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Data driven climate change adaptation Part A: Advancing future multi-sectorial climate services by mapping current usage and demand

Final scientific report of the 2020 National Centre for Climate Research Work Package 3.1.1, Data-driven climate service (part A)

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DMI report WP311 - Data driven climate change adaptation Part A: Advancing future multi-sectorial climate services by mapping current usage and demand

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DMI Report

15 January 2021

By Morten Andreas Dahl Larsen (DTU), Giorgios Karamitilios (DTU), Kirsten Halsnæs (DTU), Jun She (DMI) and Kristine Skovgaard Madsen (DMI)

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1 Abstract (ENG)

Denmark has decided to reduce its GHG emissions by 70% compared to 1990 levels by 2030, which will imply changes to technologies, economic activities and behaviour. Alongside this, climate change remains a pressing issue, requiring climate information to be integrated into current and future planned activities in order to promote effective risk-coping strategies. This study maps the current use and future demands of data and services regarding climate and weather across spatiotemporal scales as a background to understanding how more targeted and thus more efficient climate services can be developed and employed, including upscaling and wider sectoral dissemination. A key to this process is better understanding of the needs of current and potential new climate service-users. Based on a survey, we investigate how existing and potential climate service-users express their need for new data, products, services and tools within the Danish Realm, including Greenland, the Faroe Islands and the Danish Oceans. The survey was distributed to existing customers of the Danish Meteorological Institute (DMI) through personal networks and to 31,181 entry points in the Danish Business Register forming an extensive representation within Denmark. The focal sectors include agriculture, energy (including supply), and research and consultancy regarding climate issues. Key results indicate moderate differences in data characteristics between current users of climate services depending on their type of organization and sector, the low demand for future climate services compared to their current use by respondents and, finally and crucially, trust in suppliers' reliability.

2 Resume (DK)

Der er en politisk målsætning om en nedskæring af drivhusgasudledninger med 70% pr 2030, i f.h.t. 1990, hvilket vil kræve ændringer i brugen af teknologier, økonomiske aktiviteter og adfærd. Sideløbende er klimaændringer et presserende emne som kræver at klimainformation og data integreres i planlægningsprocesser for at mindske relaterede risici. Dette studie kortlægger den både den nuværende brug samt efterspørgsel af data og tjenester indenfor vejr og klima og på tværs af rumlige og temporale skalaer for at adressere hvordan fremtidige klimatjenester kan udvikles og initieres på optimal vis. Baseret på et spørgeskema er brugen af, samt behovet for nye, data, produkter og tjenester undersøgt inden for Danmark, inkl. Grønland og Færøerne, samt dertilhørende oceaner. Spørgeskemaet blev distribueret til eksisterende kunder hos DMI, igennem faglige netværk samt igennem 31.181 kontakt-oplysninger fundet igennem CVR-registret, og det har derved en stærk repræsentation inden Danmark. Fokussektorerne inkluderer landbrug, forskning og konsulentbranchen inden for klimaspørgsmål samt energi og forsyning. Resultaterne viser moderate forskelle i brugen af, og behovet for, data og tjenester imellem forskellige grupperinger af brugere, et lavt fremtidigt behov for nye tjenester sammenlignet med det nuværende brug samt, endeligt, et fælles ønske om troværdighed fra klimatjeneste-udbyderen.

3 Appendix 1 (pre-print journal paper)

Advancing future multi-sectorial climate services by mapping current usage and demand

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Abstract

Denmark has decided to reduce its GHG emissions by 70% compared to 1990 levels by 2030, which will imply changes to technologies, economic activities and behaviour. Alongside this, climate change remains a pressing issue, requiring climate information to be integrated into current and future planned activities in order to promote effective risk-coping strategies. This study maps the current use and future demands of data and services regarding climate and weather across spatiotemporal scales as a background to understanding how more targeted and thus more efficient climate services can be developed and employed, including upscaling and wider sectoral dissemination. A key to this process is better understanding of the needs of current and potential new climate service-users. Based on a survey, we investigate how existing and potential climate service-users express their need for new data, products, services and tools within the Danish Realm, including Greenland, the Faroe Islands and the Danish Oceans. The survey was distributed to existing customers of the Danish Meteorological Institute (DMI) through personal networks and to 31,181 entry points in the Danish Business Register forming an extensive representation within Denmark. The focal sectors include agriculture, energy (including supply), and research and consultancy regarding climate issues. Key results indicate moderate differences in data characteristics between current users of climate services depending on their type of organization and sector, the low demand for future climate services compared to their current use by respondents and, finally and crucially, trust in suppliers' reliability.

Keywords

Climate Services; Climate Data; Future Climate Service Demands; User Survey; Climate Service Users and Providers; Climate Change.

Key Messages

1. Climate service needs vary across organizations and sectors
2. Organizations generally do not expect to create their own climate services
3. Key future demands for climate services include trust in the providers, followed by free data
4. Local data are generally preferred across survey respondents
5. Tailored and specialised products prevail among paying users as opposed to users of free data
6. Climate projections are particularly in demand from public administration and research

1. Introduction

Climate change will have impacts on society globally and across all sectors (IPCC, 2014a). To meet the impacts of climate change, mitigation efforts cannot work alone: risk management and climate adaptation are needed to help curb these climate change-related impacts (IPCC, 2014b, 2014c). As a consequence, climate-change adaptation and management are currently being recognized and implemented by a wide range of governments and private-sector actors

(Bowyer et al., 2015; Tart et al., 2020), Climate change poses several risks for companies, citizens, investors and financial stability in general, increasing the demand for information to support climate-change mitigation and adaptation (Arent et al., 2014; Battiston et al., 2017; Brunsmeier and Groth, 2015; Carney, 2015; CDP, 2018, 2017; Halsnæs et al., 2020; Sakhel, 2017; UN Global Compact, 2015). However, there is currently a gap between potentially useful climate information and information which has been developed and is actually being used (Halsnæs et al., 2020). For example, 90% of companies reportedly faced negative climate-related impacts in the past three years, only 30% of which have actively responded to them (Amado and Adams, 2012).

The trend is also increasing with regard municipalities pursuing climate action plans (Halsnæs et al., 2020). As a consequence of climate-change risks, adaptation in response is driving a demand for access to weather and climate-related information from companies and governments across scales (Cane, 2010; Parry et al., 2007). Climate information is necessary to support decision-making both regionally and locally, especially for managing vulnerability and adaptation to climate change (Brasseur and Gallardo, 2016; Martinez et al., 2010). End-users, such as researchers, consultants, policy-makers, NGOs, the general public and the media, can use data and knowledge from climate services to support and inform decisions (Manez et al., 2013). As also highlighted in the literature review below, the climate-service market is rapidly evolving and has seen a rise in its number of users recently (Halsnæs et al., 2020; Lourenço et al., 2016), although with substantial cross-sector differences (Bruno Soares et al., 2018; Tart et al., 2020). However, there is a general consensus that vast challenges still exist in using climate services optimally, challenges that need to be addressed to improve adaptation, mitigation and general business models (Bruno Soares and Buontempo, 2019).

The potential usefulness of climate data in coping with risk have, in recent decades, resulted in the development of a range of so-called climate-service initiatives, including new platforms, institutions and research, with the aim of helping wide-scale applications of climate information (Copernicus, 2020; GFCS, 2020; Hoa et al., 2018; WMO, 2011). To some extent, national weather services and/or governmental portals also have their own climate services, as in Germany (KLIVO, 2020), Sweden (SMHI, 2020) and Denmark (DMI, 2020a). Climate-service products include basic climate data, climate-change scenarios and projections, vulnerability studies, socio-economic indicators related to climate change, and climate-change education and training (Brasseur and Gallardo, 2016; JPI Climate, 2011a; WMO, 2011).

Terms like “climate data” and “climate services” have a number of definitions, which to some extent differ from each other (Goransson and Rummukainen, 2014). Thus, to avoid misunderstandings in the study and questionnaire, climate services are defined as physical climate and weather information prepared and delivered to meet users’ needs (Abu Zeid et al., 2011; European Commission, 2015). Climate data will reflect sufficient time-frames, consistency and continuity as a basis for assessing variability and change (Drobot et al., 2004). Lastly, observational data is information derived from in-situ measurements in the atmosphere, on land and in the oceans, while model data is defined as data derived from simulations using mathematical and numerical models (Meier zu verl and Horstmann, 2011).

Climate services are distributed both through commercial markets and as open-source data. Their distribution is expected to evolve in the near future, as more investments are made and climate-change impacts become ever-clearer (Halsnæs et al., 2020; Lourenço et al., 2016; Tart et al., 2020). A key point for current and new services and products is the availability of information about their assumptions, limitations and uncertainties seen from a user perspective (Manez et al., 2013). Given the gap between users and suppliers currently in the climate services market, climate services have been strongly recommended to include a strong component of user requirements and targeted climate-impact data for both users and decision-making support (Brasseur and Gallardo, 2016; Bruno Soares et al., 2018; Bruno Soares and

Buontempo, 2019; European Commission, 2017; Giannini et al., 2016; Hoa et al., 2018; JPI Climate, 2011a). Further dissemination of climate services is required, as is understanding the barriers they face, including a lack of economic incentives, financial and human resources, and the availability of high-quality scientific information at a level of geographical detail that is relevant to users (Brasseur and Gallardo, 2016; Tart et al., 2020).

Economic sectors affected directly by the impacts of extreme weather and climate, such as the building and tourism sector, have very specific demands for climate services (Tart et al., 2020). However, climate services for sectors like these two are limited in comparison to sectors such as agriculture and food security, disaster-risk reduction, energy, health and water, all of which have more accessible information about the applications of climate services and their potential disadvantages. The Global Framework for Climate Services (GFCS) treats these sectors as a high priority , particularly in developing countries (GFCS, 2020). Nonetheless, the impacts of climate change can be seen across several, if not all, economic sectors, leading to a broader range of industries using climate services for multiple purposes (Tart et al., 2020).

The current study is part of an overall effort by the Danish government to promote the green transition in Denmark, where free access to climate, weather and ocean data and the services of the Danish Meteorological Institute (DMI , a part of the Danish Ministry of Climate, Energy and Utilities) is regarded as integral to promoting innovation and green growth; e.g. climate change information is in high demand by Danish municipalities (Madsen et al., 2019). DMI provides meteorological and ocean data and services across a range of scales and sub-disciplines, including observational data, forecasts, climate projections, sea-level data, etc. The online hubs for free data include (DMI, 2020a, b) and (Kortforsyningen, 2020) from the same Ministry. As mentioned previously, the notion of climate-service information extends to socioeconomic information However, this goes beyond DMI's scope, so the needs addressed by the survey could in practice go beyond this to involve partnerships with other providers.

The specific aim of this paper is to highlight current uses of climate, weather and ocean data and services across scales and usages originating from DMI, as well as assess the demand for new climate services by current and potential new users. As an end goal, suggestions for new products and climate services are suggested. First, we analyse the use of DMI data and products by its current customers. Secondly, we present the results of an online survey designed with the specific research questions in mind: current usage, current demand and suggested trends for new climate services. The survey was meticulously distributed through different channels: 1) the existing DMI customer database; 2) Danish municipalities; 3) the authors' extended research networks; 4) networks of climate-adaptation professionals (DANCORE, 2020; DNNK, 2020); and 5) the Danish Central Business Register (DCBR; Danish CVR). The latter included 31,181 contact points in the private and public sectors selected from relevant categories/sub-categories in the study's focus areas, namely agriculture, energy (including supply) and climate adaptation. These sectors were chosen for their potential links to climate data and services. Aggregated and anonymous data are available upon request to the authors. To the knowledge of the authors, this study forms one of the most extensive surveys, with regards to relative distribution and participation, within the topic of climate services and is therefore a valuable contribution to the field.

As a consequence of the climate-change risks outlined above, the need for adaptation is driving a demand for access to weather and climate-related information from companies and governments across scales (Cane, 2010; Parry et al., 2007). Climate information is necessary for decision-making support both regionally and locally, especially for managing vulnerability and adaptation to climate change (Brasseur and Gallardo, 2016; Martinez et al., 2010). End-users, such as researchers, consultants, policy-makers, NGOs, the general public and the media, can use data and knowledge from climate services to support and inform decisions (Manez et al., 2013). As noted below, the climate-service market is rapidly evolving and has seen a rise in users recently (Halsnæs et al., 2020; Lourenço et al., 2016), although with substantial cross-sector differences (Bruno Soares et al., 2018; Tart et al., 2020). However, there is a general consensus that vast challenges still exist in the optimal use of climate services and that these challenges need to be addressed to improve adaptation, mitigation and general business models (Bruno Soares and Buontempo, 2019).

Local governments also play an important role in climate-change adaptation, but local authorities have only recently had access to better quality climate data and been able to find understandable and useful scientific information, thanks to considerable governmental investments in research and science (Porter et al., 2015).

2. Literature review

Here we review the literature on climate-service user needs in relation to our major survey questions: categories of climate-service information requested, standardized and tailor-made information, uncertainties, the quality of climate services, and communication and interaction between providers and climate-service users. Of these studies, there was a clear focus on Europe, especially Germany, Sweden, Netherlands and Finland, including in combination, as well as some international studies (Goransson and Rummukainen, 2014; Heidenreich et al., 2013; Manez et al., 2013; Martinez et al., 2010; Räsänen et al., 2017; Tart et al., 2020).

Climate services offer various sources of information. In the Netherlands, organizations provide mostly processed data like graphics and maps, while in Sweden, climate service providers offer data and guidance workshops or similar activities and synthesis reports or other knowledge reviews (Goransson and Rummukainen, 2014). Although none of these general climate-service products are tailor-made for users, municipalities demand context-specific data. Those municipalities that are relatively advanced in climate-risk management also need support from experts and networks (Räsänen et al., 2017). Conversely, less advanced municipalities require information on how to use climate services and the economic benefits of using them in reducing risks (Räsänen et al., 2017).

(Tart et al., 2020), based on stakeholder interviews, conclude that many climate-services users regard past observational data as more reliable than projected future data. Specifically, the majority of users were interested in historical data or processed data for shorter future time horizons, while also responding that climate data for future projections exhibit high uncertainties. Stakeholder perspectives, assessed by (Manez et al., 2013), indicate a demand for information about changes, consequences, probabilities, and the range of possible climate-related outcomes.

Studies also show that users generally demand climate-projection data to be reliable, usable as inputs for the tools they use, easily applicable, and easily understandable by non-scientists, an obvious challenge due to the inherent assumptions and limitations related to downscaled climate information as opposed to, e.g., a weather forecast (Brasseur and Gallardo, 2016; Heidenreich et al., 2013). Similarly, (Martinez et al., 2010) identified a need for climate-service providers to distinguish clearly between observational data and data derived from climate models at seasonal, decadal and multi-decadal scales.

The uncertainties inherent in climate-change projections embedded in climate-service products as used, e.g., in adaptation projects can be highlighted by, e.g., stakeholders being able to access and download climate observations and data from selected regional climate models via a graphical user interface (Heidenreich et al., 2013). Regarding web services and interfaces, interoperability was seen as a main criterion to support optimal operability and accommodate the wide range of climate-service needs across sectors and individual users (Giuliani et al., 2017). (Bruno Soares et al., 2018) came to a similar conclusion, based on an online survey showing the need for shared formats following the continuous penetration of climate services across sectors, causing some fragmentation of products. Guidelines for using climate-projection data should provide an overview of the uncertainties connected with climate projections and explain how to work with collections of climate data (Heidenreich et al., 2013; Otto et al., 2016). In general, uncertainties inherent in the specific product should be transparent and dynamically updated when assessing various information layers that support decision-making frameworks (Otto et al., 2016). Finally, climate-service providers could declare the shared and similar data forcings and assumptions to be used for climate analyses in other sectors (Heidenreich et al., 2013).

Apart from data types, good communication between climate-service providers and users is essential (Krauß, 2020; Otto et al., 2016; Porter and Dessai, 2017), as highlighted by questionnaire results indicating communication and networking between providers and users and among themselves to be a main field of interest (Manez et al., 2013). A study conducted in the Netherlands and Sweden showed that 80-90 % of communication between providers and users was through direct contact (presentation of results, workshops, or similar) (Goransson and Rummukainen, 2014). Users can often access climate services directly through computer databases, data-sharing, or face-to-face advice, as well as networking, print media and the internet (JPI Climate, 2011b; Manez et al., 2013; WMO, 2011). Networking and communication between providers (but not between providers and users) is generally found to be sufficient, although some target groups have limited success for sector-specific reasons (Manez et al., 2013). The current success with including climate services in specific business plans is generally limited because of what is seen as a marginal and undefined market (Brasseur and Gallardo, 2016; Vaughan et al., 2018). Other studies suggest that the interface and communication between providers and users is the least developed aspect of climate services (Hewitt et al., 2017).

To penetrate the climate-service market successfully, providers are have been further advised to include diverse staffing across disciplines and topics (Brasseur and Gallardo, 2016; Goddard, 2016; Porter and Dessai, 2017) and conduct capacity-building (Tart et al., 2020). In Germany, results show that in climate-service use by municipalities, the communication strategy should consist of web-based platforms and face-to-face communication (Manez et al., 2013). Intensive two-way communication and information exchange between providers and users is highlighted in order to find practical adaptation solutions and, specifically, climate-services providers (Giannini et al., 2016; Heidenreich et al., 2013; Prades-Tena et al., 2020).

Users also highlight the importance of the quality of the products they use (Manez et al., 2013), this being rated second in importance. However, assessing the quality of individual climate services for end-users is very difficult, especially when information on data, methods and uncertainties is inadequate or lacking (Manez et al., 2013). Hence, climate services could be more transparent if providers labelled the quality of the data they offer so users can distinguish between services with good and suboptimal quality (Manez, Zolch, and Cortekar 2013). Nevertheless, one study conducted among climate-service users globally shows that the market seems to be meeting some users' needs, a number of survey participants stating that they had found a suitable provider (Tart et al., 2020).

Within the scientific research community, climate services are currently used to accommodate transdisciplinary studies and very specialized and/or localized information, the need to maintain and develop climate data and associated services being emphasized (Vaughan et al., 2016).

3. Methods

The aim of this study is to acquire an understanding of the existing use of DMI weather, climate and ocean data by organizations and companies, in Denmark and internationally, with a focus on the agriculture, energy/supply and adaptations sectors, and including the corresponding demands for potential future data and climate services.

As an entry point, the demand for and use of weather and climate information was assessed by first summarizing existing knowledge from specific similar studies (section 2). Secondly, a dataset of DMI's existing customers was used to assess current use of climate, weather and ocean data (section 3.1). Furthermore, an online survey of current usage and future needs was administered to existing DMI customers, Danish municipalities, the authors' own extended networks and organizations on the DCBR website (section 3.2).

3.1. Current DMI customers

This analysis assessed a dataset created from the DMI customer repository containing a catalogue of 107 paid DMI products and a list of 294 organizations and companies with full-year commercial contracts in 2020. This list includes some companies with two entries referring to different departments. The dataset contains information about the customers, like company number, company location, description of the service, branch of the company and notation, and information about its products, like title, price, variables, product type and service type. Customers with irregular contracts are not included in the dataset.

3.2. Survey

Our online survey was divided into three parts and distributed through a URL link based on SurveyXact software (SurveyXact, 2020). The first part (Figure 1, Part A) asked for the respondent's background information, such as organization type, size, sector and primary role. The second part (Figure 1, Part B) focused on current use of weather, climate, or ocean data, the questions directed only to responders that use data. If climate data or services were not used currently, the respondent was led directly to the third part (Figure 1, Part C) asking for information about unmet needs and challenges in using weather, climate, or ocean data from DMI or other sources. Hence, data on daily weather forecasts and climate projections decades ahead were included. Figure 1 provides a complete overview of the survey.

A total of 29 questions were included, although not all were relevant to all respondents, depending on their answers. The survey was distributed in both Danish and English, which the respondent could select. In developing the questionnaire, inspiration was from drawn from previous similar studies in both peer-reviewed journals and grey literature (Alexander et al., 2016; Bruno Soares et al., 2018; Goransson and Rummukainen, 2014; Kox et al., 2015; Maddern and Jenner, 2010; Manez et al., 2013; Navarro-Rivera and Kosmin, 2013; Porter and Dessai, 2017; Räsänen et al., 2017; Tart et al., 2018, 2020).

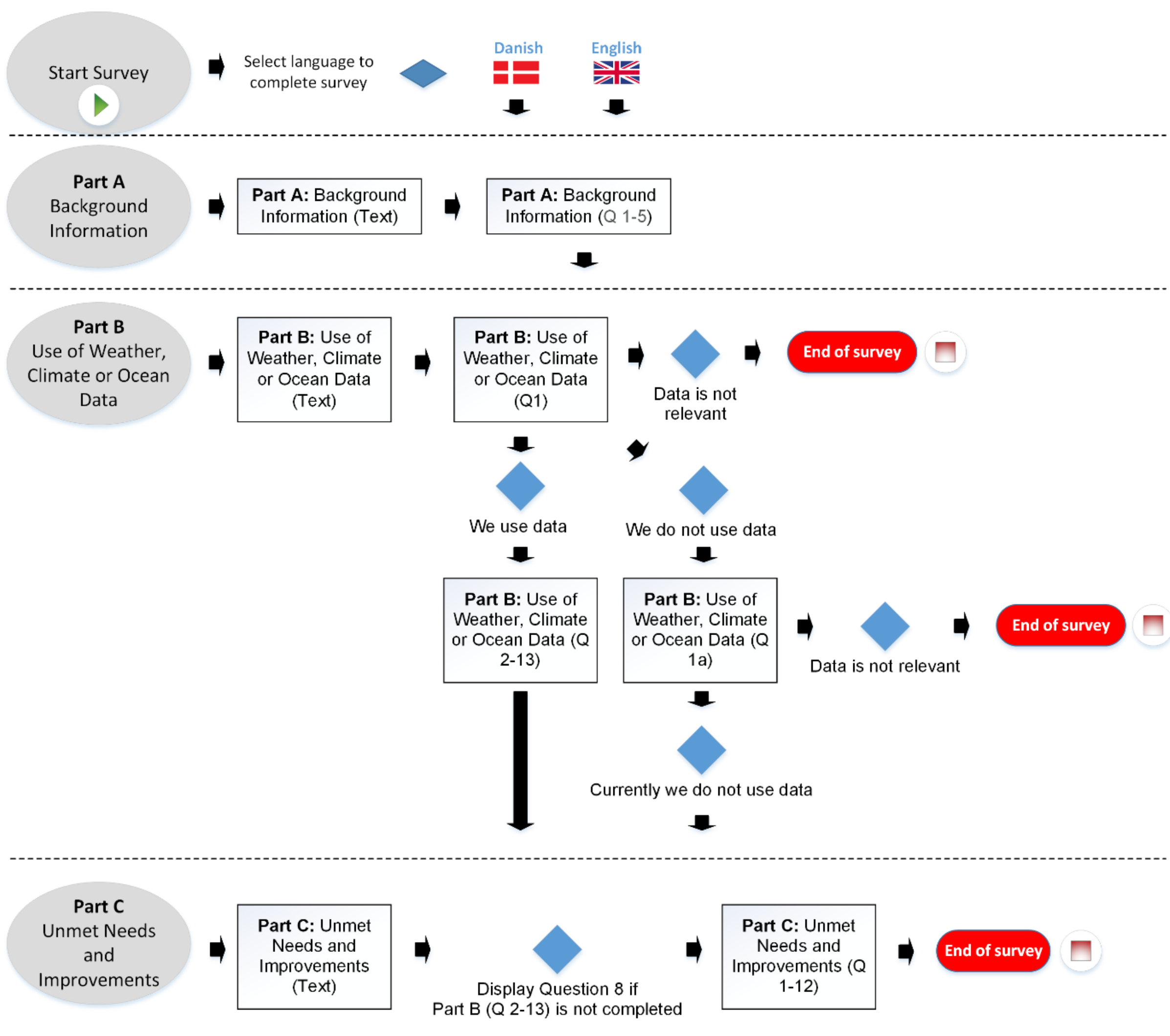


Figure 1. Survey design for this study. For a complete overview of the questions, see Appendix A.

The questionnaire (See Appendix A) was distributed through a range of channels:

a) Existing DMI customers as extracted from the DMI customer repository (294 customers contacted).
b) All municipalities in Denmark (98 municipalities contacted).
c) Companies selected from the CVR registry (CVR - Det Centrale Danske Virksomhedsregister, 2020), which has information on all companies in Denmark, categorized according to the International Standard Industrial Classification of All Economic Activities (United Nations Statistical Division, 2008), and through contact information. From this registry, the companies listed in specific categories in agriculture (including forestry and fisheries), energy (including supply), climate and water-related consultancy, management and research were selected (see Appendix B, table B1). In total, 31,181 companies were contacted.
d) The authors' own extended networks of cross-disciplinary researchers on climate, hydrology, weather and DMI customer relations in Denmark through personal emails, LinkedIn (open for sharing) (LinkedIn, 2020) and the professional networks of the (Danish) National Network for Climate Adaptation (DNNK, 2020) and Dancore (DANCORE, 2020). For all of these, the first contact was urged to redistribute the survey to extended networks by email or social media (LinkedIn). The total number of contacts through this channel is obviously unknown.

All contributions were kept anonymous. The results were analysed using R (R, 2020).

4. Results

4.1. DMI customers

Currently, DMI offers 107 different products for its customers in Denmark and globally (Figure 2a), including consultation and services, raw-, calculated-, customized- and gridded- data, graphics, reports, forecasts and climate projections. In 2020, DMI had 294 contract (i.e. paying) customers, including company sub-branches, many in different sectors. Most customers use DMI data in the fields of transportation and energy (Figure 2b), far fewer customers being in sectors like water, agriculture and fisheries, the environment, financial services and insurance, or climate adaptation. DMI's current customers (in 2020) are mostly in Denmark, but some are located abroad (Figure 2c). Within Denmark, the majority of DMI's clients are in Greater Copenhagen and eastern Jutland (Figure 4d). DMI's data are mostly distributed to its customers via an FTP account. The most common product is in-situ data from DMI weather stations in Denmark, followed by short-term atmospheric weather forecasts in Denmark delivered from the HARMONIE weather model (DMI, 2020c), subscriptions services for monitoring activities in Denmark and longer-term atmospheric forecasts (globally or for Denmark) from the European Centre for Medium-Range Weather Forecasts (ECMWF).

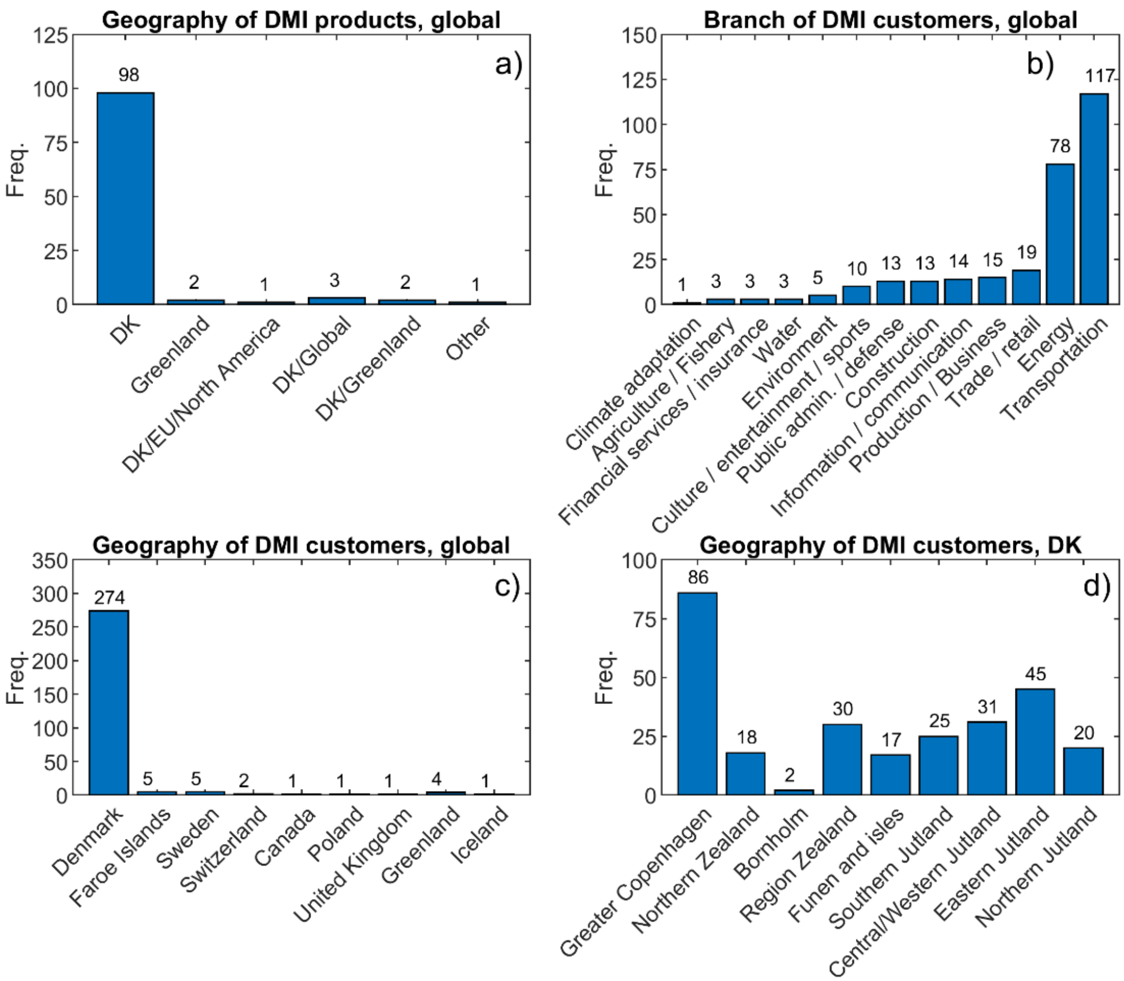


Figure 2. Geography of DMI products, customers in Denmark, and global and contract customers by branch.

4.2 – Survey results

The survey contained both close-ended questions, where respondents have a limited set of possible answers, and open-ended questions, where they provide a free-form answer. Free-form answers are only selectable when the option “other” is selected. Multiple answers are possible. There were 882 responders to the survey, of which 305 answered only partially, averaging a completion rate of 65.5%.

The survey results have been processed using two separate analytical steps:

a) The first step addresses all answers in combination and provides a combined overview (See section 3.2.1.). This analysis is referred to as "*Non-Filter*". Results for free and paying use are shown separately.
b) The second step categorizes the results based on specific responses in order to filter preferences and responses based on specific characteristics of interest to this analysis (see section 3.2.2.). This categorization is made by type of organization (question no. 1.1.), sector (question no. 1.2.), whether using paid or free data (question no. 2.1.), the data type used and from which sources (question no. 2.2.), the tailored data products used (question no. 2.8.) and the benefits gained from using weather, climate or ocean data (question no. 2.9.). This analysis is referred to as "*Filter*".

Specifically, this division enables extraction of information at different levels of aggregation. Questions are referred to as "Qx.x" for the Non-Filter analysis and "Qx.xF" for the Filter analysis.

4.2.1. Non-Filter survey results

The Non-Filter survey results in Figure 3 show a vast majority of the replies coming from private companies (71%, Q1.1). Small companies with one to ten employees make up 75% of total users (Q1.3). For sectorial users, agriculture, forestry and the fishing sector have the largest share (32.4%), followed by construction (9.0%), professional, scientific and technical activities (8.5%), water supply, sewerage and waste management (6.8%) and energy (6.6%) (Q1.2). Geographically, companies' activities are at both subnational and national scales in Denmark (Q1.4), and the most common data category is free weather, climate or ocean data (Q2.1). Moreover, only 56 respondents (882 total replies) state that such data are not relevant to their organization's activities (Q2.1a).

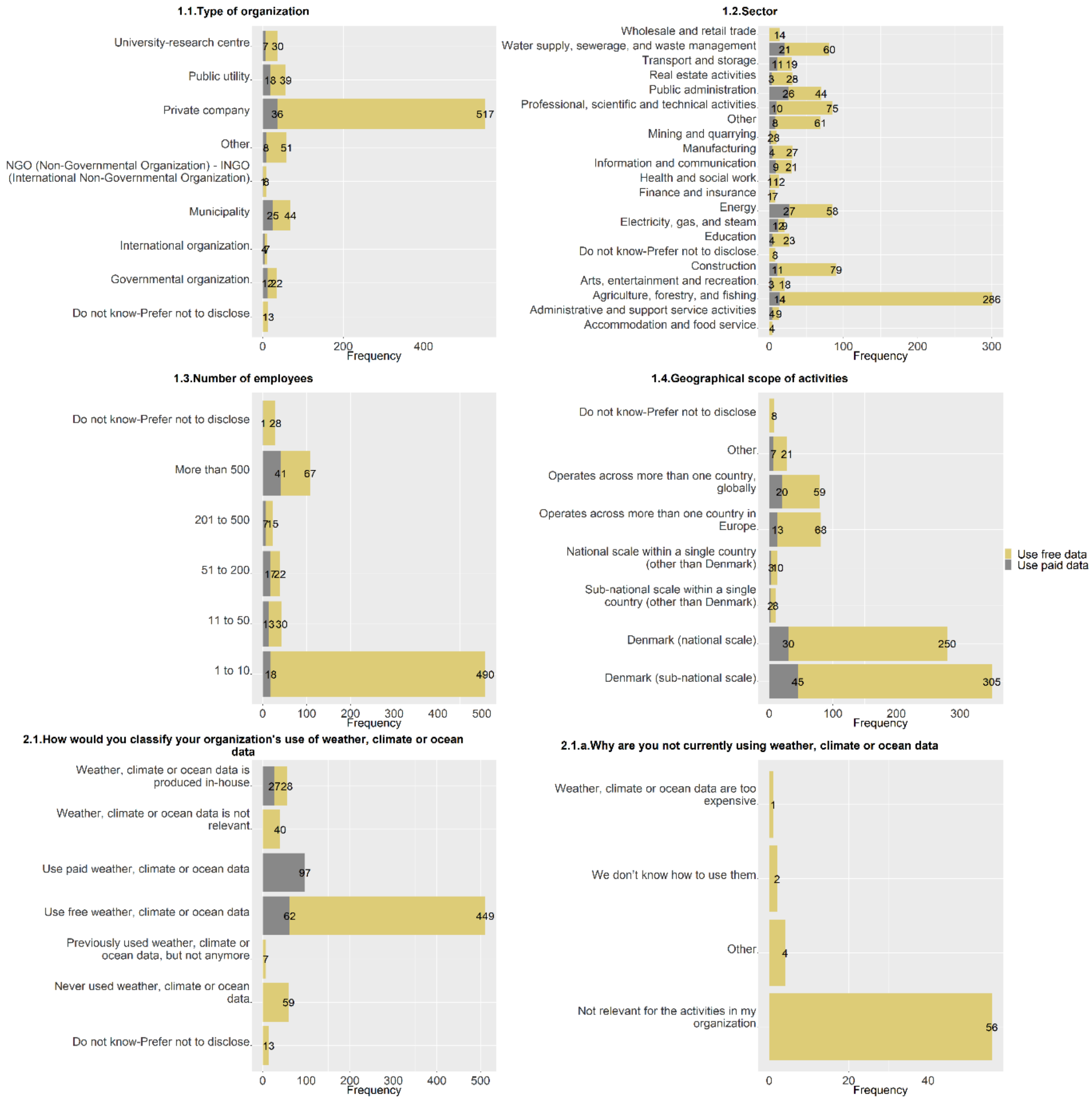
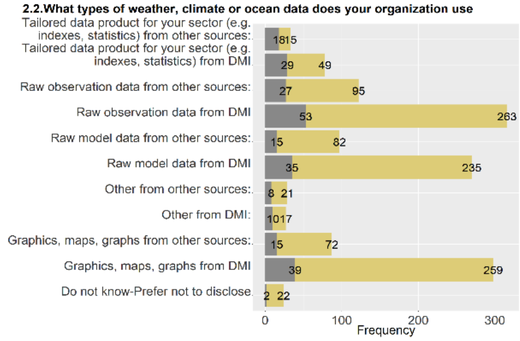


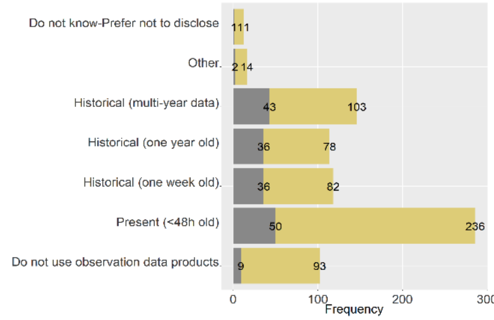
Figure 3. Survey responses to questions 1.2, 1.3, 1.4, 2.1 and 2.1a for the Non-Filter analysis.

The most common type of data used by the survey respondents (Q2.2) is raw observation (36%), followed by graphics, maps, graphs (34%) and raw model data from DMI (31%) etc. Fewer organizations (7.7%) use tailored data products. whether from DMI or from other resources. As for other data sources, common responses include SCALGO (SCALGO, 2020) and YR (YR, 2020) (Q2.2). These companies tend more to use data close to the present (<48 h) from observational data (32%) and short-term forecast (days-weeks) from model data (43%), referencing local or regional spatial scales (Q2.3, Q2.4 and Q2.5). A fair number of organizations also use historical multi-year data (17%) (Q2.3). For observational data, precipitation is most common, (45%), followed by winds (speed/direction) (41%) and near-surface air temperature (33%) (Q2.6). Thirty percent of respondents stated that they do not use tailored data, and of those that do, data on mostly precipitation and wind climatology-statistics-indexes and degree-days are used (Q2.8). The benefits of the data are cited as support for operational decisions and risk management (38% and 22% respectively) (Q2.9). Data access occurs most often via the DMI website (41%) or direct computer/database access (24%) (Q2.10). Most of these organizations have been using weather, climate and/or ocean data on a daily basis for more than ten years and do not intend to develop their own climate services (Q2.11, Q2.12 and Q2.13). Thirty respondents stated that they already have their own climate services, and nineteen replied that they are considering creating them in the future (Figure 4).

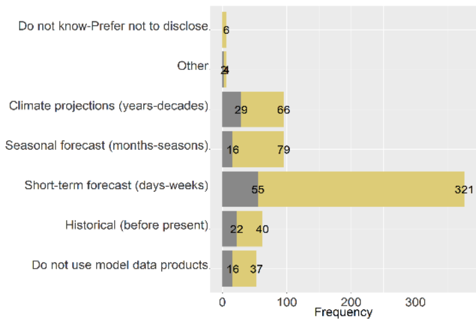
2.2.What types of weather, climate or ocean data does your organization use



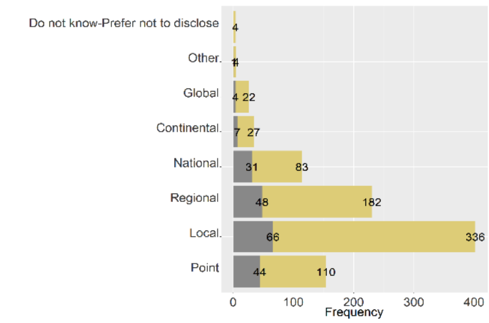
2.3.What is the time horizon of the observation data you use



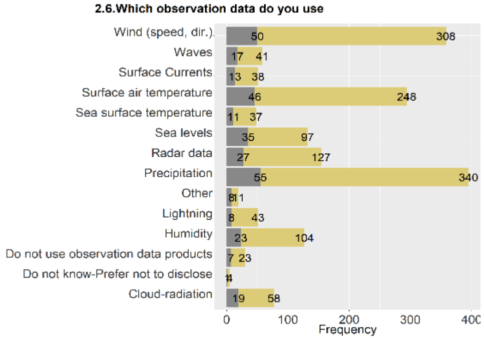
2.4.What is the time horizon of the model data you use



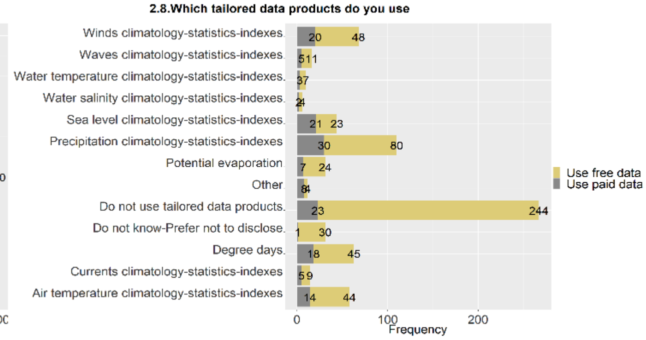
2.5.What is the spatial scale of the weather, climate or ocean data you use



2.6.Which observation data do you use

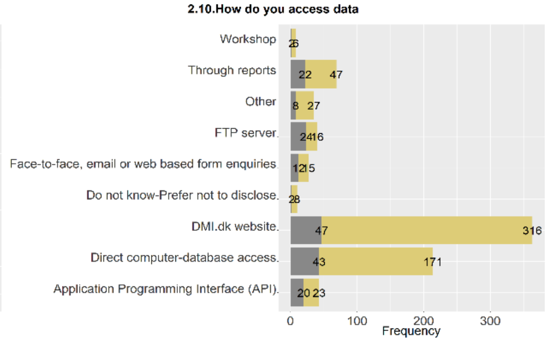


2.8.Which tailored data products do you use

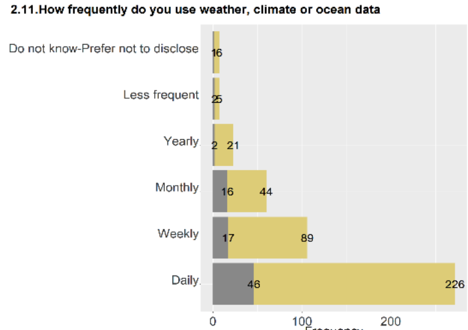


2.9.What are the benefits of using weather, climate or ocean data in your organization

2.10.How do you access data



2.11.How frequently do you use weather, climate or ocean data



2.12.For how long has your organization used weather, climate or ocean data

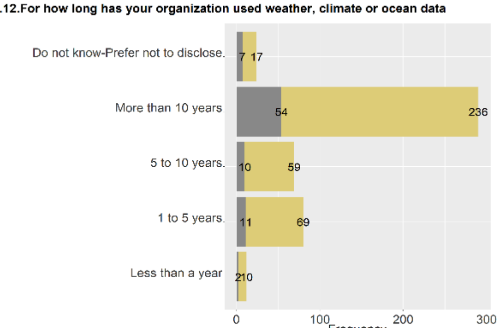
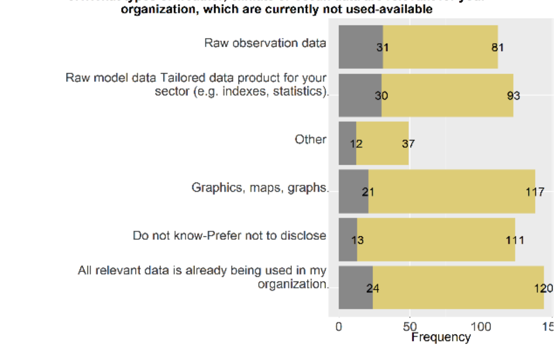


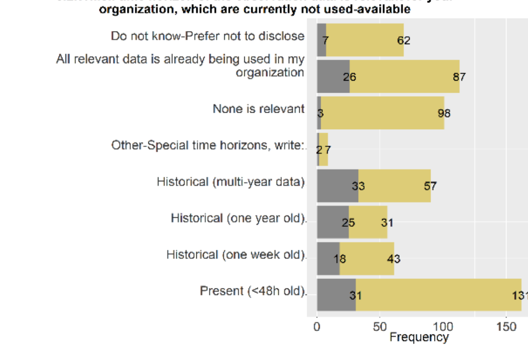
Figure 4. Survey responses to questions 2.2, 2.3, 2.4, 2.5, 2.6, 2.8, 2.9, 2.10, 2.11 and 2.12 for the Non-Filter analysis.

Part C of the survey aimed at highlighting needs that are currently not being met by available climate services and products. From this survey section, 144 respondents (16%) state that all relevant types of weather, climate or ocean data are already being used, 138 (16%) respondents identify a need for graphics, maps and graphs, 123 respondents (14%) require more model data, sectorial tailored data and information products, and 83 (9%) demand more raw observational data (Q3.1). Across organizations, local-to-regional spatial scales are the main requirement, whereas present-scale observational data (<48h old), short-term forecast data (<48 h) and medium-term model data (>48 h and <14 days) are the dominant temporal scales in demand. Across organizations, the demand for point-to-local-to-regional spatial scales predominates (Q3.4). Regarding the types of observational and model data demanded in the future, although 18-19% of respondents state that all relevant data is already used in their organizations, there are still high levels of demand for precipitation, winds and air temperature data. About 12% of respondents indicate additional needs for ocean data (waves, currents, water temperature and salinity and sea levels - Q3.5 and Q3.6). Regarding the demand for tailored data products, 189 respondents state that they need more, 83 already have sufficient, and 117 do not use them (Q3.7). Most respondents found that the optimal way of accessing data is via free websites (28%) or direct computer/database (27%) (Q3.8). The key issue regarding the general demand for future data products is the need for trust (39%), followed by the availability of free data (34%) (Q3.9). This implies that user confidence in the service provider is the most important factor. As for improvements to the data that could made, the two main replies are “to make processed data available” (11%) and “to have a better web-based interface" (9%) (Q3.10). Some of the repliers using the "other" option state that they are interested in receiving the data via mobile applications (Figure 5).

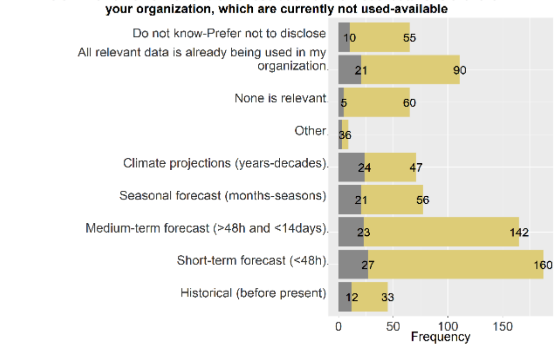
3.1.What types of weather, climate or ocean data are relevant for your organization, which are currently not used-available



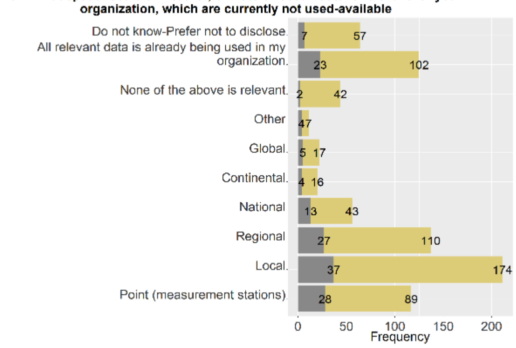
3.2.Which time horizon of the observation data is relevant for your organization, which are currently not used-available



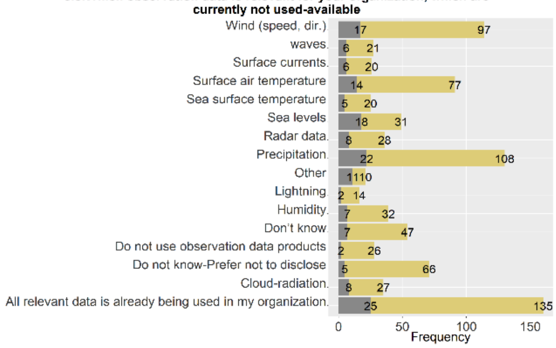
3.3.Which time horizon and time resolution of the model data is relevant for your organization, which are currently not used-available



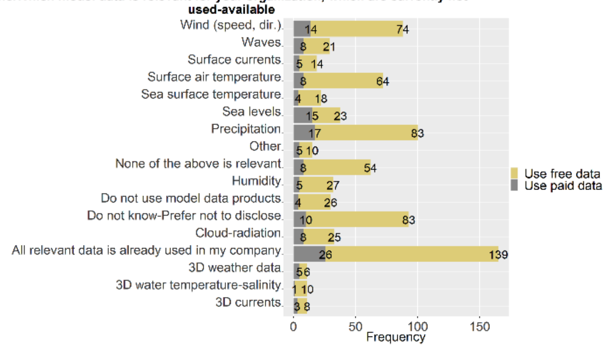
3.4.What spatial scale of weather, climate or ocean data is relevant for your organization, which are currently not used-available



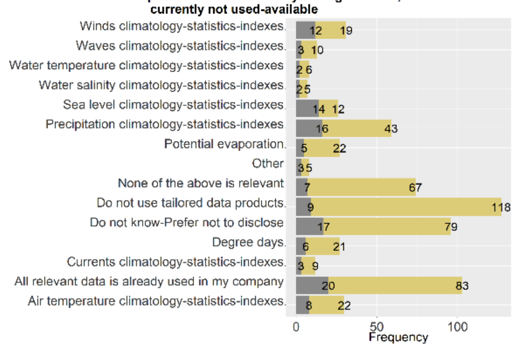
3.5.Which observation data is relevant for your organization, which are currently not used-available



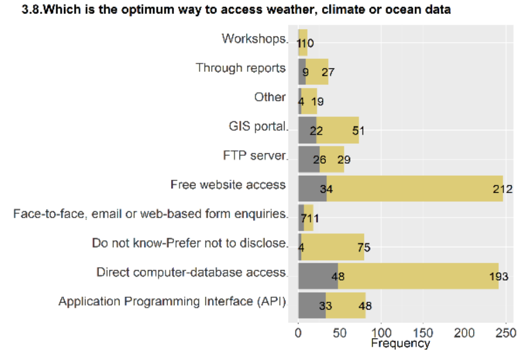
3.6.Which model data is relevant for your organization, which are currently not used-available



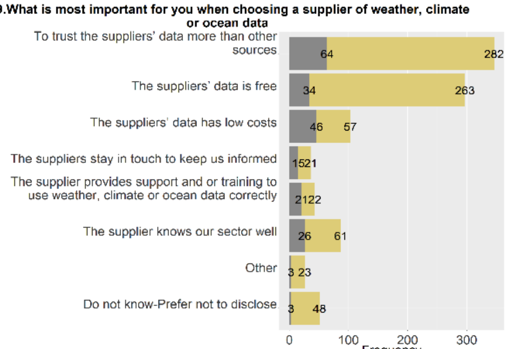
3.7.Which tailored data products is relevant for your organization, which are currently not used-available



3.8.Which is the optimum way to access weather, climate or ocean data



3.9.What is most important for you when choosing a supplier of weather, climate or ocean data



3.10.How can available weather, climate or ocean data be improved

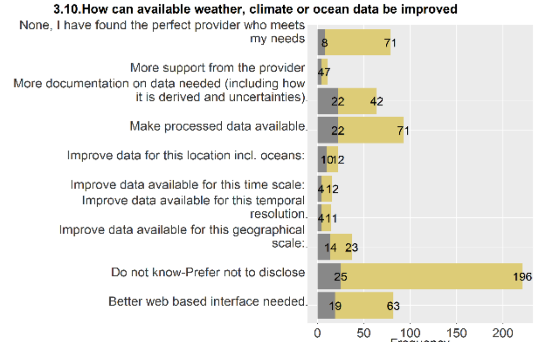


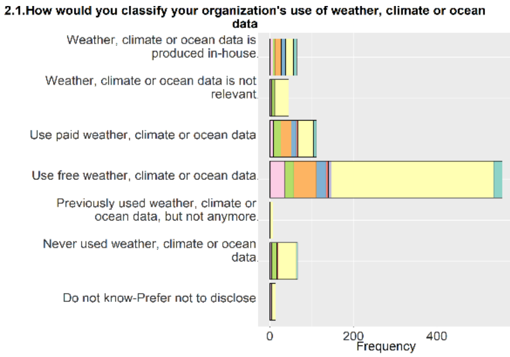
Figure 5. Survey responses to questions 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9 and 3.10 for the Non-Filter analysis.

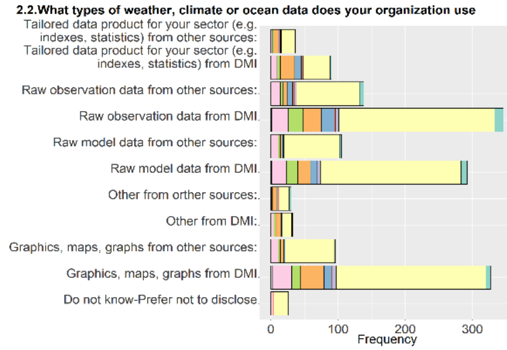
4.2.2. – Filter survey results

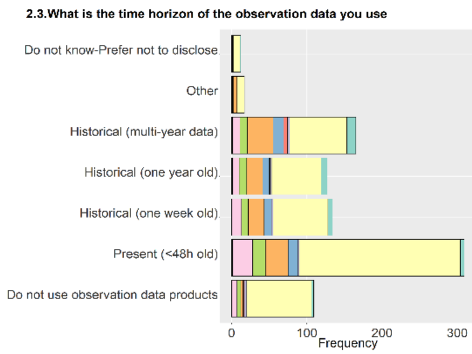
This analysis, entitled "filtering", processes and visualizes selected key questions, each response then being further sub-divided based on a previous question. This is done in order to distinguish different response patterns based on certain characteristics of the respondent. As a function, the coloured visualizations are dominated by the answer, or answers, receiving the most responses in the question through which they are filtered. A key to extracting systematic differences in the Filter analysis is therefore to assess relative differences between responses. The main results are summarized in Appendix C, tables 2C, 3C and 4C.

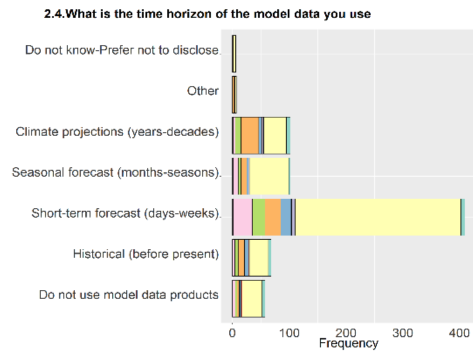
Type of organization

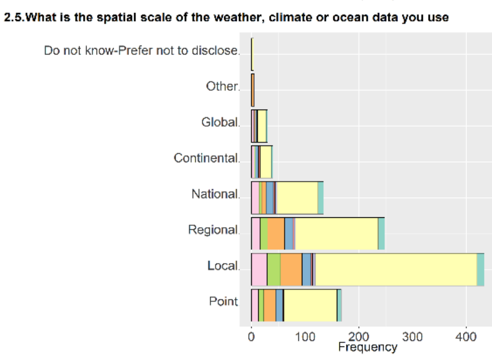
For this filter analysis, responses to questions are processed and visualized according to the responses in Q1.1 (organization type) (Figures 6 and 7). The results show that private companies mainly acquire free data (70%), whereas municipalities, utility companies and government organizations have a relatively greater tendency to use paid data (Q2.1F). These results show that Danish municipalities use mostly graphics, maps and graphs from DMI (51%) (Q2.2F). They use climate projections (45%) and more often precipitation and sea-level observational, model and tailored data (Q2.4F, Q2.6F, Q2.7F and Q2.8F), mostly for climate-change adaptation (48%) (Q2.9F), and in comparison to other organizations they use the data weekly or monthly (Q2.11F). They need more climate projections (years/decades) (25%) than short-term forecast (<48 h) (22%) model data (Q3.3F). An optimum way for municipalities to access data could also be a GIS portal (32%) (Q3.8F). As with universities and research centres, even though municipalities mostly use free data, approximately 20% produce their own weather, climate or ocean data (Q2.1F). Their main requirement is for historical (multi-year and one-year-old) observational data (Q2.3F and Q3.2F) and climate projections from model data (Q2.4F and Q3.3F), as well as data on national (19%) and regional (19%) scales for Denmark (19%) (Q2.5F). Furthermore, almost 30% of government organizations use tailored data (Q2.2F), more specifically data on precipitation (32%), wind (speed and direction) (29%) and surface air temperature (21%) climatology/statistics/indexes (Q2.8F). They consider the optimum way of accessing data to be through direct computer database (44%), followed by GIS portal (21%) and the Application Programming Interface (API) (21%) (Q3.8F). They also state that the available data can be improved by having a better web-based interface (24%) (Q3.10F). There is also a greater degree of interest in raw model and tailored data products from public utilities organizations compared with other types (19%) (Q3.1F).

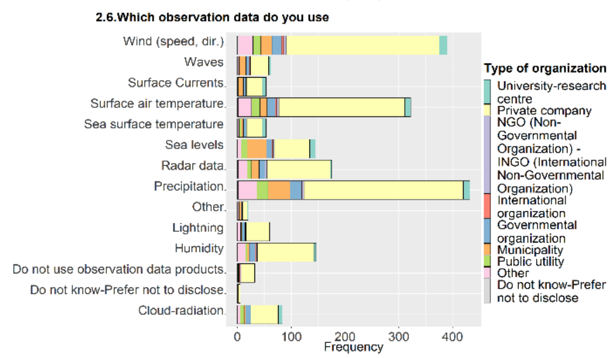

2.1.How would you classify your organization's use of weather, climate or ocean data
Weather, climate or ocean data is produced in-house
Weather, climate or ocean data is not relevant
Use paid weather, climate or ocean data
Use free weather, climate or ocean data
Previously used weather, climate or ocean data, but not anymore
Never used weather, climate or ocean data
Do not know-Prefer not to disclose
0
200
400
Frequency

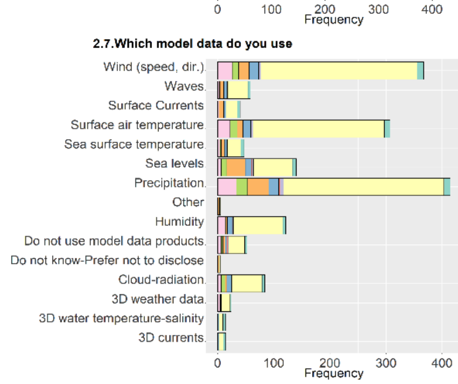

2.2.What types of weather, climate or ocean data does your organization use
Tailored data product for your sector (e.g. indexes, statistics) from other sources:
Tailored data product for your sector (e.g. indexes, statistics) from DMI
Raw observation data from other sources:
Raw observation data from DMI
Raw model data from other sources:
Raw model data from DMI
Other from orther sources:
Other from DMI:
Graphics, maps, graphs from other sources:
Graphics, maps, graphs from DMI
Do not know-Prefer not to disclose
0
100
200
300
Frequency

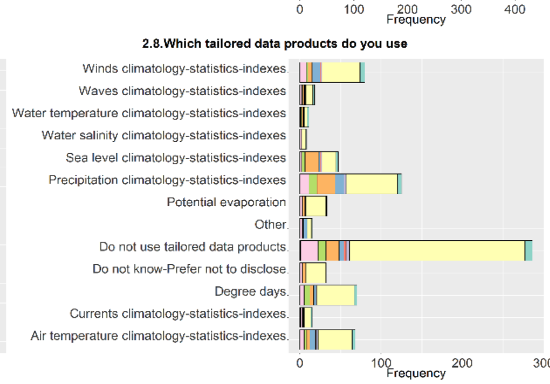

2.3.What is the time horizon of the observation data you use
Do not know-Prefer not to disclose
Other
Historical (multi-year data)
Historical (one year old)
Historical (one week old)
Present (<48h old)
Do not use observation data products
0
100
200
300
Frequency

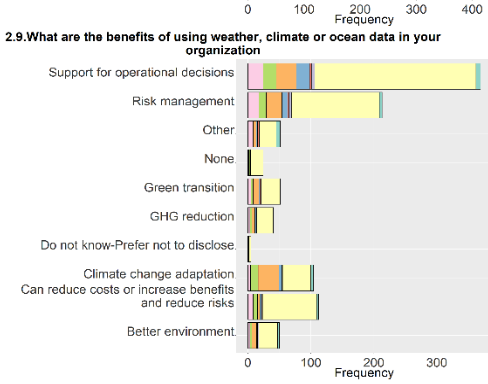

2.4.What is the time horizon of the model data you use
Do not know-Prefer not to disclose
Other
Climate projections (years-decades)
Seasonal forecast (months-seasons)
Short-term forecast (days-weeks)
Historical (before present)
Do not use model data products
0
100
200
300
400
Frequency


2.5.What is the spatial scale of the weather, climate or ocean data you use
Do not know-Prefer not to disclose
Other
Global
Continental
National
Regional
Local
Point
0
100
200
300
400
Frequency


2.6.Which observation data do you use
Wind (speed, dir.)
Waves
Surface Currents
Surface air temperature
Sea surface temperature
Sea levels
Radar data
Precipitation
Other
Lightning
Humidity
Do not use observation data products
Do not know-Prefer not to disclose
Cloud-radiation
0
100
200
300
400
Frequency
Type of organization
University-research centre
Private company
NGO (Non-Governmental Organization) - INGO (International Non-Governmental Organization)
International organization
Governmental organization
Municipality
Public utility
Other
Do not know-Prefer not to disclose


2.7.Which model data do you use
Wind (speed, dir.)
Waves
Surface Currents
Surface air temperature
Sea surface temperature
Sea levels
Precipitation
Other
Humidity
Do not use model data products
Do not know-Prefer not to disclose
Cloud-radiation
3D weather data
3D water temperature-salinity
3D currents
0
100
200
300
400
Frequency


2.8.Which tailored data products do you use
Winds climatology-statistics-indexes
Waves climatology-statistics-indexes
Water temperature climatology-statistics-indexes
Water salinity climatology-statistics-indexes
Sea level climatology-statistics-indexes
Precipitation climatology-statistics-indexes
Potential evaporation
Other
Do not use tailored data products
Do not know-Prefer not to disclose
Degree days
Currents climatology-statistics-indexes
Air temperature climatology-statistics-indexes
0
100
200
300
Frequency


2.9.What are the benefits of using weather, climate or ocean data in your organization
Support for operational decisions
Risk management
Other
None
Green transition
GHG reduction
Do not know-Prefer not to disclose
Climate change adaptation
Can reduce costs or increase benefits and reduce risks
Better environment
0
100
200
300
Frequency

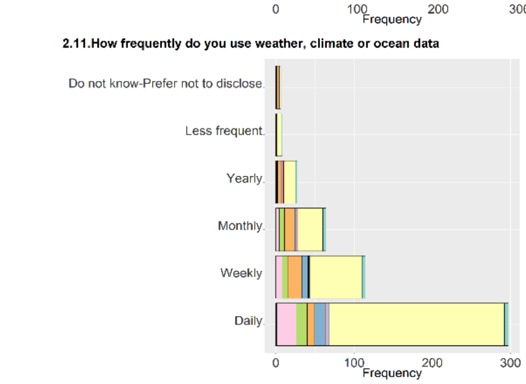

2.11.How frequently do you use weather, climate or ocean data
Do not know-Prefer not to disclose
Less frequent
Yearly
Monthly
Weekly
Daily
0
100
200
300
Frequency

Figure 6. Survey responses to questions 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9 and 2.11 for the Filter analysis based on Q1.1.

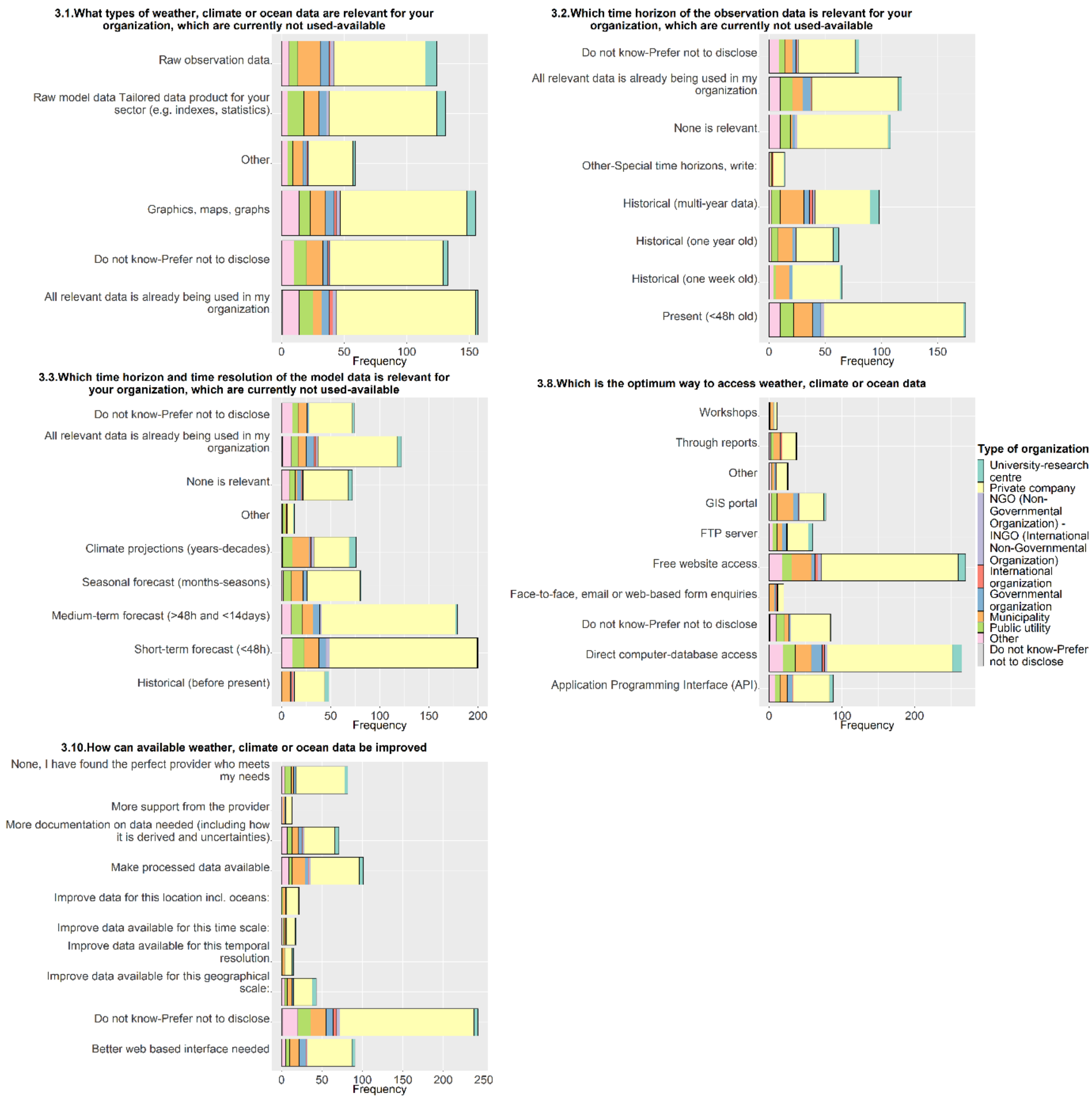


Figure 7. Survey responses to questions 3.1, 3.2, 3.3, 3.8 and 3.10 for the Filter analysis based on Q1.1.

Sectors

For current (survey part B) sector-filtered data-use as based on Q1.2, three sectors, agriculture-fishery-forests (hereafter “agriculture”), energy (including the energy sector, as well as the water supply, sewerage, waste management, electricity, gas and steam sectors) and professional, scientific and technical activities (hereafter “professional”) were selected for the sectorial analysis. Compared to the agriculture sector, the energy and professional sectors tend to work more at larger spatial and temporal scales (Q2.3F and Q2.5F), e.g. national and multi-year scales. The agricultural sector mainly uses atmospheric data, while the energy and professional sectors make similar or even higher use of ocean data compared with the agricultural sector (Q2.6F and Q2.7F). Moreover, in the energy sector, wind and air temperature are the most used variables (Q2.6F and Q2.7F).

In the future (survey part 3), the products in most demand from the agricultural sector will be graphs and maps, while the energy sector requires more tailored products, the professional sector more raw observations and graphics (Q3.1F). In respect of temporal scales, the agricultural sector demands mostly short-term observations and short- to mid-term model data, while the energy sector requires mostly mid-term and seasonal scale data, and the professional sector has significant demand for climate projections (Q3.2F and Q3.3F). For future needs regarding parameters, precipitation, winds and surface air temperature are most in demand by the agricultural and professional sectors, and winds and surface air temperature in the energy sector for both observations (Q3.5F) and model data (Q3.6F). As for potential improvements in future data provision, both the energy and professional sectors would like to have more documentation on the data and greater availability of processed products (Q3.10F) (Figure 8).


2.3.What is the time horizon of the observation data you use
Do not know-Prefer not to disclose.
Other.
Historical (multi-year data)
Historical (one year old).
Historical (one week old).
Present (<48h old).
Do not use observation data products
0 50 100 150 200
Frequency
2.5.What is the spatial scale of the weather, climate or ocean data you use
Do not know-Prefer not to disclose.
Global.
Continental
National.
Regional.
Local.
Point
0 100 200
Frequency
2.6.Which observation data do you use
Wind (speed, dir.)
Waves.
Surface Currents.
Surface air temperature
Sea surface temperature
Sea levels
Radar data.
Precipitation.
Other
Lightning
Humidity.
Do not use observation data products.
Do not know-Prefer not to disclose
Cloud-radiation
0 100 200
Frequency
2.7.Which model data do you use
Wind (speed, dir.)
Waves
Surface Currents.
Surface air temperature
Sea surface temperature.
Sea levels
Precipitation
Other.
Humidity.
Do not use model data products.
Do not know-Prefer not to disclose.
Cloud-radiation
3D weather data
3D water temperature-salinity.
3D currents
0 100 200
Frequency
3.1.What types of weather, climate or ocean data are relevant for your organization, which are currently not used-available
Raw observation data.
Raw model data Tailored data product for your sector (e.g. indexes, statistics)
Other.
Graphics, maps, graphs
Do not know-Prefer not to disclose.
All relevant data is already being used in my organization
0 25 50 75
Frequency
3.2.Which time horizon of the observation data is relevant for your organization, which are currently not used-available
Do not know-Prefer not to disclose.
All relevant data is already being used in my organization.
None is relevant.
Other-Special time horizons, write:.
Historical (multi-year data).
Historical (one year old).
Historical (one week old).
Present (<48h old)
0 25 50 75 100
Frequency
Benefits
Energy and supply
Professional, scientific and technical activities
Agriculture, forestry, and fishing
3.3.Which time horizon and time resolution of the model data is relevant for your organization, which are currently not used-available
Do not know-Prefer not to disclose.
All relevant data is already being used in my organization
None is relevant.
Other
Climate projections (years-decades)
Seasonal forecast (months-seasons).
Medium-term forecast (>48h and <14days)
Short-term forecast (<48h).
Historical (before present)
0 50 100
Frequency
3.5.Which observation data is relevant for your organization, which are currently not used-available
Wind (speed, dir.)
waves
Surface currents.
Surface air temperature
Sea surface temperature
Sea levels
Radar data.
Precipitation.
Other
Lightning
Humidity
Don't know.
Do not use observation data products.
Do not know-Prefer not to disclose
Cloud-radiation.
All relevant data is already being used in my organization.
0 30 60 90
Frequency
3.6.Which model data is relevant for your organization, which are currently not used-available
Wind (speed, dir.)
Waves
Surface currents
Surface air temperature
Sea surface temperature
Sea levels
Precipitation
Other
None of the above is relevant
Humidity
Do not use model data products
Do not know-Prefer not to disclose
Cloud-radiation
All relevant data is already used in my company
3D weather data
3D water temperature-salinity
3D currents
0 30 60 90 12
Frequency
3.10.How can available weather, climate or ocean data be improved
None, I have found the perfect provider who meets my needs
More support from the provider
More documentation on data needed (including how it is derived and uncertainties)
Make processed data available.
Improve data for this location incl. oceans:
Improve data available for this time scale:
Improve data available for this temporal resolution.
Improve data available for this geographical scale:
Do not know-Prefer not to disclose
Better web based interface needed.
0 50 100
Frequency

Figure 8. Survey responses to questions 2.3, 2.5, 2.6, 2.7, 3.1, 3.2, 3.3, 3.5, 3.6 and 2.10 for the Filter analysis based on Q1.2.

Paid vs free data

Only 97 respondents state that they use paid data, i.e. only one third of DMI's regular paying customers. According to the responses in Q2.1 (use of paid or free data), in comparison with other organizations, the organizations that buy weather, climate or ocean data are larger companies with more than five hundred employees) (40%) (Q1.3F) working in the energy sector (26%), public administration (25%) and water supply, sewerage and waste management (20%) (Q1.4F). Companies using paid data tend to have a greater interest in tailored data (28%) (Q2.2F), mostly using, more specifically, precipitation (29%), sea-level (20%) and winds (19%) climatology/statistics/indexes (Q2.8F). Organizations already buying data from DMI or other sources find raw observational data (30%) and raw model tailored data products (29%) relevant for their organizations but do not use them currently (Q3.1F). They are interested especially in short-term forecast (<48 h) model data (26%) and climate projections (years/decades) (23%) (Q3.3F). As for the type of observation and model data, there is a greater interest in precipitation data especially, but also in sea levels (Q3.5F and Q3.6F). Organizations buying data mainly want to be able to trust the suppliers' data more than other sources (62%) and want the data to come at low cost (45%): they do not find it so important for the data to be free, but do require more documentation on data (21%) (Q3.9F and Q3.10F).

Data type

Figure 9 shows the future user demand based on the data's temporal scales (Q3.3F) and different tailored products (Q3.7F), categorizing the previous answer with reference to data type

(Q2.2). It is seen that, e.g., organizations that use tailored data, whether from DMI or from other sources, are mostly interested in climate projections (Q3.3F) and that a reasonable share of respondents employing data from other sources than DMI demand e.g. precipitation statistics and data (Q3.7F).

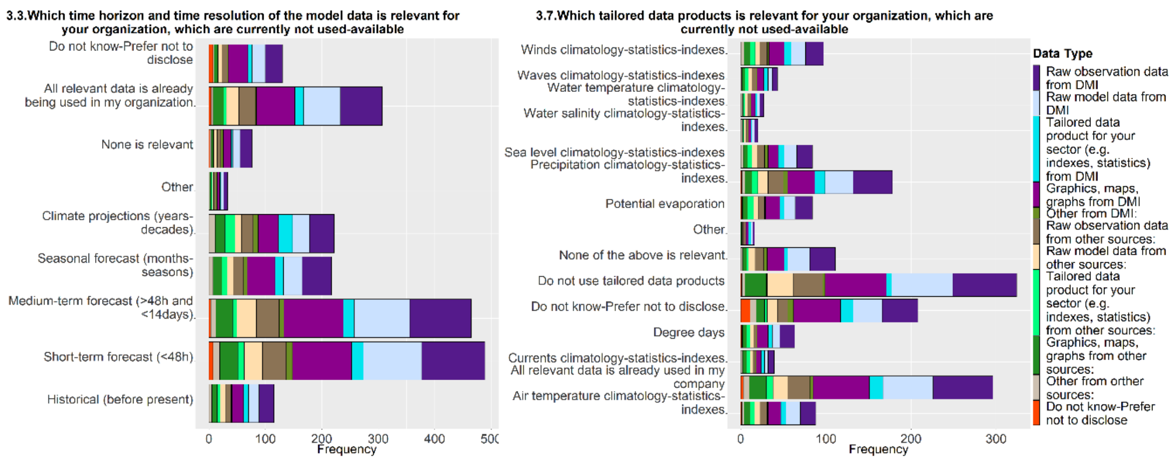


Figure 9. Survey responses to questions 3.3 and 3.7 for the Filter analysis based on Q2.2.

Tailored products

Figure 10 shows existing use and projects future demand from users that use different tailored products by aggregating the responses related to Q2.8 (use of tailored products). For large-scale applications operating across more than one country or globally, the majority of organizations are those using ocean tailored data products (Q1.4F), which is not surprising, since in many cases ocean applications need to know sea basin-scale conditions. These ocean-users tend to benefit from using weather, climate or ocean data for purposes of climate-change adaptation, operational decision-making and risk management (Q2.9F). Organizations that use sea level tailored data use mostly historical data (Q2.3F). Climate projection products are more important at present, as they will be in the future, for organizations that use waves, water temperature, precipitations, sea level and currents tailored data (Q2.4F and Q3.3F). Lastly, organizations that use potential evaporation data need more medium-term forecasts (>48h and < 14 days) (Q3.3F).

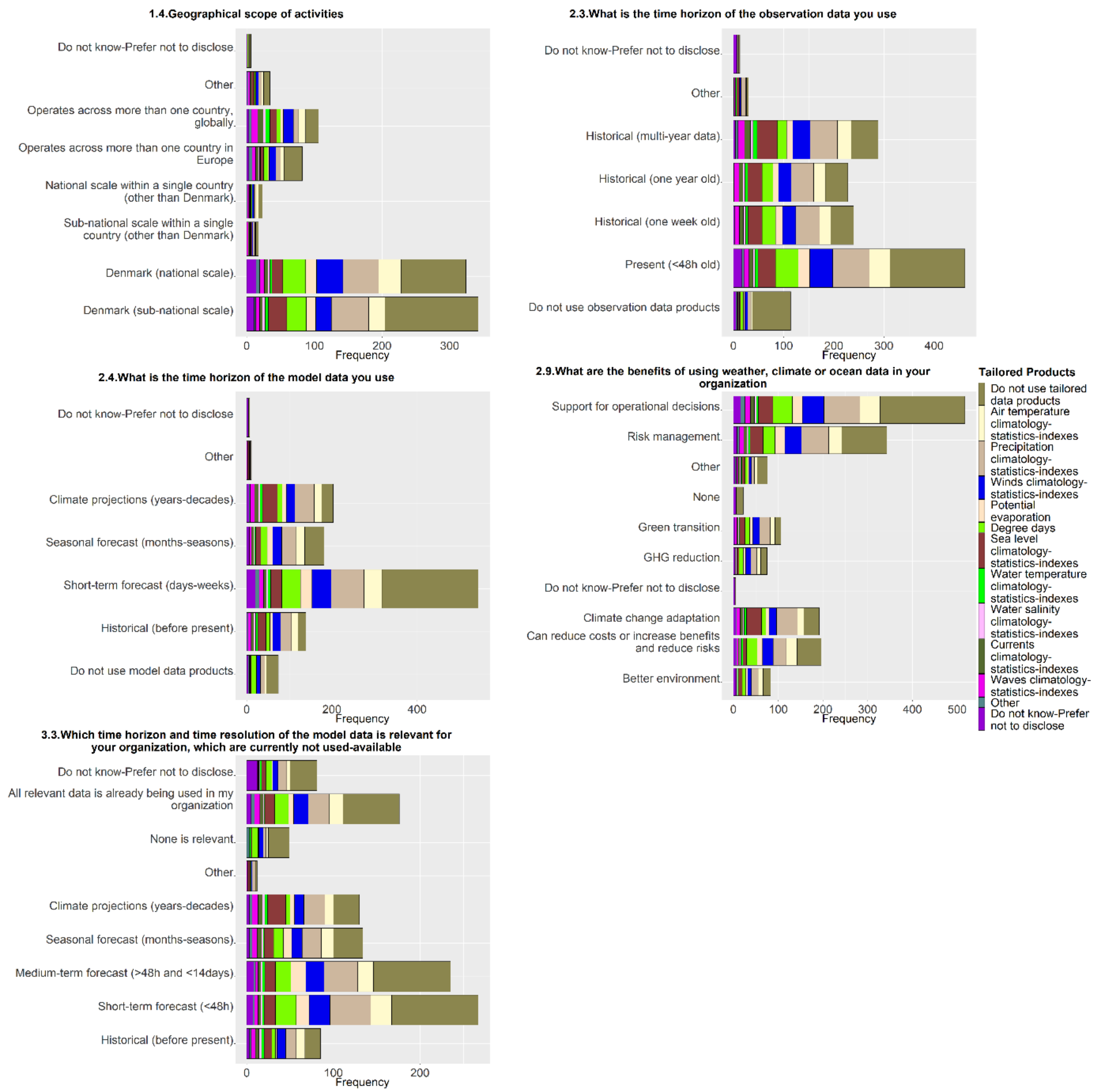
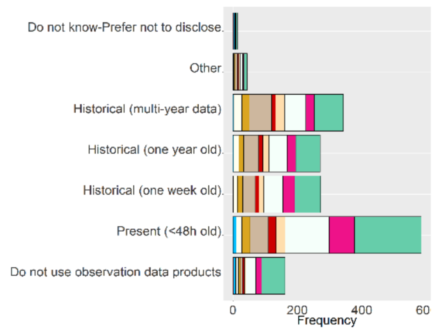


Figure 10. Survey responses to questions 1.4, 2.3, 2.4, 2.9 and 3.3 for the Filter analysis based on Q2.8.

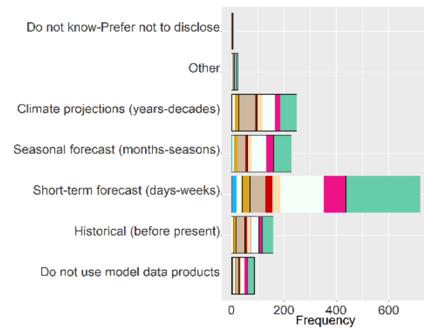
Benefits

According to the responses in Q2.9 (benefits gained from the use of data), those organizations that find benefits in climate-change adaptation have current and future needs mostly for historical (multi-year) observation data and climate projections from model data (Q2.3F, Q2.4F, Q3.2F and Q3.3F) (Figure 11). In relation to the type of the data, they use and need mostly precipitation, sea level or wind (speed or direction) from observation, model and tailored data (Q2.6F, Q2.7F, Q2.8, Q3.5F, Q3.6F and Q3.7F). Those organizations that find benefits in GHG reduction need more medium-term forecast model data (Q3.3F).

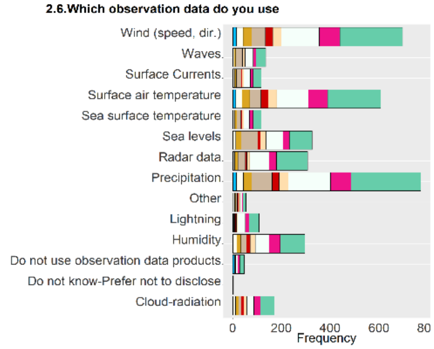
2.3.What is the time horizon of the observation data you use



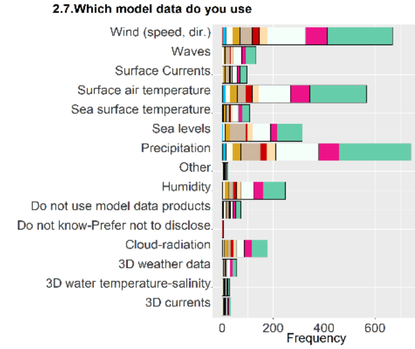
2.4.What is the time horizon of the model data you use



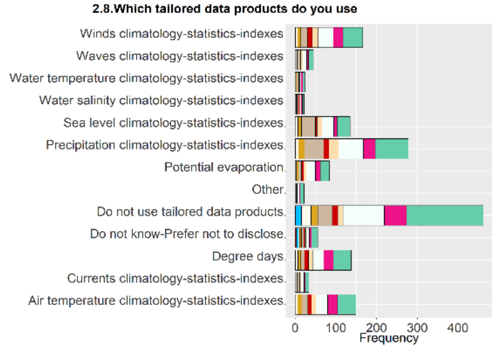
2.6.Which observation data do you use



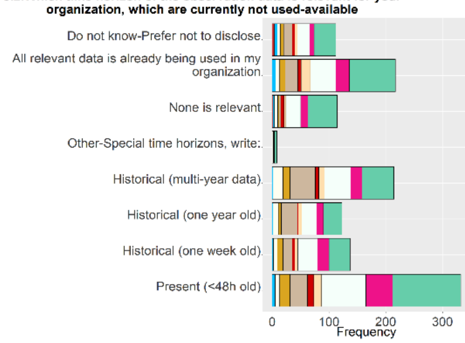
2.7.Which model data do you use

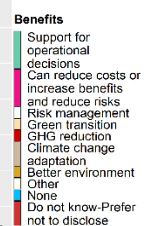


2.8.Which tailored data products do you use

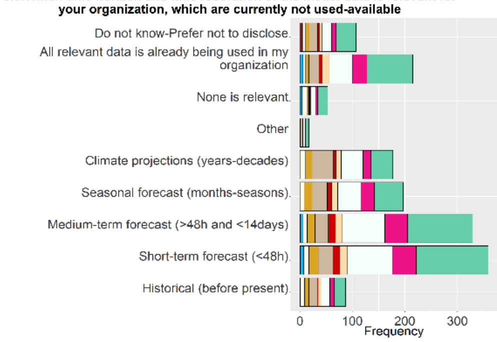


3.2.Which time horizon of the observation data is relevant for your organization, which are currently not used-available

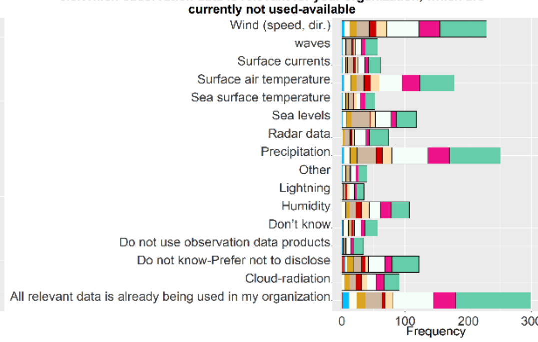




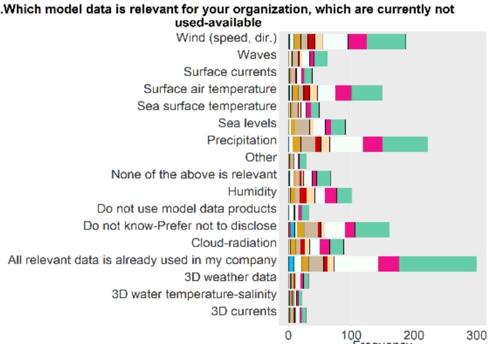
3.3.Which time horizon and time resolution of the model data is relevant for your organization, which are currently not used-available



3.5.Which observation data is relevant for your organization, which are currently not used-available



3.6.Which model data is relevant for your organization, which are currently not used-available



3.7.Which tailored data products is relevant for your organization, which are currently not used-available

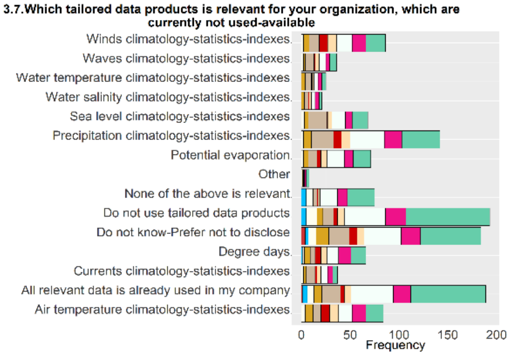


Figure 11. Survey responses to questions 2.3, 2.4, 2.6, 2.7, 2.8, 3.2, 3.3, 3.5, 3.6 and 3.7 for the Filter analysis based on Q2.9.

5. Discussion

5.1. Current use of climate services

One major finding from the study is the vast dominance of agricultural users (Q1.2, figure 3) receiving DMI climate services. This is also visible in the question on number of employees (Q1.3, figure 3), where an establishment of one to ten employees is predominates by far, corresponding to the company structure of individual farms in Denmark. Furthermore, respondents in the agricultural sector have a preference for data and products, including forecasts, with shorter time-frames (<48h), local-to-regional spatial scales, and precipitation, wind and temperature data (Figure 8); moreover, only a very limited number use paid data (Q2.1, table 4C). Also, agricultural respondents seem to have the least demand for additional products (28%, table 4c) compared to other sectors. The predominance of agriculture is also found in other studies (Tart et al., 2020; Vaughan et al., 2018), which did not, however, apply the filtering approach used here to obtain additional and separated layers of information. This also corresponds well with the findings of (Vaughan et al., 2016), where 63% of survey respondents regarded agriculture as the most developed sector with regard to climate-service use and development.

In the energy and supply sector, climate services have been relevant for a number of years due among other things to projections of temperature influencing heating supply/demand patterns (Larsen et al., 2020), energy-system efficiencies, power-plant cooling (hydro-meteorological) (Larsen and Drews, 2019), electricity trade markets and the introduction of renewables, including hydropower, wind and solar (Halsnæs et al., n.d.). As a result, a range of variables and spatio-temporal scales is currently in demand, as well as what would be expected in the future (Halsnæs et al., 2020). In general, however, climate services and data for the energy sector are underdeveloped, poor or non-aligned (Brasseur and Gallardo, 2016; Larsen et al., 2019). In this study, the results from the energy and supply sector mainly come from private companies (76%, Q1.1), span a range of sizes from one to ten employees (68%) to companies with 500-plus employees (11%, Q1.3) and currently mainly employ observational data (38%, Q2.2) at recent (39%, Q2.3) and both local and regional scales (38% and 26% Q2.5). Where energy and supply are combined, precipitation dominates the requested variables (40-41%, Q2.6-Q2.7), closely followed by wind (39%, Q2.6-Q2.7). However, for energy alone (not shown), wind vastly predominates (70-71%, Q2.6-Q2.7), which is likely to reflect the differences between energy companies working on the implementation and planning of renewables and supply companies working on, e.g., the dimensioning of sewage systems. The predominance of shorter time horizons may reflect daily work flows, where continuous forecasts are used more frequently than decadal scale projections, which have had a tendency to show the same general patterns in the recent ten to twenty-year period, despite modelling and computational advances improving the available spatio-temporal scales (Christensen et al., 2019).

Regarding professional, scientific and technical activities (hereafter “professional”, as above), the predominance of the demand for longer-term yearly and decadal projections (Q2.3 and Q3.3) is likely related to a larger share of work in climate adaptation as opposed to the applied sciences (Cortekar et al., 2016).

5.2. Demand for future climate services, data and products

For all questions in part C of the survey, it is important to emphasize that they were designed in order to reflect an additional demand, i.e. a demand for climate services that are not already in use. This is the likely explanation for the generally lower selection rate in part C of the survey compared to part B. The high selection rate in part B, on current climate service usage (multiple selections possible), could also imply that the use of climate services is generally well distributed across the sectors and organizations addressed here. This finding tends to contradict previous findings, such as (European Commission, 2015; Halsnæs et al., 2020). However, there is a possible bias here related to current climate-service users, and therefore to those with a general interest in this matter, tending to be over-represented, whereas non-users would simply ignore such emails, not least because of the general abundance of more or less relevant and credible emails, often with a commercial component. For a discussion of other biases and uncertainties relating to the survey, see below.

The findings highlighted here point to a demand from currently paying users for data and services that are trustworthy, directly available through online databases or ftp links, are in a more raw or unprocessed form, cover longer periods and have local or point-based origins. Users of free data, on the other hand, tend to have a much smaller future demand for trust in the supplier (62% vs 36%) and prefer free access to website data and shorter time-horizon data. Moreover, in general for the users of free data, future demand seems to be much less developed, with fewer general responses across questions. This is in line with the expectation that paying users have reached a certain level of expertise and a more advanced state in their business plans, broadly defined, in their use of climate data, and that some of the processing and analysis involved can be undertaken by the customer. In this light, in the literature capacity-building is identified as key to climate services increasing market penetration (Bowyer et al., 2015; Giannini et al., 2016; Räsänen et al., 2017; Tart et al., 2020). Continued efforts to promote the use of climate services either with regard to platforms and availability (Cortekar et al., 2020), such as the Copernicus C3S initiative (Copernicus, 2020), or politically (European Union, 2015; Street, 2016) is likely to advance the use of climate data and services into a more developed form with regard to both levels of expertise and numbers of users (Halsnæs et al., 2020).

The finding that trust in and the reliability of suppliers of data and services are essential should come as no surprise, since this has been the finding of a vast number of other studies, such as (Bruno Soares et al., 2018; European Commission, 2015; Kox et al., 2015; McNie, 2013; Perrels et al., 2020; Räsänen et al., 2017; Street, 2016; Tart et al., 2020; Vaughan and Dessai, 2014; Vincent et al., 2018; Williams et al., 2020). Among these, (European Commission, 2015) summarizes the multiple definitions of reliability as applicable to both users and suppliers, with shared elements around trustworthiness, reputation, organization size, public and independent status, and being close to the generation of raw data. Another study performing an online survey among climate-service users worldwide found the exact same result of trust being rated highest in selecting a data provider (Tart et al., 2020).

The differences in relative climate-service demands throughout most questions and between sectors are very apparent. Thus there is much greater demand for multi-year/decadal-scale data for scientific and technical activities as opposed to, e.g., agriculture (figure 8, Q3.2F-Q3.3F), though the differences across sectors can be seen throughout questions Q1.2, Q2.3-Q2.4, Q2.6-Q2.8 and Q3.1-Q3.7 (table 3C) and Q1.4, Q2.6-Q2.8, Q3.1-Q3.6 (table 4C). For a climate-service provider like DMI to be able to accommodate such differences, one approach could very well be to deliver and prioritize data types, formats, spatiotemporal scales etc. in the order of greatest demand, possibly modified by the associated work load. While deliverables should be prioritized, the task is very complex, as also highlighted in the literature review above. To obtain an overview of this task and avoid tunnel vision, communication with end-users over their demands is essential (Porter and Dessai, 2017). We argue accordingly that this survey provides a significant contribution in this regard, although two-way correspondence is also important (Giannini et al., 2016; Kirchhoff et al., 2013). One complementary approach would be to include interoperability in climate products and services, as highlighted by (Giuliani et al., 2017), essentially to be able to share platforms, selection criteria, formats and assumptions, thus enabling a fuller picture of the inherent uncertainties as a basis for enhanced decision-making (Otto et al., 2016).

5.3. Uncertainties

The unequal proportions of respondents across organizational types and sectors, as understandably highlighted by agricultural users in the private organization category, has the potential to mask the findings and affect the conclusions of this study. An attempt has been made to mitigate this in the Filter part of this analysis, where subsequent responses have been filtered in accordance with descriptive characteristics. In doing so, each sector can, e.g., be depicted from the private-organization type to highlight other lines of business too, such as consultancy etc.

In designing the survey, general good-practice survey guidelines were followed (Iarossi, 2006), including a transparent appearance and wording, so that every respondent, regardless of work-setting or discipline, was aware what was being asked in each question and not least what was not being asked, that is, what will follow in additional questions. For example, the respondent needed to know that questions regarding potential future climate-service needs (part C of the survey) will appear after answering the questions on the current usage (part B of the survey) in order to not influence results across, as here, current and future needs. In practice, however, there is a risk of this transparency not being fully appreciated by the respondent. In another example, similarly, the survey design whereby part B is omitted completely in case of no current climate service usage was regarded as essential in order to reduce the number of incomplete survey answers and random selections.

Due to the immense task of performing and analysing stakeholder interviews, it was decided to focus fully instead on our ambitious survey with regard to its distribution and design. Also, working with interviews was not aligned with the staffing and man-hours available for the project.

6. Conclusions

This study was initiated in order to assess the current usage and future demands of climate services and data in Denmark. In this context, climate services were defined broadly as covering a wide range of spatio-temporal scales, including forecasts and oceans. One key purpose was to aid in the design and planning of future initiatives in Denmark, as hosted by DMI, in order to satisfy user demands at their fullest. The main methodology included a survey, distributed widely in Denmark, of the focal sectors of I) energy and supply, II) agriculture, and III) professional, scientific and technical activities.

A total of 882 responses were received to the survey, including 305 partial answers, corresponding to a completion rate of 66%. The background information included in the survey suggested broad coverage across disciplines, sectors, fields and company/affiliation sizes. The significant number of respondents offered unique insights into current uses of climate data and services, as well as future demand. A key conclusion identifies wide differences between current users of climate services, depending on their type of organization and sector. These differences include the type of work for which data are used, the period of usage, whether the data are paid for or not, the time horizon of the data themselves, the variables, and the platform for data acquisition. Very few organizations intended to develop their own climate services: six out of nineteen, of which thirteen were private companies. Far fewer respondents indicated a demand for future climate services compared to their current use, which could indicate either the evolution of a new stage in climate-service usage or a lack of recognized needs. Another central issue across respondents when it came to choosing their future climate services was the need for trust and reliability on the part of the supplier.

7. Acknowledgements

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