?facets=Range,Medium%20(15%20days)
[76] https://www.ecmwf.int/en/forecasts/charts/catalogue/?facets=Range,Extended%20(30%20days)
[77] https://www.ecmwf.int/en/forecasts/charts/catalogue/?facets=Range,Long%20(Months)&time=2020020100,744,2020030300&stats=tsum
[78] http://www.meteofrance.fr/climat-passe-et-futur/climathd
[79] http://www.drias-climat.fr/

lot of information, the details of the information needed by the local case study are very limited, so it is unclear for us whether all this information is sufficient to address the local issue. Therefore, it is difficult in this case to deduce limitations of the current services and options for improvement.

7.2 Water management and coastal risks

Sea level rise is a threat to the current coastal infrastructure, including the water management system, and there could be an impact of pollution by seawater on the access to drinkable water (Meinke et al., 2019).

- **Climate services, knowledge gaps, missing formats, challenges for communication of climate change on local scale, and options for co-development / improvement of sustainable local climate services**

As the discussion about sea level rise for Kerourien in Brest revolves around essentially the same points as in the case of the Gulf of Morbihan earlier in D3.3, we refer here to that discussion regarding the current limitations and options for improvement of current climate services, and regarding the possibility of new local services.

7.3 Planning of renewable energy

Local decision-makers might be interested in the planning of renewable energies in the territory, including the collection of solar energy (Meinke et al., 2019).

- **Climate services, knowledge gaps, missing formats, challenges for communication of climate change on local scale, and options for co-development / improvement of sustainable local climate services**

Regarding wind and solar (renewable) energies, the most relevant climate variables might be near-surface wind direction and speed, as well as sunshine duration and surface solar radiation (Jerez et al., 2015). This information might be relevant for local planning under the form of forecasts (next weeks and months) and projections (next years and decades) at the finest scale possible (e.g. hourly and kilometre).

[80] https://www.eea.europa.eu/data-and-maps/indicators#c0=30&c12-operator=or&b_start=0&c12=climate-change-adaptation

As described above in D3.3 for Kerourien, weather services give information about the weather conditions from today to the next weeks and months (Météo-France, Météo-Bretagne, Copernicus, ECMWF), and climate services for the next years and decades (Climat HD, DRIAS, IA). However, this information does not include the solar and wind conditions in all cases. Météo-France gives one local measure of wind direction and speed (supposedly average and maximum) per three hours[81], and Météo-Bretagne one per part of the day (night, morning, afternoon, evening)[82]. Météo-France also describes the duration of sunshine per day and per month over the last ten years[83] (individual values, and climatological mean). The ECMWF website has maps of surface solar radiation[84] but at coarse spatial and time scales. The EUMETSAT[85] website has a lot of data[86] and online tools[87] covering wind conditions and solar radiation but they might be difficult to use for non-experts. There also are a few private providers of climate services that can provide interesting observation. The WAQI[88] monitors and forecasts local wind speed at a few locations in Brest[89]. The SODA[90] website offers maps of well-resolved radiation data over Europe[91], including the possibility to get local forecast data[92]. Two other private providers offer more user-friendly information[93]. Although their information does not cover the area of Brest, they could collaborate with Brest local decision-makers regarding the planning of solar energy. There is also the possibility to conduct local-scale simulations (as in e.g. Pryor et al., 2020) to study the expected wind power generation based on the spatiotemporal variability of the weather and associated wind turbine operating conditions (e.g. extreme wind speeds).

[81] http://www.meteofrance.com/previsions-meteo-france/brest/29200
[82] https://www.meteo.bzh/previsions/ville/Brest-29200
[83] http://www.meteofrance.com/climat/france/brest/29075001/normales
[84] https://www.ecmwf.int/en/forecasts/charts/obstat/?facets=Parameter,All%20sky%20radiances&time=2020030500&Satellite=METOP-A&Channel=1&Area=Northern%20Mid-Latitudes&Flag=All
[85] European Organisation for the Exploitation of Meteorological Satellites
[86] https://www.eumetsat.int/website/home/Data/Products/Atmosphere/index.html#Wind and https://www.eumetsat.int/website/home/Data/Products/Atmosphere/index.html#Radiation and
[87] https://www.cmsaf.eu/EN/Products/Tools/Tools_node.html
[88] World air quality index
[89] https://aqicn.org/city/france/bretagne/brest/jean-mace/
[90] Solar radiation data (http://www.soda-pro.com/contact)
[91] http://www.soda-pro.com/help/cams-services/cams-radiation-service/download-europe-volume
[92] http://www.soda-pro.com/web-services/radiation/helioclim-3-real-time-and-forecast
[93] https://montoitsolaire.noveltis.fr/toulouse/ and https://simulateur.insunwetrust.solar/simulateur

To conclude about the planning of renewable energy in Kerourien (Brest), the situation is similar to the discussion on housing and urbanization in the context of climate change, i.e. we do not know if the information available from climate service providers is sufficient to address the local issue, which restricts our ability to deduce limitations of the current services and options for improvement.

7.4 Air quality and ship traffic

The local air quality seems to be impacted by pollution from particles emitted by the traffic of ships nearby (Meinke et al., 2019).

- **Climate services, knowledge gaps, missing formats, challenges for communication of climate change on local scale, and options for co-development / improvement of sustainable local climate services**

The two most relevant climate services that we found for observing and forecasting the local air quality in Kerourien are Copernicus[94] and WAQI[95]. Copernicus provides information about the regional and large-scale context of atmospheric circulation and daily air quality[96] (mean and maximum concentrations), whereas WAQI gives very local information on weather conditions and air quality[97]. The information available from these two services is very complementary between large- and local-scale, and might be sufficient to address the local issue. However, since we cannot know this for sure, and since the details of the information needed by local decision-makers in the case study are very limited, it is not possible at this stage to derive limitations and options for improvement.

8 Conclusion

The feasibility discussion gave insights in challenges for communicating climate change on local scales. Limitations from the scientific and climate service providers'

[94] https://www.regional.atmosphere.copernicus.eu/ and http://macc-raq-op.meteo.fr/index.php?category=ensemble&subensemble=hourly_ensemble&date=LAST&calculation-model=ENSEMBLE&species=o3&level=SFC&offset=000
[95] World air quality index, https://aqicn.org/city/france/bretagne/brest/jean-mace/
[96] O3, CO, SO2, NO2, PM10, PM2.5, PM from wildfire, pollens, dust
[97] 03, NO2, PM10, PM2.5

perspectives have been identified. Moreover, options for the (co-) development / improvement of sustainable local climate service have been discussed and documented.

Challenges for communicating climate change on local scales vary between the different case study sites. This might be due to the different approaches of the evaluation and feasibility studies, resulting from the heterogeneous material available from the WP 1 and 2 basis. Overall, communicating climate change on local scales faces one joint challenge in all case study sites: In many instances, local specific information needs could not be specified. However, the reasons vary among the study sites: For instance, when the local matters of concerns, questions, or information needs from the local case study sites were not explicit, difficult to derive, or not detailed, the discussion of the feasibility of local climate services was inherently limited. As starting point for the feasibility discussion, this local basis was sometimes lacking of hints regarding additional local specific stakeholder information needs and communication formats beyond the already existing climate service formats. Moreover, a stronger local contextualization of existing formats was only possible when we could gain in depth insight from the stakeholder's demands or interviewees' perceptions (climate-related personal concerns). Therefore, there are instances where it is unknown from the perspective of the feasibility discussion whether local specific information needs could have been localized within a direct stakeholder dialogue or if these needs do not exist. When the identification of the climate-related personal concerns of the interviewees was possible, cognitive schemes were discussed in this feasibility study, which may enable local climate service providers to further contextualize existing climate information to local conditions. However, evidence on additional local specific information needs was difficult to find based on the social narratives and stakeholder workshops. One reason could be that neither the narratives (WP1) nor the scenario design and development (WP2) were meant to relate their research to stakeholder's expectations and needs with regard to local climate information.

Moreover, better understanding the context of the results in WP1 and WP2 relies on knowing the national language as well as the local knowledge (local familiarity). If this prerequisite of local familiarity is missing, it is very difficult for a climate service provider to contextualize climate information locally, or to initialize a stakeholder dialogue on local climate change. Beside the reasons discussed above, which may be improved by an adapted design of future projects, another reason that local specific climate information needs could not be specified was that they explicitly don’t exist. On one hand because stakeholders did not identify any information need, and on the other hand because missing information was not the reason for missing action.

Several limitations and gaps from the perspective of climate research have been identified. For instance, the inherent uncertainty of regional climate scenarios due to the multi-model, multi-scenario approach can be encountered in practice by no regret adaptation strategies. These no-regret strategies could be co-developed within a science-stakeholder dialogue, initialized or accompanied by a local climate service. In parallel, an ongoing monitoring of the main critical parameters (physical and social) needs to be established. Within a long-term science stakeholder dialog, the adaptation strategies could be adjusted according to the insights of the monitoring. Among the generally requested increased spatial resolution of regional climate scenarios, there is a particular demand of regional sea level rise projections, since rising sea levels are a joint threat for all case study sites. Moreover, current and future adaptation strategies need to be considered to estimate exposure and vulnerability with regard to sea level (see chapter 3.2, 4.3.1, 6.1 and 7.2). Many web tools exist, showing flooded areas at varying amounts of sea level rise (e.g.: https://www.floodmap.net/, https://ss2.climatecentral.org, https://www.climate.gov/maps-data/dataset/sea-level-rise-map-viewer). However, none of them is accounting for the existing coastal protection measures or future coastal adaptation strategies of the respective areas. The Northern German Coastal and Climate Office has developed a web-tool, showing the present and possible future coastal protection need (www.kuestenschutzbedarf.de). With this information, the areas, which are currently protected against high water levels, can be localized and the need of future coastal protection can be identified. Besides accounting for regional coastal protection measures, there is a research need on future local socio-economic scenarios as this is the major driver of increasing risks to human settlements in the next decades. In order to estimate future vulnerability due to sea level rise on local scales, these physical, technical and socioeconomic aspects have to be available, accounted for and combined within a local climate service in order to provide adequate local climate information formats.

Another joint aspect of relevant climate information is changes within seasons, including extreme events (see 3.1., 4.4, 5.1, 6.3). Using seasons as a cognitive scheme (since they present an essential point in local contextualization), has already been applied as approach for several web-tools, e.g. www.norddeutscher-klimamonitor.de (recent climate change & variability, Meinke et al. 2014) and www.norddeutscher-klimaatlas.de (possible future climate change, Meinke et al. 2009). From the physical climate perspective, seasonal climate change is localised as far as possible, here. However, these web-tools could be enhanced by various aspects of seasonal climate change impacts if related research would be available. Future scenarios on ecosystem service interactions as well as the impact of seasonal changes on health, social, economic, and cultural aspects of society are the identified research gaps, here. For the latter, the collection of narratives and scenario workshops as applied in WP1 and 2 could be a suitable approach if a specific focus would be set on changes in seasons and if relevant stakeholder groups (agriculture, tourism, health) would be systematically involved. Beside information on long-term changes within seasons, seasonal predictability is subject of discussion among stakeholders, especially within agricultural sectors. Much stronger than within long-term scenarios of regional climate change, uncertainties within (medium range) seasonal predictions reduces their usability significantly since no regret options are rare and explicit mid-term decisions need to be taken. Beside, reducing the uncertainty, one of the central challenges of seasonal forecasting is to communicate its quality and reliability. Although the forecast system (and the experts) can easily determine how likely its statements are it is difficult for laypersons to interpret the results.

Additionally to challenges and limitations described above, some overarching options for the (co-) development and improvement of sustainable local climate service have become evident. The Co-Cli-Serv approach clearly showed that the co-development of a local climate service has some prerequisites. These are the knowledge of the respective national language, familiarity with the particular local circumstances and most importantly, the direct stakeholder dialogue with regard to climate change, related action and supporting information. Rather than having separated work packages, focussing on single disciplines in social science, (physical) climate research and art representation formats, joint integrative work packages, focussing on specific case study sites, each, are a promising approach for co-development and transdisciplinary work. The science-stakeholder workshop in the Jade Bay case study, accounting for the narratives of WP1 and the physical science basis of WP3 is a promising co-development approach in this regard. The direct interaction of the regional climate service provider (here the Northern German Coastal- and Climate Office) with local stakeholders in the Jade Bay region enabled an extensive analyses of the dialogue which was directly related to climate change in that region. Through the personal participation of the climate service provider in these stakeholder interactions, aspects of action and thinking became observable that were comparatively inaccessible in the project reports and other literature in social science on these interactions. As the feasibility discussion shows, this format of a science-stakeholder workshop allows for a contextualization of specific climate change related aspects discussed, regarding further development of a local climate service. Even though a local climate service has the objective to directly refer to local stakeholders' demands, the freedom of its orientation might also be narrowed down by its hosting institution. Thus, a transdisciplinary research-based arena for climate communication and dissemination linked to local meeting places might be promising for dialogues and co-operation across various sectors in society.

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