The Power of Partnership

Public and Private Engagement in Hydromet Services

GLOBAL FACILITY FOR DISASTER REDUCTION AND RECOVERY

THE WORLD BANK
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Tornado touchdown. Photo: clintspencer.

Foreword

The needs of societies for more accurate and reliable weather, climate, and hydrological («hydromet») information are at the highest levels today. Weather events–including hurricanes, heat waves, floods, and droughts–jointly cause more economic damage and loss of life than any other disaster. Around the world, better warning systems, better meteorological and hydrological services, and customized service delivery can help prepare for and reduce the cost of weather events, minimize loss and damage, and build socio-economic resilience. Reliable hydromet services are in high demand in weather-dependent sectors like aviation, agriculture, shipping, transport, energy, and tourism. As the effects of climate change modify the patterns and intensity of natural hazards and as rapid urbanization and population growth increase vulnerability, adequate hydromet services are increasingly a very high value proposition.

For over a decade, the World Bank has invested in the modernization of National Meteorological and Hydrological Services (NMHSs). Some countries have been more successful than others with sustaining and multiplying the outcomes of these investments. We have also witnessed that many countries are struggling to keep up with the ever-increasing demand for more sophisticated services to protect lives and assets as well as to support economies.

Over the same decade, advances in technology and innovation have widened the scope of products and services that can be used to improve weather data, warning systems, and hydromet information. Private-sector actors are playing an important role and along with the academic community are helping to push the frontiers of knowledge, investing in innovative solutions that deliver more reliable forecasting and more efficient and diverse services. The dynamics between the public, private, and academic sectors have been evolving, creating more opportunities than ever to join forces to deliver the socio-economic benefits of a more informed and resilient world.

This report looks at the current landscape of partnerships and analyzes the experience from eight countries that have explored different approaches to partnership as they seek to strengthen the provision of hydromet services. Not surprisingly, these experiences show that collaboration across public, private, and academic actors in this field is changing rapidly, can be complex and challenging, but is worth the effort. The report offers ideas about lessons learned so far as countries attempt to structure a balanced model that builds on an awareness of comparative advantages, a shared commitment to improving global public goods in the service of strengthening global resilience.

We are grateful to everybody who shared their experiences and worked with us in writing this report, and look forward to working with you to identify, and cross together, the next frontiers.

Julie Dana

Practice Manager, Global Facility for Disaster Reduction and Recovery

Acknowledgements

This report provides guidance to regulators, hydromet service providers, and private actors as well as development practitioners to achieve successful public-private-academic engagements. It is based on a systematic analysis of the various forms taken by private-public engagements in hydromet services in different countries. The report was prepared by a World Bank team led by Makoto Suwa, Senior Disaster Risk Management Specialist, including Anna-Maria Bogdanova, Operations Officer; Guillermo Siercke, Disaster Risk Management Specialist; and Daniel Kull, Senior Disaster Risk Management Specialist, and benefited from the guidance and reviews provided by Vladimir Tsirkunov, Lead Specialist; David Rogers, Lead Consultant; and Alan Thorpe, Visiting Professor, University of Reading, U.K.

Stefan von Grünigen, econcept AG; Christoph Ramshorn, Manage Your Options B.V.; Christian Vogler, econcept AG, and; Thomas Frei, Research and Consulting conducted primary and secondary research and drafted the document. Their activities included developing the iterative scenario-based approach for the study, consultation with numerous private entities, government agencies, development partners, and other stakeholders.

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Abbreviations

Abbr.	Definition
AI	Artificial Intelligence
API	Application Programming Interfaces
AWS(s)	Automatic Weather Station(s)
BAPPENAS	Ministry of National Development Planning (Indonesia)
BEIS	Department for Business, Energy, and Industrial Strategy (U.K.)
BMKG	Meteorological, Climatological and Geophysical Agency(Indonesia)
BNPB	National Disaster Management Authority (Indonesia)
CAA	Civil Aviation Authority
CEO	Chief Executive Officer
DMH	Department of Meteorology and Hydrology, National Meteorological and Hydrological Service (Myanmar)
DPT	PSI Data Team (U.K.)
DRM	Disaster Risk Management
DWD	National Meteorological and Hydrological Service (Germany)
ECMWF	European Centre for Medium Range Weather Forecasts
ECOMET	Economic Interest Grouping of the National Meteorological Services of the European Economic Area
ESA	European Space Agency
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FAQ	Frequently Asked Question
GBP	Great Britain Pound
GCAA	Ghana Civil Aviation Authority
GDP	Gross Domestic Product
GFDRR	Global Facility for Disaster Reduction and Recovery
GFS	Global Forecast System
GIS	Geographic Information System
GMet	Ghana Meteorological Agency
GTS	Global Telecommunications System
GWE	Global Weather Enterprise
HQ	Headquarters
ICAO	International Civil Aviation Organization
ICT	Information and Communication Technologies
IIGF	Indonesia Infrastructure Guarantee Fund
IMO	International Maritime Organization
IMS	Israel Meteorological Service
IOT	Internet of Things
JICA	Japan International Cooperation Agency

Abbr.	Definition
JMA	Japan Meteorological Agency
JMBSC	Japan Meteorological Business Support Center
KNUST	Kwame Nkrumah University of Science and Technology (Ghana)
MLIT	Ministry of Land, Infrastructure, Transport, and Tourism (Japan)
MOU	Memorandum of Understanding
NASA	National Aeronautics and Space Administration (U.S.)
NCAR	National Center for Atmospheric Research (U.S.)
NCAS	National Centre for Atmospheric Science (U.K.)
NCEP	National Centers for Environmental Prediction (U.S.)
NEXRAD	Next Generation Weather Radar
NGO	Non-Governmental Organization
NMHS(s)	National Meteorological and Hydrological Service(s)
NOAA	National Oceanic and Atmospheric Administration (U.S.)
NWP	Numerical Weather Prediction
NWS	National Weather Service (U.S.)
PPE	Public-Private Engagement
PPP	Public-Private Partnership
PRIMET	European Trade Association for Meteorological Service Providers
PSI	Public Sector Information
R&D	Research and Development
SMS	Short Message Service
TAHMO	Trans-African Hydro-Meteorological Observatory
U.K.	United Kingdom
U.S.	United States
USD	United States Dollar
VGF	Viability Gap Fund
VRA	Volta River Authority (Ghana)
WASCAL	West African Science Service Centre on Climate Change and Adapted Land use
WIGOS	WMO Integrated Global Observing System
WIS	WMO Information System
WMO	World Meteorological Organization
WNI	Weathernews Inc.
WRF	Weather Research and Forecasting
WXBC	Weather Business Consortium (Japan)

Photo: Kinwun.

Executive Summary

Motivation

Effective weather, climate, and hydrological services (hydromet services) are critical to protect lives and property and to enhance socio-economic benefits. However, NMHSs are facing serious challenges in responding to increasing societal and economic demands. The issue is more severe in low- and some middle-income countries where due to lack of resources, basic infrastructure, technical capacity, and visibility within their governments, timely provision of hydromet services and of adequate response are major difficulties. At the same time, in developed countries, technological advances and open-data policies have significantly enlarged the role of the private sector in the provision of hydromet services. Leveraging private-sector capabilities without jeopardizing the provision of public hydromet services is a key condition to maximize socio-economic benefits. There is thus much interest among countries and stakeholders to explore the best ways of maximizing the public-private engagement (PPE) opportunities in their development projects.

This study provides guiding principles for PPE and a shared understanding among public, private, and academic stakeholders of the hydromet value chain and its economics. The study is based on evidence collected through the analysis of eight countries selected as case studies (Ghana, Indonesia, Japan, Myanmar, U.K., U.S., Germany, and Israel) and interviews with more than 50 stakeholders from the public, private, and academic sectors.

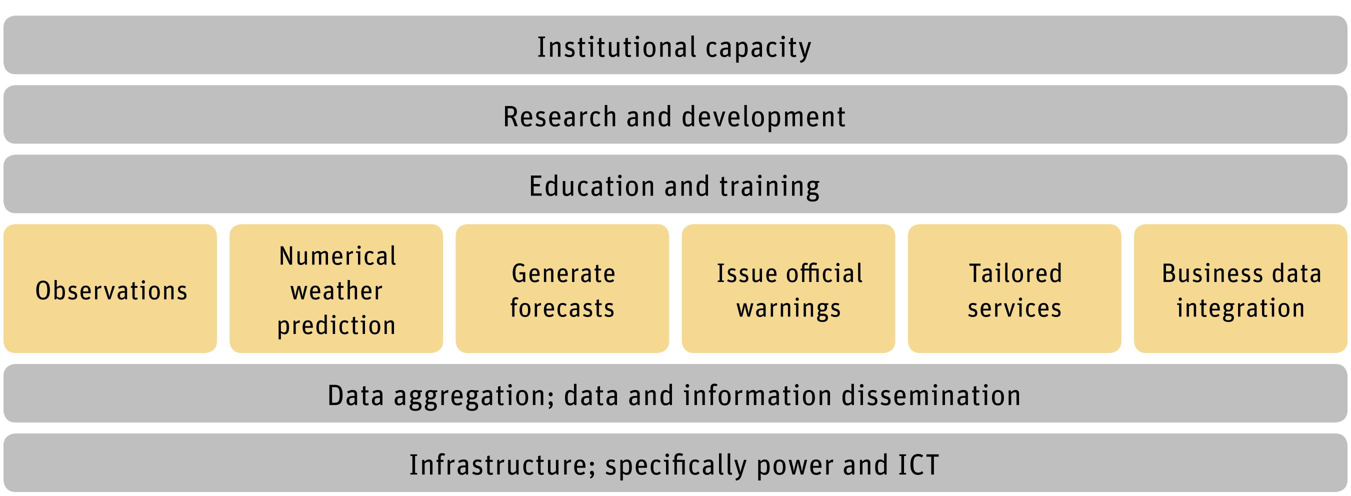
This study is designed to answer the following key questions:

- What are the characteristics, advantages, challenges, and potential risks of the various PPE models in the hydromet sector?
- What are the available options for developing countries that wish to streamline and augment public and private engagement to strengthen the provision of hydromet services, and, accordingly, the conditions necessary to succeed?

Key concepts

Hydromet value chain

The analysis is based on a simplified hydromet value chain, which is represented in the figure below along with its key enablers. In the country case studies, the level of development (or «maturity»") of the hydromet value chain elements is assessed as is the relative importance of the contributions of the public, private, and academic sectors. These elements define, along with



the relevant regulatory framework, the country-specific boundary conditions for PPE.

Economic principles

The services generated within the hydromet value chain consist predominantly of data and information and therefore exhibit specific economic properties which must be taken into consideration when framing PPE in a given country. Hydromet services can be divided into «public» services, which are not likely to be adequately provided by market mechanisms, and «non-public» services, which could be provided by the private sector. Examples of public hydromet services include operating a nation-wide surface observation network or providing general weather forecasts; examples of non-public services include customized services for specific users and the provision of weather and risk indices for insurance companies. However, the characterization of a service as public service does not necessarily mean that it must be provided by a public entity such as an NMHS; for example, some public services can be provided by the private or academic sector, albeit under the supervision of a regulator.

Scenarios

PPE options must be assessed in their country-specific context. Three reference scenarios articulate how the best options change depending on the context:

- **Scenario «Jump-start»** for value chains of low maturity: Take advantage of private-sector capacity to jump start the value chain while laying the foundation for a sustainable NMHS.
- **Scenario «Strengthen»** for intermediate value chains: Strengthen and focus the NMHS on providing public services, thus laying the foundation for the private sector to efficiently provide non-public services.
- **Scenario «Optimize»** for advanced value chains: Optimize the cost of public services by leveraging synergies with the private sector.

Main conclusions

- **The socio-economic benefits of hydromet services are underestimated:** Governments tend to underestimate the socio-economic benefits of a well-developed hydromet value chain—especially, but not only in developing countries—even though they are by now well documented (e.g. WMO 2015a). Consequently, development of the whole value chain is often not prioritized, potential benefits are not realized, and regulatory policies are mainly discussed with respect to their effects on the NMHS alone or related public entities.
- **Economic principles should guide models of service delivery:** The economic properties of hydromet services must be strongly considered in the design of the regulatory framework governing the service delivery models. This study discusses key economic principles and provides guidelines for choosing the optimal service delivery model for different types of hydromet services.
- **Government commitment to the hydromet domain is a smart investment for safeguarding the public:** The private sector can flourish when governments support a public entity to provide public hydromet services. A government may receive support from development partners to start the process, but ultimately the government is responsible for sustained (through operations and maintenance) public hydromet services.
- **Understanding the characteristics of a hydromet value chain is essential for developing PPE:** To leverage PPE in any given country, it is indispensable to understand the whole hydromet value chain in that country. The three aspects are crucial: *maturity* of the hydromet value chain (how mature is the hydromet value chain and each element of the value chain in a given country); *sector balance* (to what extent do the public, private, and academic sectors contribute to the hydromet value chain); and *policy framework* which shapes the hydromet value chain.
- **The approach to hydromet value chains varies considerably among countries:** The case studies show considerable differences not only between developed and developing countries, but also between countries with similar levels of development.
- **Developing PPE requires a systematic approach:** The study identifies several good practices to foster the development of a sustainable hydromet value chain or of successful PPE. These good practices are in the area of governance, funding of public services, capacity building, development support, and sustaining technical infrastructure and expertise. While referring to these good

practices, country-specific action plans to build and strengthen the hydromet value chain need to be developed (e.g. based on the three reference scenarios mentioned above).

- **The academic sector is an important vehicle for PPE growth in the hydromet domain:** Research and development ensure the ability to innovate value chain elements pushing boundaries of the entire global weather enterprise. Taking advantage of scientific advances and applying them in the specific context should be regarded as one of the critical enablers of the hydromet value chain while availability of human resource with required skillsets increases its sustainability.
- **Key elements of the regulatory foundation for PPE are the NMHS mandate and the data access policies:** The mandate and the duties of the NMHS, as well as all policies regarding data access, are the key regulatory aspects relevant to PPE. If the role of the NMHS is not clearly defined and if there is no clear distinction between public and non-public services, the development of the value chain and vibrant and purposeful cooperation between the public and private sectors is hindered.
- **Consistency of severe weather warnings is critical:** The coexistence of public and private weather information providers can lead to inconsistent warnings with low perceived quality and (thus) low effect. This is a much-debated topic and a key challenge in the relationship between the public and private sectors. Strong coordination or regulation where applicable (e.g. by establishing mandatory standards for visualization and classification of warnings) and careful consideration of the communications of warnings and the degree of public trust are needed to ensure consistency and thereby the effectiveness of the system. In particular, official warnings must be easily recognizable as official.
- **Development projects should focus on improving the whole value chain in an inclusive manner:** Many development projects focus primarily on NMHS infrastructure and capacity, thereby losing sight of the impacts of the value chain. While these effects may be inherent to the framework of development cooperation, it would be beneficial to explore possibilities to reshape the setup of future development projects. The findings of this study can inform this process and help to align the incentives of future projects.

Recommendations

Country-specific strategy

1. Develop country-specific approaches to foster PPE, starting from one of the reference scenarios «Jump-Start», «Strengthen», or «Optimize».
2. Develop an overall strategy at the country level to maximize socio-economic benefit of the full hydromet value chain.

Institutions and policies

3. Support the development of a transparent legal and regulatory framework.
4. Properly and sustainably fund the NMHS according to its role.
5. Aim for an open and free access to all data and public services produced by public entities.
6. Consider minimal regulation of the non-public hydromet services market.
7. Minimize the role of public entities in the provision of non-public hydromet services. If non-public hydromet services are provided by public entities or state-owned companies, an independent regulator must ensure a level playing field between the private and public sectors.
8. Ensure the consistency and effective communication of severe weather warnings, either by designating a single authoritative voice for issuing warning or by fostering a better coordination between the issuers of warnings.

Dialogue and awareness-raising

9. Develop a structured, continuous, and open dialogue between the public, private, and academic sectors to promote trust between the sectors, to clarify the boundary between public and non-public services and to sustain the hydromet value chain.
10. Invest in awareness-raising, especially concerning the socio-economic benefits of hydromet services and the benefits of using hydromet information for businesses.

Development projects

11. Shape future development projects based on recommendations 1 to 10, for instance:

- Use scenario-based planning to align stakeholders and create project plans that can be easily adapted to changing circumstances.
- Embrace a lean start-up approach, especially for low-maturity value chains.
- Prioritize and support the review or the development of sound policy frameworks.
- Build the commitment of governments by cost-benefit analyses showing the hydromet value chain impact and by supporting the NMHS in raising its profile.
- Focus the incentives for development partners on sustainable hydromet value chain impact rather than investment volumes.

1. Introduction

1.1 Initial position

Meteorological and hydrological hazards jointly cause more economic damage and loss of life than any other disaster (see, for example, Munich RE 2017 and WEF 2019). Improving weather, climate, and hydrological services (together constituting «hydromet services»)—or creating them in the first place—is an important prerequisite to increase the world's weather and climate resilience. Hydromet services and products play a crucial role in countries facing impacts of extreme weather, harsh climate, and climate change, allowing them to improve protection of lives and property and to maximize socio-economic benefits. Against this backdrop, demands for more elaborate hydromet services have been increasing across the globe. However, NMHSs, which are normally public-sector entities mandated to provide meteorological and hydrological services, are facing serious challenges in responding to such increasing demands—especially in low- and some middle-income countries—due to lack of resources, basic infrastructure, technical capacity, and, among other reasons, visibility within their own government.

Over the past 40 years, the ability to observe and predict hydromet events has greatly improved. Hydrometeorological weather events are now being predicted on spatial and temporal scales that more closely match society's need for hydrometeorological information. Five-day forecasts today are as good as one-day forecasts were in the 1980s (Bauer et al. 2015). The resolution of global numerical weather prediction modeling systems has been doubling every eight years and is currently in the range of about 9–15 kilometers. The implementation of ensemble weather forecasts[1] that provide probabilistic information has extended these potential gains in lead time, allowing the development of more reliable early warning systems. Our ability to observe the atmosphere has also experienced corresponding advances allowing the possibility to better «nowcast» weather systems.

The potential roles of and dynamics in GWE have been evolving rapidly in recent years. While the private sector has been part of the hydromet value chain for a long time, its role has been growing in recent years. New business opportunities for the private sector have been rapidly emerging thanks to the previously mentioned advances in forecast systems along with the rapid development of information, measurement and telecommunication technologies, artificial intelligence (AI), and machine learning, along with the availability of and ability to communicate large hydromet and associated data sets. The private sector has become increasingly aware of the socio-economic benefits for individuals and companies derived from these advances. These changes have led to new companies developing services within and along the hydromet value chain[2] and to large, established tech companies entering the hydromet market. NMHSs, on the other hand, often face budgetary constraints and have to rethink the scope of their activities.

In many developing countries, the hydromet value chain is not well developed. In order to maximize future socio-economic benefits from developing hydromet services, it is almost imperative today that these countries consider how to strategically embrace the benefits of a growing private sector without jeopardizing the provision of public services. This entails a comprehensive view of the hydromet value chain rather than just focusing on a country's NMHS.

1 An ensemble weather forecast is a set of forecasts that presents the range of future weather possibilities. Multiple simulations are run, each with a slight variation of its initial conditions and with slightly perturbed weather models. These variations represent the inevitable uncertainty in the initial conditions and approximations in the models. They produce a range of possible weather conditions (https://www.ecmwf.int/en/about/media-centre/fact-sheet-ensemble-weather-forecasting). Multi-model ensembles take this one step further by combining the results from a range of different simulation models (http://content.meteoblue.com/en/time-dimensions/forecast/meteograms/multimodel-ensemble).

2 The hydromet value chain summarizes all activities, by private, public, and academic entities, generating or using hydrological and/or meteorological information. This report uses a simplified version of the hydromet value chain, described in detail in Chapter 2.1.

Studies have been conducted on how to best modernize a country's hydromet services (e.g. Rogers et al. 2019; Rogers and Tsirkunov 2013; Gunasekera 2004; and WMO 2014), and many discussions, panels, and workshops have been organized on how to best leverage public-private engagement (e.g. at the WMO[3]). This study builds on these recent activities and shifts the focus from improving individual players to improving the overall value chain.

The study's primary objective is to provide guidance on public-private engagement in hydromet services. Its development is based on a comparative analysis of public-private engagements in countries that represent possible ways to organize hydromet services. The study analyzes the characteristics, advantages, challenges, and potential risks of different PPE models and lays out options in given circumstances. Countries which currently provide only basic hydromet services and are considering modernization of their hydromet infrastructure and services can benefit from a better understanding of the interaction between the public and private sectors and from lessons learned from the long history of public-private engagement by many NMHSs.

1.2 Research approach

This study was designed to answer the following key questions:

- What are the characteristics, advantages, challenges, and potential risks of different PPE models in the hydromet sector?
- What are the available options for developing countries that wish to strengthen the provision of hydromet services by streamlining and augmenting PPE, and what are the key success factors for developing and sustaining PPE?

As this study shows, the conceptualization and understanding of the value chain and its components varies among stakeholders at the national and global levels. Prescribing universal solutions is not plausible, as characteristics of optimal public-private engagement depend on the specific country context. However, there are general principles and key success factors that apply in most contexts. Strategizing PPE, to determine the optimal implementation of these key success factors, requires an in-depth analysis and understanding of a country's value chain.

A shared understanding of the hydromet value chain and its economics emerged as one of the important goals of the study. This study first collected evidence through case studies and interviews. It then organized the information into articulated scenarios.

1.2.1 Case studies of selected countries and additional interviews

The way countries handle PPE and shape their hydromet value chains varies. In order to capture this variability, the study gathers empirical evidence by analyzing case studies. The case studies were developed using materials gathered through deskwork and interviews, provide the necessary specificity, and combine objective and subjective information to help understand the underlying issues.

The selection of countries aims at covering a broad spectrum of the different ways in which countries organize their hydromet services and includes both developed and developing countries. The countries were selected based on: (i) a preliminary classification of their hydromet services markets and strategies into three categories depending on the level of state control (state-dominated, state-biased, and open; see Table 1 for details); (ii) their potential to provide pertinent information; and (iii) expert consultations.

Six countries were selected for in-depth case studies: Ghana, Indonesia, Japan, Myanmar, U.K., and U.S. In addition, two more countries (Germany and Israel) were analyzed focusing on specific issues, such as the impacts of changes to data access policies.

Additional interviews with experts and stakeholders from the public and private sectors complement the analysis. These interviews provide insight into the perspective of transnational weather companies and international organizations.

3 https://public.wmo.int/en/our-mandate/how-we-do-it/partnerships/Public-Private-Academic%20Sectors%20Engagement.

A total of 58 explorative and half-structured interviews and meetings with experts and stakeholders from the public and private sectors were conducted. They were conducted face-to-face during on-site visits or international conferences or virtually (Table 2).

Scenario construction

The evidence from the case studies and interviews is structured based on methods from decision engineering and scenario-based planning. This structured picture is built around the notions of «frame» and «scenario».

Framing a project describes its context. Constructing a scenario with its constituent strategy and realization is a way to systematically map out available options and possible outcomes. In a specific scenario, chosen options make up a strategy, and expected outcomes make up a realization or «future world» (see Figure 9 in Chapter 4). Options capture what can be done; outcomes describe what could happen.

Frame and scenario are like maps that can be studied to navigate a complex problem space. They are a useful basis to identify common and conflicting stakeholder interests, identify good trade-offs, and plan projects that face large uncertainties. While this report cannot present specific plans for a particular improvement project, it aims to lay a foundation on which such plans can be built. The notions of frame and scenario are further explained and applied in Chapter 4; additional detail is provided in the annex.

Table 1 | Preliminary classification of markets and strategies of hydromet services.

	State-dominated	State-biased	Open
Strategy	State keeps full control of the hydromet information and recovers as much of the cost as possible.	State controls the market but takes advantage of the private sector in some areas.	Maximize the benefits that the private sector and competition can bring.
Market observations	State monopoly.	State dominates the hydromet market.	Open competitive market.
	Private hydromet services do not act independently, because the state defines their tasks and regulates their business activities.	The national weather service is the most powerful weather provider because its product portfolio covers and influences the whole market; it is often subsidized. Private weather services are scarce, and in some instances, the national weather service tries to drive them out.	National weather provider focuses on public services. Private weather services act independently and provide mostly non-public services.[4]

Table 2 | Overview of the interviews conducted during the study. Many interviews were attended by two or more persons.

Group	Remarks	# Interviews
Public sector	Most public-sector interviewees were executive or technical staff of NMHS and DRM organizations	31
Private sector	Representatives of national and international companies	19
Others	Independent experts, academia, industry associations, and WMO	8
Total number		58

4 See Chapter 2.2 for a definition of public and non-public services.

1.3 Structure of the report

The report is structured as follows:

- **Chapter 1** presents the introduction, objective, and research approach.
- **Chapter 2** sets the scene and introduces the technical and economic concepts which form the basis for consistent treatment of the issues discussed in this report.
- The case studies, which make up most of the comparative country analysis, are documented in **Chapter 3**. This is the evidence underpinning the structured picture in Chapter 4.
- **Chapter 4** synthesizes a structured picture of the context and the issues that development practitioners and hydromet value chain stakeholders face when trying to improve a country's hydromet services, and the options available to them. This takes the form of reference scenarios informed by the case studies' findings, interviews with stakeholders, and the background knowledge of the study team.
- Conclusions and recommendations are summarized in **Chapter 5**.
- **The annex** provides further detail on the reference scenarios presented in Chapter 4 and can serve as a starting point for planning development projects, with practical options considered in a project's context.

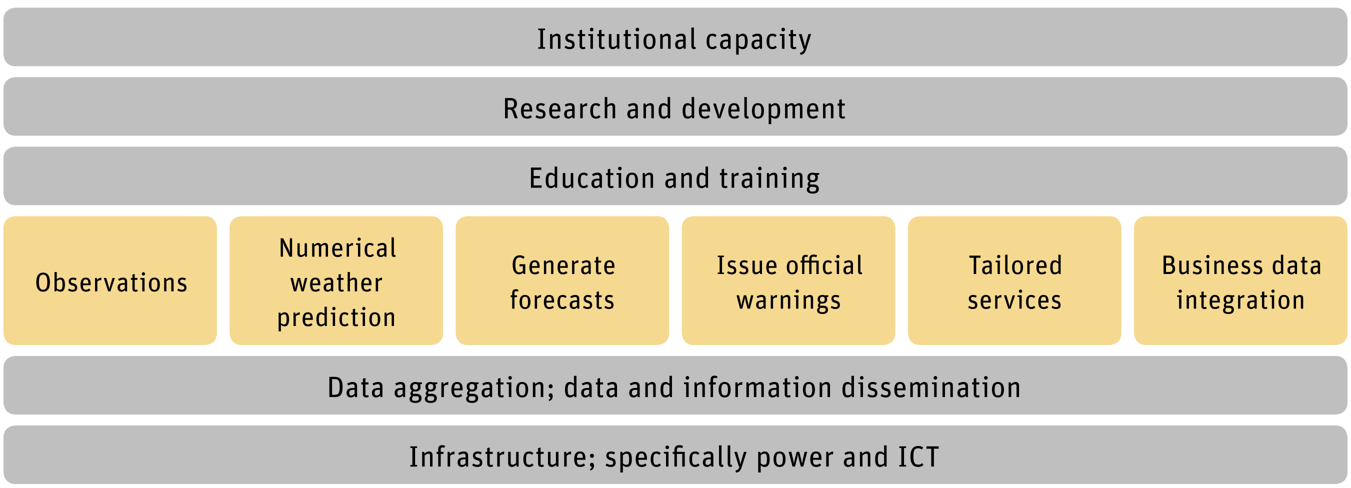
2. Setting the scene

This chapter discusses a notional hydromet value chain and introduces many of the concepts used in this study.

2.1 Hydromet value chain

The analysis is based on the concept of a hydromet value chain, shown in Figure 1 with its key enablers. This is a simplified notional value chain, tailored to this study. It does not cover the specifics of hydrological services, which are out of the scope of the analysis.

Figure 1: **Simplified hydromet value chain (yellow) and key enablers (grey). The value chain should be read left to right. Due to simplification, there is no strict sequence; for example, «Issue official warnings», «Tailored services», and «Business data integration» can be independent of each other. Institutional / organizational enablers are depicted above the value chain, technical enablers below.**



In the study's analysis, the hydromet value chain elements and enablers are defined as follows. Note that enablers are further divided into institutional / organizational enablers and technical enablers:

2.1.1 Hydromet value chain elements

- *Observations:* This subsumes all observations, including the operation of manual and automatic weather stations, upper air stations, remote sensing, aircraft-based sensors, Internet of Things (IoT) sensors, etc. No distinction is made here between high-quality observations used in data assimilation and other observations (e.g. used in post-processing of numerical weather prediction results).
- *Numerical weather prediction (NWP):* The creation, operation, and maintenance of numerical weather prediction systems, including global and limited-area models.
- *Generate forecasts:* The manual or automatic evaluation of available data, including NWP outputs to generate weather forecasts. This includes post-processing of NWP outputs such as to increase forecast quality with the help of model output statistics.
- *Issue official warnings:* The issuance of official warnings which can lead to emergency procedures (e.g. evacuations). Note that the *dissemination* of official warnings is not included in this element: it is included in the *data and information dissemination.*

The role and possible risks of non-official warnings issued by private weather providers is a much-debated topic, as the coexistence of public and private weather-information providers can lead to a confusing multitude of inconsistent warnings (e.g. different severity levels or different types of visualizations for the same event). The issue is becoming more important with the increase of private providers and channels to access weather information and warnings and in some cases, to even refine the warnings with additional observations. Since the differences between the official hydromet services and private actors and any behind-the-scene communications are not always transparent to the public, the public trust in official warnings can be weakened by inconsistent warnings.

Weyrich et al. (2019) examined the influence of inconsistent warnings from multiple providers in Switzerland. They showed that people use different warning providers; warnings are often perceived as inconsistent; and the quality of consistent warnings was evaluated more positively than the quality of inconsistent warnings.[5]

- *Tailored services:* The design and delivery of hydromet products and services are tailored to inform operational decisions. For example, deliver agricultural forecasts that help farmers to determine when to plant, fertilize, or apply pesticides. For the purposes of this report, tailored services also include issuing and disseminating warnings that do not have official status alerts (e.g. alerting farmers to changes to an earlier forecast as well as disseminating official warnings).

  Note that the economics of the hydromet value chain discussed in Chapter 2.2 distinguishes between «targeted services» and «industry-specific services», both of which are subsumed in «tailored services». However, the distinction becomes important when deciding where to draw the boundary between public and non-public services.

- *Business data integration:* Industry-specific forecast services where up-to-date business data are integrated with weather information. Examples include supply chain optimization for beverage distribution.

2.1.2 Institutional / organizational enablers

- *Institutional capacity:* The capacity of public, private, and academic institutions to co-design, co-implement, and co-manage the hydromet value chain.
- *Research and development:* The capacity to innovate value chain elements. Research and development are much interlinked with the cooperation between the public and academic sectors. One of the challenges of such cooperation is the different timescales: the long-term objectives of applied research and the short-term operational needs.
- *Education and training:* The capacity to develop individual and organizational skills needed in the hydromet value chain.

2.1.3 Technical enablers

- *Data aggregation; data and information dissemination:* The ability to collect data (e.g. from automatic weather stations) and to make the data available where needed. Likewise, the ability to disseminate data and the derived information to where they are needed. Notably, this includes the dissemination of official warnings.
- *Infrastructure, specifically power and Information and Communication Technology (ICT):* Required infrastructure in support of the hydromet value chain. Of specific interest are the availability of electrical power and suitable ICT systems.

The maturity of hydromet value chains and their elements differs vastly among countries and affects boundary conditions for potential public-private engagements. At the same time, the relative contribution to the value chain from the public, private, and academic sectors is an important factor. It defines the dynamics between those three sectors and thus provides important information on the country. In the case studies, the level of development (i.e. maturity) of the hydromet value chain and its elements and the relative contribution of the public, private, and academic sectors to the value chain are qualitatively assessed to provide the country context. In order to sustainably optimize the value chain, assessing its overall maturity and that of its elements helps to direct improvement efforts.

[5] The Swiss case is interesting, because there are different providers of severe weather warnings in Switzerland, and the warnings regularly differ in visualization and text. For example, for the same heavy rain event on November 2017 in the southern part of Switzerland, Weyrich et al. (2019) identified four warnings, all issued by Swiss providers, that differed in color, text, and predicted amount of rain.

Table 3 defines maturity levels for the purposes of this study. Note that a country's ability to issue and disseminate official warnings is used as an indicator for the overall maturity of its value chain. Each row in Table 3 should be considered as independent of the others, at least in principle. In particular, the table does not imply that a country's hydromet value chain can be defined as advanced only if all its components are advanced.

Table 4 defines maturity levels for two key enablers: (i) research and development and (ii) education and training.

Table 3 | **Elements of the hydromet value chain and classification of their maturity level. Note that this classification refers to the value chain, not a specific organization (e.g. an NMHS).**

	Levels of Maturity			
	Advanced	**Intermediate**	**Low**	**Not available**
Entire value chain	Socio-economic benefits of hydromet services are widely realized. Official warnings have state-of-the-art accuracy and reach everybody affected.	Some socio-economic benefits of hydromet services are achieved. Official warnings have mixed accuracy and/or do not reach everybody affected.	Very few or no socio-economic benefits of hydromet services are achieved. There are only very basic official warnings and they reach a minority of the people affected.	No benefits are derived from hydromet services. There are no official warnings.
Observations and their usage	Adequate coverage with ground-based and upper-air observations. Access to most satellite data. All data available timely where needed. Participates in the receiving and sharing of observations for the global observing network. Effective use of observations in nowcasting hazards.	Gaps in the nation's observational network. Relevant satellite data sometimes not received and/or well utilized. Shortcomings in the receiving, utilization, and sharing of observations fort the global observing network. Difficulty in nowcasting some hazards.	Very sparse coverage of ground-based observations and difficulty in using observations to nowcast hazards. Satellite data hardly available and poor participation in the global observing network. Nowcasting of hazards is poor and not timely.	No ground-based observations. Satellite data not available. Nowcasting capabilities are not present.
Numerical weather prediction	NWP codes created and/or innovated with local resources. Models achieve state-of-the-art skill, run regularly. Models run at global, regional, and local scale (if it adds value). Model ensembles and multi-model ensembles quantify forecast uncertainty. Model output readily available.	Access to and effective use of international global models. Downscaling of global systems and/or regional NWP models set up and operated with local resources. Capable of locally integrating and post-processing and output from global and local/regional systems.	Access to NWP output from international sources only in the form of limited maps and diagrams generated elsewhere. Local resources operate a local NWP model or down-scaling set up by a third party. Global models often outperform local systems.	Poor access to and limited usage of international models. No capability to downscale or run local NWP models or participate in regional efforts.
Generate forecasts	Generate forecasts from a mix of global, regional, and local NWP output. Add NWP results obtained from elsewhere to enhance the forecast in specific situations. Add local expertise and statistical post-processing to improve the forecast.	Generate forecasts from a mix of local NWP output and NWP results obtained from elsewhere. Add local expertise to improve the forecast.	Generate forecasts primarily from NWP results obtained from elsewhere.	No forecasting capability.

Table 3 | cont.

	Levels of Maturity			
	Advanced	**Intermediate**	**Low**	**Not available**
Issue official warnings	Official warnings have state-of-the-art accuracy and reach everybody affected. The warning system is resilient.	Official warnings have mixed accuracy and/or do not reach everybody affected.	Only very basic official warnings and they reach a minority of the people affected.	No official warnings.
Tailored services	A large variety of tailored forecast products and services regularly used by organizations. Needs for new services are quickly identified and met.	Some tailored forecast services regularly used by organizations. Considerable time required to meet new needs. Significant dependence on international services/ products.	No significant development of new services. Significant dependence on international services/ products.	No activities.
Business data integration	Widely used operational decision making based on continuous data feeds combining weather forecasts, real-time weather information, and real-time business data.	Weather and business data integration used by some organizations. Individual projects evaluate advanced approaches. Possible significant dependence on international resources.	A few projects evaluate whether integrating weather and business data could be beneficial. Significant dependence on international resources.	No activities.

Table 4 | Two key enablers of the hydromet value chain and classification of their maturity level.

	Levels of Maturity			
	Advanced	**Intermediate**	**Low**	**Not available**
Research and development	Efforts in place locally to evaluate data quality, NWP skill, and forecast accuracy. Basic and applied research efforts relevant to all aspects of the forecast system (observations, NWP, post-processing, societal use) to maintain a state-of-the-art forecast system.	Efforts in place locally to evaluate data quality, NWP skill, and forecast accuracy. Applied research to advance some aspects of the forecast system but limited local innovation. International research partnerships.	Detailed evaluation of the components of the forecast systems done sporadically or by others. Innovations developed elsewhere are adapted slowly at the local level.	No activities.
Education and training	Ongoing efforts in place locally to maintain well-trained work force and a pipeline of new employees are available, as needed, across the relevant sectors. Effective partnerships exist between the academic, public, and private sectors and specialized users to ensure forecasts and products are state-of-the-art and well-utilized.	Periodic efforts to train a work force in place through external partnerships, but some difficulties in maintaining a pipeline of new employees. Some gaps in the partnerships between the academic, public, and private sectors and specialized users.	Struggle to maintain a well-trained work force as external partnerships are ineffective and local academic sector is quite limited and/or partnerships between the sectors do not exist.	No activities.

Figure 2: Sector balance diagram used in this report.

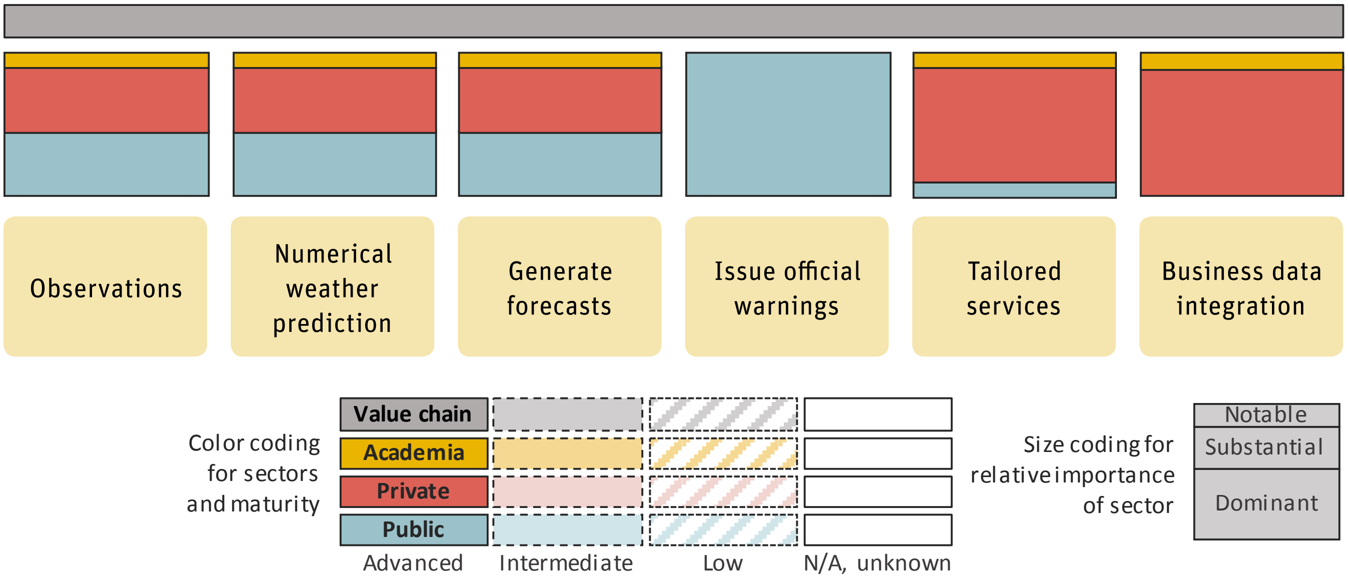


Figure 2 provides an example of how the analysis is visualized in a hypothetical country. This diagram simultaneously shows the maturity of each hydromet value chain element and the relative contribution from the public, private, and academic sectors to each element in that country. In this example, all value chain elements are advanced, and in most elements, both the public and private sectors contribute substantially while the academic contribution is notable in most elements. Further, official warnings are issued exclusively by public sector entities, while dissemination of such warnings could be taken up by the private sector as well.

A weather forecast per se has limited commercial value until its implications are understood and acted upon in the context of a particular business, process, or activity. Weather observations are a costly service while most revenues are created at the customer end of the chain, through valuable products or services. The aggregated socio-economic benefit,[6] however, does not follow the same pattern. Basic weather forecasts and especially official warnings can induce a high socio-economic benefit (e.g. by reducing the morbidity or reducing health-care and safety costs). Issuing official warnings has a special place in the value chain, as in many countries it falls within a government's remit to safeguard lives and property.[7] Additionally, the relatively lower cost at the customer end of the value chain is only possible if global data sets and the results of global forecasting centers are available. Further, the production of warnings and tailored products require higher qualification and incur a significant «hidden» cost element attached to training and sustaining a high-quality workforce.

Observation networks, observation data management, and large numerical weather prediction systems run as public services (i.e. information, funded by governments, provided free at the point of use) continue to form the backbone of the larger hydromet services around the world. The academic sector plays an important role in innovation and capacity building. At the same time, private-sector capabilities are increasing, and not only in providing specialized information to the public and specific users but also in becoming more competitive in elements traditionally dominated by the public sector. Many developed countries leverage private-sector capabilities in various forms of public-private engagement; other countries could benefit from adopting such approaches. There are many trade-offs to consider, and the simplified value chain allows us to look at them in a systematic way.

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6 The term «aggregated socio-economic benefit» is used to capture the total rise in economic welfare which is induced by using hydromet data, products, and services in a country or region.

7 Disseminating official warnings is as important as issuing them; in this report, dissemination of official warnings is subsumed under data and information dissemination (Figure 1).

2.1.4 International Requirements

International requirements as stipulated by WMO and other international organizations such as the International Civil Aviation Organization (ICAO) and International Maritime Organization (IMO) obligate their Member States to fund and produce certain information and to provide services needed at the international level. For example, the ICAO's Chicago Convention requires each contracting State to provide aeronautical meteorological services which are highly standardized. The International Convention on Safety of Life At Sea (SOLAS), which is managed by IMO, mandates States to organize and provide certain services for shipping. These elements are important when considering the level of maturity and scope of the NMHS or other agencies involved.

2.2 Economics of the hydromet value chain

Services generated within the hydromet value chain can have significant economic implications (see, for example, Gunasekera 2004) which must be taken into consideration. The main considerations include: (i) effective public-private engagement which takes the economic implications of public goods into consideration; (ii) technological advances, which have shifted some economic conditions (e.g. cost of automatic weather stations and availability of nanosatellites); and (iii) stakeholder interaction, which may benefit from clearer definition of notions such as «public good», «public interest», and «public service».

2.2.1 Cost structure and efficiency gains

Hydromet information (e.g. forecasts and official warnings) is expensive to produce but relatively cheap to reproduce. This is because large fixed costs (e.g. infrastructure and personnel costs for the observation network, ICT and NWP facilities, and research and development (R&D) expenditures) are incurred to produce the information. Once the information is produced, the cost of disseminating it is relatively low. Three key economic principles pertain to this study.

Economies of scale

If the cost per unit of output decreases with increasing scale (quantity) of production, economies of scale are occurring. In economic terms, this means that for each additional unit of output, its marginal cost is beneath its average cost. Due to their cost structure (high fixed costs, low variable costs) **most hydromet services exhibit strong economies of scale**. Note that part of the reason why regional cooperation is so important for establishing cost-effective meteorological services is because of the economies of scale.

Economies of scope

Economies of scope occur if the gain in efficiency comes from the variety of output and not from the scale of production. If economies of scope occur, the average costs can be lowered by producing more types of products at the same time or within the same organization. Economists speak about positive spillover effects: The inputs needed to produce product A have a positive effect on the efficiency of product B's production. In the hydromet context, economies of scope are often realized if the same infrastructure (e.g. observation networks and supercomputers) and skillset (e.g. data handling, modeling, and forecasting) are needed to produce different hydromet services (e.g. general weather forecasts, official warnings, and tailored services). **Note that both infrastructure and skills are needed to generate economies of scope.** For example, designing, producing, delivering, and supporting a tailored hydromet service can require an organization and skill profile very different from those required to operate a good public weather service (e.g. personnel trained in marketing and sales that understand customer needs and are able to develop, pitch, and support marketable products; fast product development cycles rather than scientific processes; and facilities for individual customer support). The dependency on skills is often underestimated when discussing economies of scope in the hydromet services context (see, for example, the typology of hydromet services in Section 2.2.3).

Natural monopolies

In most industries, the total average cost (sum of fixed and marginal cost per unit of output) falls with increasing output until a minimum is reached and then increases again. This behavior is typically due to the interaction between efficiency gains through economies of scale and efficiency losses because of the complexity of large organizations. However, industries with small and roughly constant marginal costs exhibit a different cost structure: within reasonable boundaries, the total average cost will always decrease with increasing production, and thus the minimum cost is reached at a maximal output level. Such industries are often referred to as natural monopolies. Note that natural monopolies can occur because of other reasons (e.g. very high market entrance barriers). A simpler and more general definition of a natural monopoly is an industry in which production by multiple suppliers is costlier than production by a single supplier. Examples of natural monopolies include network-based industries such as electricity supply, water supply, railroads, or gas pipelines.

Often the «upstream end» of the hydromet value chain, especially the observation network, is assumed to have natural monopoly characteristics. While this may have been true in the past, the situation is not that clear anymore. The massive technological advances in the hydromet domain drive down cost and lead to technological substitution effects and new business models. For example, with today's ready availability of automatic weather stations, the costs of operating an observation network are lower than 50 years ago. As another example, a future technological substitution could be the use of sensor data from cars or mobile phones to complement observation stations (some countries have already started incorporating sensor data).

2.2.2 Public and other goods

Economists classify goods using the concepts of «rivalry» and «excludability». A good is rivalrous if its consumption by one consumer prevents simultaneous consumption by other consumers. A good is excludable if consumers can be prevented from accessing it. The four possible combinations of rivalry and excludability result in four classes of goods as shown in Table 5.

Table 5 | Classification of goods.

	Excludable	Non-excludable
Rivalrous	Private goods (e.g. apples)	Common goods (e.g. fish stock)
Non-rivalrous	Club goods (e.g. streaming service)	Public goods (e.g. free-to-air television)

Public goods are an example of market failure,[8] because they exhibit positive externalities (economic benefits) for which the producer is not compensated through the price mechanism. Therefore, public goods are often insufficiently produced by a free market. Also, public goods should not be confused with public interest. The term «public good» refers to the classification of goods and means non-rival and non-excludable goods, regardless of a good's importance to the public.

2.2.3 Typologies of hydromet services

Hydromet services are often grouped into categories. This study uses the categorization in Table 6 (based on Gunasekera 2004), which uses the economic principles mentioned above to define the type of service.

Table 6 | General typology of meteorological services using economic criteria as defining criteria. For instance, services which are generally non-rival, excludable, and exercise economies of scale and scope are defined «targeted services».

Type of services	Economic characteristics				
	non-rival	non-excl.	economies of scale	economies of scope	nat. monopoly
Basic systems					most
Basic services					
Targeted services					
Industry-specific services					
Value-added services					

8 Market failure occurs when the allocation of goods by a free market is not efficient, leading to welfare losses. This can occur for all type of goods.

Table 7 provides examples of hydromet service categories. The categorization is illustrative, and many grey areas exist; for example, the light red boxes suggest an alternative categorization of the service. Note that «targeted services» and «industry-specific services» together correspond to the «tailored services» element of the hydromet value chain (Figure 1).

Public services

The free market is unlikely to provide services with public good and natural monopoly traits sufficiently («basic system» and «basic services» in the typology) because such traits can lead to market failure. Therefore, there is a need for strong regulation and intervention by public entities to ensure the availability and quality of such services. Within this report, those services are referred to as «public services». The differentiation between public services and non-public services is, however, not clear-cut. There will be always gray areas with room for interpretation and country-specific preferences (see, for example, the last paragraph of Chapter 2.2.4). When facing the issue of whether a specific service should be considered public or non-public, decision makers may also consider if competition is likely to increase innovation and to lead to better or less-expensive services for the consumer.

The characterization of a service as public service does not necessarily mean that it must be provided by a public entity such as an NMHS. Some public services can also be produced by the private sector under the supervision of the public sector and/or a regulator. For example, the public sector contracts a private company to produce a specific service.

The production of public services can be funded through taxes or fees. The difference between a fee and a tax is that a fee is paid for specific goods or services rendered by the government, while a tax has no direct connection to the benefits received.

Non-public services

For all other services («non-public services»), competition is likely to generate considerable benefits **As in the**

Table 7 | **Examples of services and their categorization to illustrate the typology of hydromet services. Light red boxes suggest a second possible categorization.**

Service	Basic systems	Basic services	Targeted services	Industry-specific services	Value-added services
Surface observation network	X				
Classic satellites	X		(X)		
New generation of satellites[9]	(X)		X		
Basic numerical weather prediction models	(X)	X			
Public weather forecasts		X			
Extreme weather warnings		X			
Climate information		X			
Forecasts for specific user groups (e.g. pilots, mariners, farmers)		(X)	X		
Information provided to shipping companies, airlines, …			(X)	X	
Personalized weather advice				(X)	X
Services for media					X
Services that integrate customer's business data (e.g. ship routing, powerplant management)					X

9 Nanosatellites which are much less expensive to deploy and to run.

case for public services, non-public services are not necessarily provided exclusively by the private sector. Therefore, the regulator must ensure a free market and a level playing field for all competitors. This is especially important if the public sector is producing non-public services alongside public services.

2.2.4 Guidelines for choosing the optimal service delivery model

The delivery of hydromet services along the hydromet value chain can be organized in different ways. The model chosen for a specific country depends not only on the economic principles discussed above but also on the country-specific situation and priorities. The following guidelines can help countries to navigate the issues and to decide on the optimal service delivery model.

Step 1

Define which services should be provided by the hydromet value chain

This has to be done by considering the country-specific public interest and the potential socio-economic benefit those services provide. Some aspects of the public interest are equally important for most countries (e.g. safeguarding lives and property); others differ from country to country. For instance, country-specific public interests can be dependent on geographical features (e.g. a landlocked country does not need marine forecasts), economic priorities (e.g. agriculture, fisheries, and off-shore drilling), or geopolitical requirements (e.g. worldwide operating armed forces).

Step 2

Assess which services are public services and which are not

The assessment should be based both on supply- and demand-side characteristics:

- Does a service have public good characteristics?
- Is there public interest in providing the service (e.g. public safety and security)?
- Is there a natural monopoly in the sense that production by multiple suppliers is costlier than production by a single supplier?[10]
- Are economies of scale and/or scope to be expected?

Services which are of public interest and which show public good characteristics or natural monopoly features should be considered public services. In the typology introduced earlier, public services include «basic systems» and «basic services».

Step 3

Determine the form of service provision for public services

- *Choose between a «do-it-yourself» option and a «contracting-out» option for the provision of public services:* Which public services should be produced by the NMHS and which public services should be contracted to the private sector? Beside strategic considerations, decisive factors may also include the feasibility of sustainable long-term contracts with the private sector and the cost of service provision. Even if some services are contracted to the private sector, the public sector must ensure the provision and the quality of public services. Hence, the NMHS (if it has regulatory duties) or another regulatory body must be able to provide the necessary technical and organizational oversight.

  For the part of the basic system with strong natural monopoly supply features, a regulated private monopoly could be an alternative to the production by the NMHS, although such practice is not common for hydromet services today.

- *Determine the funding mechanism for public services:* taxes or fees. Fees are applicable only if a clearly defined sub-set of the population uses the services/products.

Step 4

Organize the form of service provision for non-public services

Three approaches can be identified for the provision of non-public services:

- Provision by the private sector without any hydromet-specific regulation;

[10] This will be a conceptual exercise and not a precise calculation. In practice, natural monopolies are rare (e.g. train network, high voltage transmission grid). In the hydromet domain, the basic surface observation network and classic satellites might have natural monopoly properties.

- Provision by the private sector with some form of hydromet-specific regulation (e.g. licensing and quality requirement); and
- Provision by a public entity complying with competition policy and competitive neutrality to ensure a level playing field.

The last option may provide a government the best value for money. However, it is very challenging from an institutional perspective, as a regulator must ensure a level playing field between the private and public sectors. This is especially challenging if public and non-public services are produced within the same organization. Moreover, from a regulatory perspective, it is a complex task which requires strong institutions and a developed legal framework. This point is particularly critical for most developing countries where institutions and the legal framework may not be adequate yet.

While the economic principles discussed in this chapter provide an important and useful guideline, there is room for interpretation and weighting of arguments. In general, using only economic principles would underestimate the complexity of the topic and the role of country-specific preferences; the existing institutional, legal, and administrative environment; and the current allocation of responsibility in a specific country. Those factors must be taken into consideration when choosing the optimal service delivery model: for a specific country, this choice cannot be dictated by a single institution or by experts but has to be developed through a political process informed by sound economic principles and fact-based evidences.

3. Case studies

This chapter elaborates on the hydromet value chain in six selected countries as per the selection criteria described in Chapter 1. Information was gathered about the essential services, the actors (public and private alike), the users, and the channels of information distribution. The legal and policy frameworks and other factors that shape service delivery in general and public-private engagements in particular were included in the scope of the case studies.

In countries where data or services are provided by private companies, the study examines their relations and interactions with the NMHS and any impediments to private-service provision. Illustrative examples of public-private engagement were collected to better understand the role of the involved actors, the business model, the involvement of the NMHS, and the impact of the engagement on the market. A transnational perspective of weather companies which operate and/or provide services in many countries complements the country case studies.

The details vary among countries according to the extent and ready availability of pertinent information. The chapters on Germany and Israel focus solely on their recent policy changes, to gain additional insights into the regulations of data access and scope of services rendered by the NMHS.

The countries' order of appearance reflects the fact that the developed countries are used as reference and therefore are mentioned ahead of developing countries.

3.1 Overview

Table 8 provides an overview of basic indicators in the analyzed countries. The analysis and the conclusions are not based solely on those indicators. This is especially true for indicators related to the NMHS budget because:

- NMHSs' mandates vary considerably. For example, the Japan Meteorological Agency (JMA) covers seismology and volcanology in addition to meteorology but not hydrology; the Meteorology, Climatology, and Geophysical Agency of Indonesia (BMKG) covers meteorology and seismology but not volcanology.
- The budgets reported to WMO, which are mainly used here for comparability reasons, may be underestimated due to contributions by other agencies and regional governments. For example, in some developed countries, the task of producing weather forecasts and warnings is often split among agencies, while in developing countries this is often not the case. In addition, these budgets may be affected by considerable exchange rate fluctuations.
- The NMHS funding mechanisms are very heterogeneous throughout the sample of countries.

Hence, while it is not possible to compare NMHS budgets in detail, Table 8 provides useful insights about the nature and magnitude of the differences among countries. The right-most column depicts the ranking of a country in the World Bank Group «Ease of Doing Business» (2017). A high ranking means the regulatory environment is conducive to starting and operating local companies.

Table 8 | Overview of basic indicators in selected countries (in order of appearance in this report).
Data sources (accessed September 2018): (a) http://wdi.worldbank.org/table/2.1; (b) http://wdi.worldbank.org/table/4.2; (c) https://www.wmo.int/cpdb > converted to USD; (d) https://www.wmo.int/cpdb; (e) http://www.doingbusiness.org/en/rankings; and (f) personal communication.

Country	Total Population[a]	GDP[b]	GDP per capita	NMHS budget[c]	NMHS budget per capita	NMHS number of staff)[d]	Ease of Business Rank[e]
	Million 2017	USD billion 2017	USD 2017	USD million div.	USD div.	Number div.	190 total countries 2018
U.S.	325.7	19,390.6	59,535	1,000[11]	3.07	4,402	8
U.K.	66.0	2,622.4	39,733	298	4.52	1,997	9
Japan	126.8	4,872.1	38,424	593	4.68	5,027	39
Indonesia	264.0	1,015.5	3,847	165	0.63	4,748	73
Myanmar	53.4	69.3	1,298	1.7	0.03	843	171
Ghana	28.8	47.3	1,642	6.2 (f)	0.22 (f)	380 (f)	114
Germany	82.7	3,677.4	44,467	385	4.66	2,336	24
Israel	8.7	350.9	40,333	5	0.57	n/a	49

11 This is a significant underestimation as many agencies, besides the NWS, contribute to the task.

Each sub-chapter begins with a short summary of the main findings and a diagram summarizing the maturity of the country's value chain and its components. The balance between the public and private sectors and the role of academia are depicted as well. The maturity of each sector is assessed as advanced, intermediate, low, or not available, following the classification in Table 3. The importance of each sector in the provision of services is qualitatively categorized as notable, substantial, or dominant; the relative size of shapes in the diagrams reflects this categorization and cannot be interpreted as a quantitative measure.

3.2 United States

3.2.1 Overview and Summary

The overall maturity of the hydromet value chain in the United States (U.S.) is advanced, and both the private and public sectors play a major role in the first four elements of the value chain (Figure 3). Academia plays an important role in the U.S., not only for education, training, research and development, and innovation but also for elements of the hydromet value chain. Public services (for a definition see Chapter 2.2.3) are provided by the National Weather Service (NWS) and other agencies under the National Oceanic and Atmospheric Administration (NOAA). Following a policy framework which emphasizes free and open data access, the private sector clearly dominates tailored services and business data integration. Business data integration is at an intermediate stage of development.

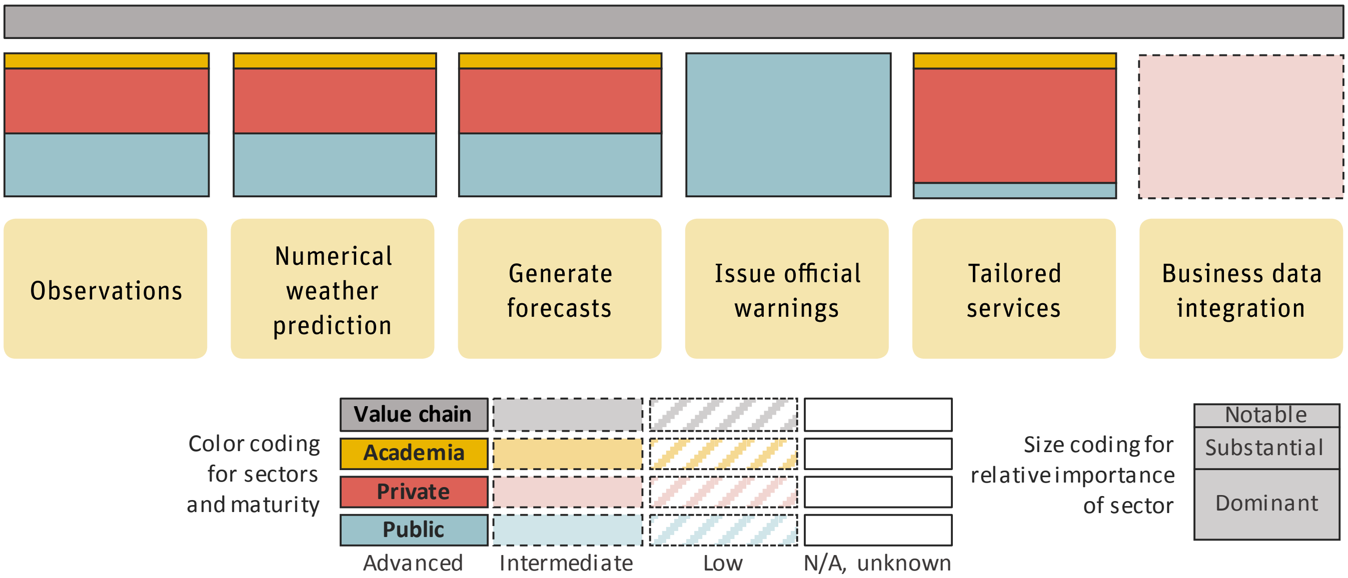
The role of the NWS and other agencies involved in the hydromet value chain is explicitly regulated and restricted to public services. The agencies are fully funded by the public and no direct cost recovery is pursued. Therefore, hydromet agencies' PPE focuses on customer-supplier relationships. The production of some data sets is already outsourced to the private sector, and NOAA is considering increasing outsourcing (e.g. in the fields of cloud services for high-performance computing and space-based observation systems).

3.2.2 Services, users, and providers

The United States has a large and active hydromet value chain serviced by government agencies, large and small private companies, and academic institutions.[12] In 2017, the market value of the U.S. weather industry was estimated at USD 9 billion, with revenues ranging from USD 2 billion to USD 4 billion.[13]

12 http://www.nws.noaa.gov/im/metdir.htm.
13 https://www.weather.gov/media/wrn/calendar/EnterpriseStrategySession_2017.pdf.

Figure 3: **Sector balance and maturity in U.S. hydromet value chain.**



Essential services and channels of communication

NOAA is a government agency under the U.S. Department of Commerce. NWS is part of NOAA and is organized in nine National Centers for Environmental Prediction (NCEP). NWS covers every aspect from weather, ocean, and climate prediction to space weather prediction:

1. Aviation Weather Center
2. Climate Prediction Center
3. Environmental Modeling Center
4. National Hurricane Center
5. NCEP Central Operations
6. Ocean Prediction Center
7. Space Weather Prediction Center
8. Storm Prediction Center
9. Weather Prediction Center

The Aviation Weather Center provides aeronautical meteorological services. The National Hurricane Center, Storm Prediction Center, Ocean Prediction Center, and Space Weather Prediction Center provide official warnings for their respective areas of operation. NCEP Central Operations runs NWP models and prepares NCEP products for dissemination. A key product used worldwide is the freely available Global Forecast System's (GFS) output.[14] NWS field operations and forecasts (including aviation) are done both at NCEP and at the 122 weather forecast offices, 13 river forecast centers, and 21 center weather service units.[15] NOAA operates a large website communicating its work, providing educational material and access to weather forecasts. NWS' yearly budget amounted to around USD 1 billion in 2012.[16]

Operational weather prediction in the U.S. is supported by a large research enterprise, including seven research laboratories overseen by NOAA's Oceanic and Atmospheric Research Division. The mission of these research laboratories is to integrate research, technology, and services to understand and predict changes that occur in the atmosphere, oceans, and inland waters. NOAA also supports 16 Cooperative Institutions through partnerships with 42 universities and research institutions to further their mission in these areas. Research related to atmospheric and hydrological systems also takes place at the National Center for Atmospheric Research (NCAR), National Aeronautics and Space Administration (NASA), and Department of Energy (DoE) laboratories and within the university community through support of various federal agencies. The efforts

[14] http://www.nco.ncep.noaa.gov/pmb/products/gfs/.
[15] http://www.nws.noaa.gov/organization.php.
[16] https://www.weather.gov/media/wrn/calendar/EnterpriseStrategySession_2017.pdf.

in the U.S. also include unique partnerships, such as the Northwest Regional Modeling Consortium that involves universities, the National Weather Service, and a variety of users focused around high-resolution regional modeling undertaken at the University of Washington.

The National Center for Atmospheric Research (NCAR) «provides scientists across the U.S.—and the globe—with a host of tools, from community models to research aircraft to supercomputers to workshops».[17] NCAR also provides training and support to academia, the government, and the private sector in the U.S. and internationally. NCAR's open source Weather Research and Forecasting (WRF) numerical weather prediction system has an extensive worldwide community of registered users (a cumulative total of over 39,000 in over 160 countries).[18] NCAR is a federally funded research and development center. The National Science Foundation is the majority financial investor; other financial agencies and non-federal sources are minority investors.

Additionally, extensive academic research is conducted by U.S. universities and government laboratories such as NASA's Jet Propulsion Laboratory (JPL) and the DoE-sponsored Lawrence Livermore National Laboratory, among others. Federal departments and agencies provide public-sector hydromet services (i.e. Dept. of Defense, Dept. of Agriculture, Dept. of Transportation, and U.S. Geological Survey) and numerous federal agencies support research related to hydrometeorology.

3.2.3 Legal and policy framework

The principal statutory authority governing NWS is the National Weather Service Organic Act of 1890. The law directs NWS to collect meteorological data, provide meteorological forecasts, and produce a range of meteorological services. The Weather Service Modernization Act of 1992 served to modernize the technology and operations of the National Weather Service (NWS); it requires the Secretary of Commerce to «certify that the modernization process will not degrade local weather services».

NWS forecasts and data are in the public domain and thus available to anyone for free in accordance with U.S. law. In 2005, the NWS Duties Act was proposed to prohibit NWS from freely distributing weather data if the data could be provided by the private sector. The bill was widely criticized by users of NWS services, especially by emergency management officials who rely on NWS for information during emergencies (e.g. fires, flooding, and severe weather). As a result, the NWS Duties Act was not adopted.

The most recent and important act governing NWS activities is the Weather Research and Forecasting Innovation Act of 2017. This legislation aims to improve NOAA's weather forecasts and official warnings, both for the protection of lives and property and for the enhancement of the national economy. The act also covers topics such as future weather satellite data needs, gaps in Next Generation Weather Radar (NEXRAD) coverage, and improvements in the transfer of advances in research and development to NWS operations.[19] U.S. Code § 2074 makes it illegal to counterfeit weather forecasts or official warnings.[20]

Data policy

The U.S. government has a comprehensive open data policy (U. S. Government 2016). According to U.S. policies, agencies must apply the following principles concerning open data:

- **Public.** Consistent with the Office of Management and Budget's Open Government Directive,[21] agencies must adopt a presumption in favor of openness to the extent permitted by law and subject to privacy, confidentiality, security, or other valid restrictions.
- **Accessible**. Open data must be made available in convenient, modifiable, and open formats that can be retrieved, downloaded, indexed, and searched. Formats should be machine-readable. To the extent permitted by law, these formats should be non-proprietary, publicly available, and without restrictions on their use.
- **Described.** Open data must be described fully so that consumers have sufficient information to understand the data's strengths, weaknesses, analytical limitations,

[17] https://ncar.ucar.edu/what-we-offer.
[18] https://www.mmm.ucar.edu/weather-research-and-forecasting-model.
[19] https://www.everycrsreport.com/reports/R44838.html.
[20] https://www.law.cornell.edu/uscode/text/18/2074.
[21] https://project-open-data.cio.gov/policy-memo/.

security requirements, and how to process them. This involves the use of robust, granular metadata, thorough documentation of data elements, data dictionaries, and, if applicable, additional descriptions of the purpose of the collection, the population of interest, the characteristics of the sample, and the method of data collection.

- **Reusable.** Open data must be made available under an open license that places no restrictions on their use.
- **Complete.** Open data must be published in primary forms, with the finest possible granularity that is practicable and permitted by law and other requirements.
- **Timely.** Open data must be made available as quickly as necessary to preserve the value of the data.
- **Managed Post-Release.** A point of contact must be designated to assist with data use and to respond to complaints about adherence to these open data requirements.

Regulation of public-private engagements

Different policies govern the roles of the private and public sectors in the hydromet value chain.[22] Important principles of the partnership between the public and private sectors are documented in NOAA's 2007 «Policy on Partnerships in the Provision of Environmental Information». The policy is dedicated to strengthening the partnership between the public, private, and academic sectors. The following extracts[23] present the main aspects of the policy regarding public-private engagement and the consequences of the data policy discussed above:

- NOAA has a responsibility to foster the growth of this complex and diverse enterprise as a whole to serve the public interest and the U.S. economy.
- NOAA will not haphazardly institute significant changes in existing information dissemination activities, or introduce new services, without first carefully considering the full range of views and capabilities of all parties as well as the public's interest in the environmental information enterprise.
- To advance the environmental information enterprise, NOAA will provide information in forms accessible to the public as well as underlying data in forms convenient to additional processing, to the extent practicable and within resource constraints.
- NOAA recognizes that cooperation, not competition, with the private sector and academic and research entities best serves the public interest and best meets the varied needs of specific individuals, organizations, and economic entities.
- NOAA will take advantage of existing capabilities and services of commercial and academic sectors to support efficient performance of NOAA's mission and avoid duplication and competition in areas not related to the NOAA mission.
- NOAA is committed to open consultation with all who are affected by NOAA's environmental information services and will use appropriate mechanisms to encourage the maximum practicable and timely input from and collaboration with interested persons and entities on decisions affecting the environmental information enterprise.
- NOAA will promote the open and unrestricted exchange of environmental information worldwide and seek to improve global opportunities for developing the enterprise.
- NOAA recognizes that open and unrestricted dissemination of high quality publicly funded information, as appropriate and within resource constraints, is good policy and is the law.

The formal framework now embodied in NOAA and NWS policies follows six informal principles, developed by NWS in 2001 to maximize fairness and openness. According to NWS, the six informal principles can still be helpful in interpreting these policies or addressing issues not covered in the formal policy.[24] In this context, it is also important to mention the «Fair Weather» report (National Research Council 2003), which has been fundamental in providing a basis for PPE in the U.S. with policy and engagement recommendations.

22 https://www.noaa.gov/work-with-us/partnership-policy.
23 https://www.corporateservices.noaa.gov/ames/administrative_orders/chapter_216/216-112.html.
24 https://www.weather.gov/coo/policydocs.

NWS increasing use of private sources of data, which have more restrictive (re)use and redistribution policies than data produced by public entities, is sparking a new debate around the open and unrestricted dissemination of data, especially for the academic community.[25] An additional challenge is the international availability of observations taken by the private sector that are useful for global numerical weather prediction.

3.2.4 Funding

NWS annual budget is approximately USD 1 billion and is provided by the federal government;[26] **no direct cost recovery is pursued.** NWS provides the foundation to enable businesses to derive economic value from weather knowledge, very roughly estimated at USD 13 billion across sectors (National Weather Service 2017).

3.2.5 Public-private engagement

Following policy changes, NOAA started to stay out of the commercial exploitation of weather data (including NWP results) in the early 2000's.[27] Public-private engagement focuses on supplier relationships and cooperation in the field of R&D. There is an ongoing debate on what roles the private and public sectors should play within the (U.S.) weather enterprise.[28] Part of this discussion is fueled by the fact that some private companies, adopting new technological possibilities, have shifted or expanded their activities to include parts of the hydromet value chain which were traditionally considered public services. For instance, companies have launched their own weather satellites or run their own weather models which they claim can compete with NOAA's GFS or with European NWP models. At the same time, the production of some data sets is already outsourced to the private sector, and NOAA is considering increasing outsourcing (e.g. in the fields of cloud services for high-performance computing and space-based observation systems).

The inter-agency (NCAR, NOAA, Dept. of Defense, and Dept. of Transportation) development of the open source WRF model is an example of academic-public-private engagement, considering its widespread international use and large user community.

Another area of cooperation between the public and private sectors is aeronautical meteorology, where NCEP services air traffic control and private companies help airlines optimize their operations. All services are coordinated to avoid conflicting information leading to misalignment of air traffic control requirements and airline operational plans.

3.2.6 International cooperation

There is strong cooperation between the U.S. and many other countries. For example, developing the open source WRF model with over 39,000 accumulated users from more than 160 countries benefits public and private users around the world and has also benefitted from the contributions of a large international community. NWS is mandated to coordinate and monitor bilateral agreements for cooperation in meteorology and hydrology between the U.S. and other countries and to coordinate with WMO.

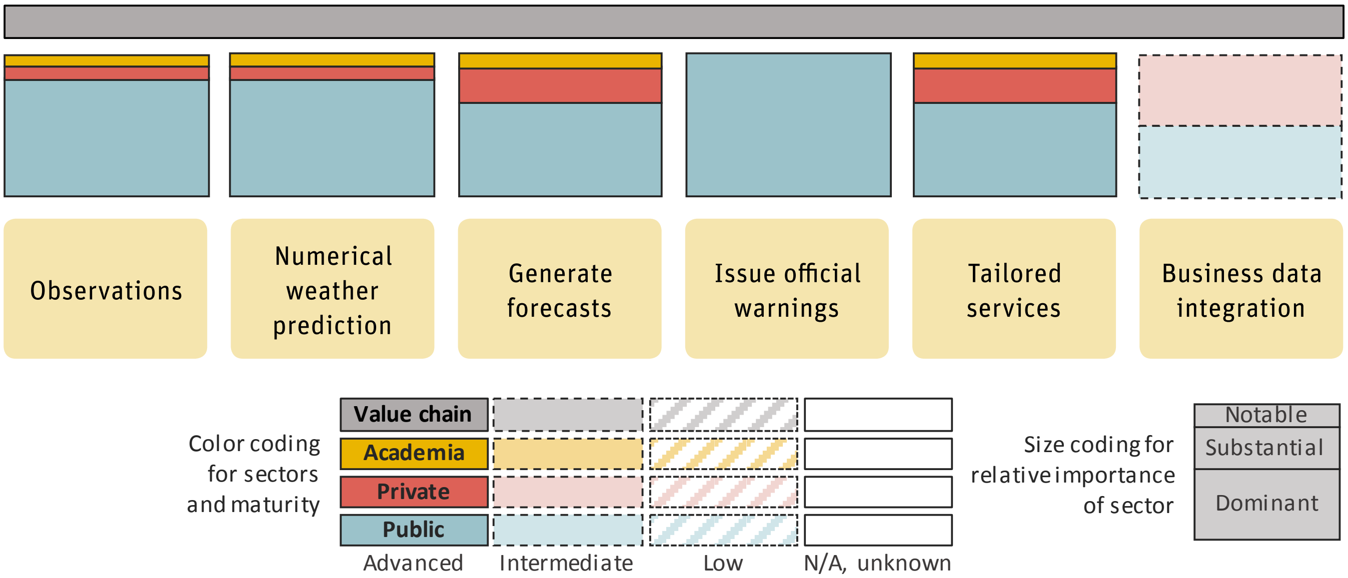
3.3 United Kingdom

3.3.1 Overview and Summary

The overall maturity of the hydromet value chain in the United Kingdom (U.K.) is advanced. The NMHS (Met Office, U.K.) is the dominant weather provider; its services portfolio covers the entire value chain (Figure 4). A distinctive feature of the Met Office in comparison to many developed countries (e.g. Germany, Japan, and U.S.) is that the Met Office operates as a «Trading Fund». A Trading Fund is a legal framework that enables an organization within the public sector to handle its own revenues and expenses according to targets set by its owners. In that sense, a Trading Fund acts more like a business without being a corporation. This means that the Met Office is required to operate on a commercial basis and to meet targets approved by its owner, the U.K. Department for Business, Energy, and Industrial Strategy (BEIS).[29] This may be one of the reasons why the Met Office dominates the hydromet market in the U.K., although one large and several niche

25 See for example: https://spacenews.com/tempers-flare-when-meteorologists-discuss-commercial-weather-data/; Serra et al., 2018.
26 https://weather.com/science/news/2018-02-13-trump-national-weather-service-budget-cut-jobs.
27 NOAA had already limited its commercial involvement and developed a policy to reduce the friction that existed with the private sector.
28 https://www.forbes.com/sites/marshallshepherd/2016/06/07/when-it-comes-to-u-s-weather-forecasting-private-public-or-both/#1a2860663a37.
29 Day-to-day ministerial oversight and the formal business ownership role are delegated to the Minister of State for Universities, Science, Research and Innovation.

Figure 4: Sector balance and maturity in U.K. hydromet value chain.



private providers exist. The Met Office plays an active role internationally and supports many countries in their effort to build and maintain NMHSs. The U.K. academic sector makes significant contributions to the state of the art in weather and climate analyses and predictions.

3.3.2 Services, users, and providers

Essential services and channel of communication

The Met Office is the U.K.'s national weather service, offering most of the spectrum of the hydromet value chain, including weather and climate data that it licenses. The Met Office provides weather and climate-related services to the armed forces, government departments, the public, civil aviation, shipping, industry, agriculture, and commerce.

The Met Office develops, runs, and maintains its own «Unified Model» which is a suite of NWP models.[30] In addition, it operates a weather and climate website and apps for smartphones with comprehensive information targeted at the general public.

The international private weather company MeteoGroup[31] operates in the U.K. and offers solutions for a number of industries, including shipping, offshore, transport, media, and energy, as well as the consumer app business. With an estimated turnover of EUR 15 million in the country, the company's revenues represented around 60 percent of the U.K.'s total private market (i.e. revenues generated by privately owned companies) in 2016 (Gutbrod and Schludecker, in preparation). Notably, in 2016, MeteoGroup competed for and won the valuable BBC (British Broadcasting Corporation) contract for weather forecasts, replacing the Met Office which had held the contract for nearly 100 years.[32] Other hydromet service companies operate in the areas of agriculture, energy, insurance, marine services, and other sectors. Some operate small-scale weather sensor networks. Overall, they do not have a significant market share but cover niches which are not occupied by the big players; generally, these companies appear to have yearly earnings of less than EUR 2 million (Gutbrod and Schludecker, in preparation). For example, a company provides legal weather services, historical weather data, forensic meteorology, and expert witness services to the legal profession and all those involved in criminal or civil litigation. The Met Office no longer provides expert witness services.

30 https://www.metoffice.gov.uk/research/modelling-systems/unified-model.
31 The company was acquired by TBG-AG, a Switzerland-based private holding company in 2018.
32 https://www.telegraph.co.uk/news/2016/08/17/meteogroup-replaces-met-office-as-bbcs-new-weather-forecaster/.

Official Warnings

As the U.K.'s mandated public weather service, the Met Office is responsible for issuing official weather warnings, including potential impacts of severe weather. Official warnings are issued by the National Severe Weather Warning Service and are communicated via the Met Office website, TV, newspapers, and social media. Flood warnings are not issued by the Met Office, but by the Environment Agency. The two agencies have formed a collaborative «Flood Forecasting Centre».[33] Private companies are allowed to further disseminate official warnings via their platforms and apps.

Observation network

The Met Office operates and maintains a modern and sophisticated measurement and observation network. Its synoptic stations cover the entire U.K., and stations within the network are separated by an average of about 40 kilometers.[34] In addition, supplementary stations provide a limited range of data to meet specific requirements, such as climate modelling, measurements of temperature and/or wind parameters at a customer's site, and dense rainfall networks to aid water management and flood forecasting. The Met Office operates a network of marine observation systems,[35] initiates official warnings, and prepares routine forecasts for dissemination on behalf of the Maritime & Coastguard Agency. The Met Office also operates many radar systems. The current system upgrade is jointly funded by the Met Office and the Environment Agency as a business relationship between government departments. The general public can make contributions to observation data, using the Weather Observations Website[36] to enter observation data from around the world.

Role of academic institutions

The Met Office has built a strong network for scientific collaboration formed by academic and research relationships **with centers of excellence and leading universities**, by combining skills and capabilities and by aligning research and development programs.[37] The U.K. parallel to NCAR in the U.S. is the National Centre for Atmospheric Science (NCAS). NCAS is an independent organization funded by the Natural Environment Research Council and distributed across many U.K. universities.

3.3.3 Legal and policy framework

Trading Fund

The Met Office, as established under U.K. law, has the distinct feature of being a Trading Fund[38] as described in 3.3.1. The Secretary of State of the Department for Business, Energy, and Industrial Strategy has oversight responsibility. However, day-to-day ministerial oversight and the formal business ownership role are delegated to the Minister of State for Universities, Science, Research and Innovation.[39]

The funded operations of the Met Office are set out in Schedule 1 to the Meteorological Office Trading Fund Order. Several other regulations govern how the Met Office interacts with its customers, including other government agencies.

According to its 2018 Annual Report,[40] the Met Office is organized in two reportable business segments (Government Services and Business Group) and provides competed[41] as well as non-competed services to public- and private-sector customers. Most non-competed services relate to the Met Office's role as the U.K.'s National Meteorological Service and its support to the Ministry of Defense and other government departments. These services are further divided into «public task» and «non-public task» activities, with the former being defined by the Met Office's Public Weather Service Customer Group.[42] To ensure a fair and level competition between the Met Office and the private sector, the Met Office's «public task» activities are ring-fenced and separated from its competed, «non-public task» activities. For instance, data or products that are required for the commercial services of the Met

33 http://www.ffc-environment-agency.metoffice.gov.uk/.
34 https://www.metoffice.gov.uk/guide/weather/observations-guide/uk-observations-network.
35 https://www.metoffice.gov.uk/weather/specialist-forecasts/coast-and-sea/observations/.
36 https://bom-wow.metoffice.gov.uk/.
37 https://www.metoffice.gov.uk/research/collaboration.
38 http://www.legislation.gov.uk/uksi/1996/774/contents/made.
39 https://www.metoffice.gov.uk/about-us/who/management.
40 https://www.gov.uk/government/publications/met-office-annual-report-and-accounts-2017-to-2018.
41 Competed services are subject to competition with the private sector.
42 https://www.metoffice.gov.uk/about-us/what/pws/pwscg/faqs.

Office business segments are supplied on the same terms and conditions that apply to external customers. This is expected to ensure that the requirement to operate on a commercial basis does not skew the free market, for example through cross-funding.

Data policy

In general, observation data, NWP model output, and forecast data and products are made commercially available, some for a fee meant to cover the cost of providing the data, others at market prices. The Met Office Open Data Policy[43] lays out how the Met Office determines which data are available for free, which are available for a nominal fee, and which can be purchased at market prices. Met Office Open Data are licensed under the U.K.'s Government License for public-sector information. The Open Data Policy classifies data into three categories: «open», «managed», and «internal». Due to challenges impacting the release of data, such as technological hurdles, funding requirements, and license terms of background data, a set of eight criteria was defined to classify the data.

The Met Office provides certain data for free via a web services or for download. In 2011, the web service «DataPoint»[44] was introduced upon request of the government to provide access to open data. DataPoint provides access to a range of data sets free of charge (e.g. single site forecasts, historic and live observations, mountain forecasts, pressure charts and map layers, and satellite map layers). Today, DataPoint has approximately 20,000 registered users, of which 70 percent located in the U.K. and 30 percent based overseas. Compared to the U.S. or Germany, the free data are limited to single locations and a small number of maps. The Met Office makes significant volumes of data freely available to the research community through mechanisms such as the British Atmospheric Data Centre[45] and the British Oceanographic Data Centre.[46] Much of the content on the Met Office website can be reused under an Open Government License in line with the website's terms of use.

Ever-increasing volumes of data are challenging traditional delivery methods. The Met Office is developing alternative solutions to meet the diverse needs of their users. It is currently transforming how third parties will access and download its reusable data sets in the future. Application programming interfaces (API), which can offer scalability by using a third-party cloud provider, is being considered. The new data discovery and dissemination platform is expected to go live in autumn 2019.

The U.K. Civil Aviation Authority (CAA) regulates aeronautical meteorological services (Civil Aviation Authority 2013). CAA states: «within the U.K. there are a number of commercial organizations that create Met products outside the scope of ICAO Annex 3 or repackage Met information already produced and supply to industry as, or within, value added services. Under current U.K. legislation there are no regulatory requirements in place for these commercial providers». However, providers of all other services must be certified by CAA.

Regulation of public-private engagements

The U.K. has acts and guidelines on public-private partnerships (PPP),[47,48] **though none relates specifically to the weather market.** The existing acts and guidelines focus on infrastructure projects, contract management, private financing, and public procurement. For instance, the U.K. Treasury issued a PPP policy and guideline in 2012. It provides guidance on assessing the value-for-money of privately financed projects and of finance, procurement, and contract management.

3.3.4 Funding

The Met Office is required to operate on a commercial basis and to meet financial targets: for the financial year 2017/18, its total revenues amounted to GBP 229.9 million and its operating profit to GBP 20.3 million. The Business Group accounted for roughly 10 percent of revenue and operating profit: the vast majority of the revenue was derived from public sector entities.

43 https://www.metoffice.gov.uk/about-us/legal/open-data-policy.
44 https://www.metoffice.gov.uk/datapoint.
45 http://data.ceda.ac.uk/badc/corral/images/metobs/.
46 https://www.bodc.ac.uk/.
47 A PPP is defined as a cooperation between the public and private sectors for public-interest-infrastructure provision. PPP is a finance scheme and not a transfer of public obligations to the private sector.
48 https://ppp.worldbank.org/public-private-partnership/legislation-regulation/laws/ppp-and-concession-laws#examples.

In the same reporting period, the Met Office payed GPB 8.5 million as dividend to its owner. As a Trading Fund, Met Office is not expected to lose money, but ultimately the public is liable to cover losses. Since becoming a Trading Fund, the Met Office has been profitable and has returned dividends.

3.3.5 Public-private engagement

Although the Met Office largely dominates the U.K. weather market and the hydromet value chain, it engages with the private sector. Examples of such engagements are illustrated below.

Data sharing

The Met Office openly publishes Public Sector Information (PSI) which is available for reuse on the ECOMET[49] website.[50] ECOMET, in turn, directly notifies all members of the European Trade Association for meteorological service providers (PRIMET) of data that are available for reuse. The Met Office's PSI reuse catalogue includes live and historic observations as well as numerical weather prediction model outputs. The Met Office PSI Data Team (DPT) licenses PSI data to diverse market sectors. This includes, for example, renewable energy, with about 40 businesses reusing the Euro 4 model output to drive their European renewable energy forecasts. Most data sets listed in the ECOMET catalogue are chargeable (information charge and handling fees), with proceeds being used to offset the cost of producing and delivering PSI data to the public weather service. Additionally, DPT is the leading licensing agent for the European Centre for Medium-Range Weather Forecasts (ECMWF), licensing ECMWF's data to a global customer base; it also licenses EUMETSAT's[51] data and ECOMET members' data (80 percent of DPT's users are based overseas).

Engagement with the private sector for the provision of observations

The Met Office works with the private sector to consider the direct provision of satellite services. This includes undertaking the scientific assessment of trial data, discussing business model options for future provision, and recognizing the emerging opportunities of small satellite solutions for specific capabilities.

Big data infrastructure

The cost of supercomputing and big data infrastructure drives endeavors to closely collaborate with companies like IBM[52] and CRAY.[53] These endeavors can develop new solutions to handle the big data produced and shared daily by the Met Office. This includes outsourcing solutions such as computing-as-a-service.

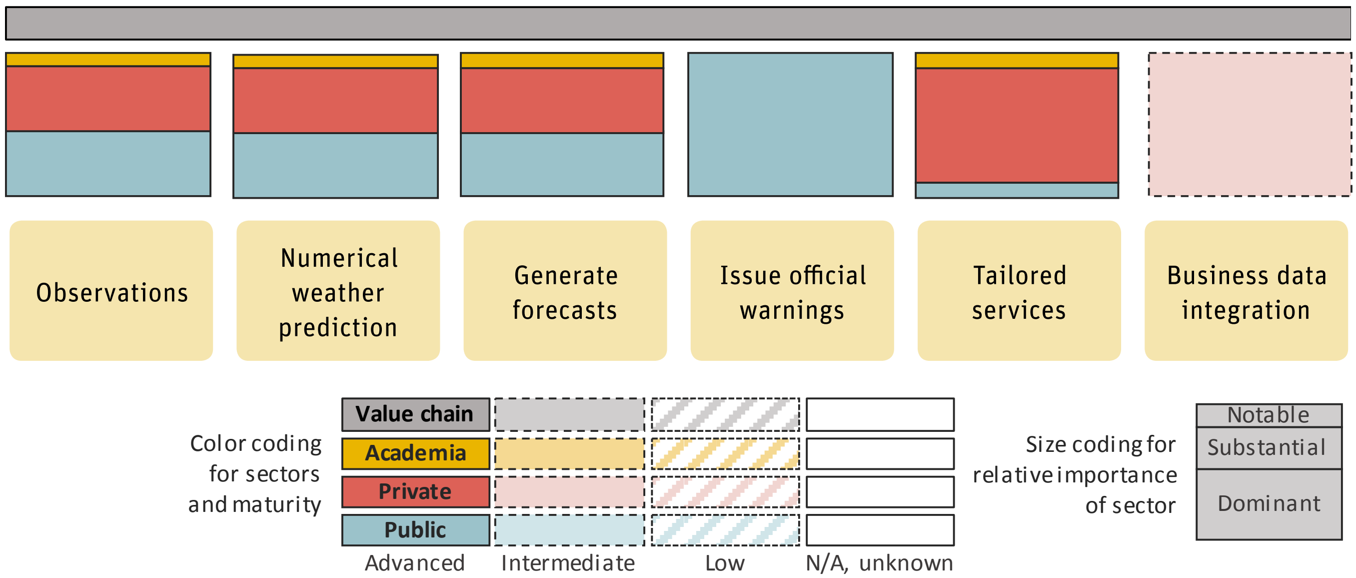
3.3.6 International cooperation

The U.K. is a member of WMO and ECMWF and shares observation data and NWP output with other member states. The U.K. is also a full member of the European Space Agency (ESA), EUMETNET, and EUMETSAT through which most of the U.K.'s contribution to the satellite component of the Global Observing System is made (similar to the NOAA/NASA mechanism in the U.S.). The Met Office works closely with the U.K. Space Agency to support U.K. industry interests. These are important given the geo-return mechanisms through which ESA operates, with a significant impact on the EUMETSAT contracts.

The Met Office has a large number of international research cooperation projects to further-develop forecasting and climate science.[54] Furthermore, it supports developing countries to develop NMHSs to access high-resolution models at a global and regional level to enhance their national forecasting skills.[55] The Met Office is collaborating with the development partner community and is supporting NMHSs in specific countries to build capacities and to sustainably develop hydromet services. The Weather and Climate Science for Service Partnership Programme[56] is supported by the U.K. government Newton Fund and comprises projects with Brazil, China, South Africa, and several Southeast Asian countries. The projects aim to build the basis for increasing the resilience of vulnerable communities to weather and climate variability.

49 ECOMET is the Economic Interest Grouping of the National Meteorological Services of the European Economic Area (http://www.ecomet.eu).
50 http://www.ecomet.eu/component/e2etables/?view=e2etables&Itemid=241.
51 EUMETSAT is the European Organization for the Exploitation of Meteorological Satellites (www.eumetsat.int).
52 https://www.ibm.com/case-studies/met-office.
53 https://www.bbc.com/news/science-environment-29789208.
54 https://www.metoffice.gov.uk/research/collaboration.
55 https://www.metoffice.gov.uk/services/government/international-development.
56 https://www.metoffice.gov.uk/research/collaboration/newton.

Figure 5: **Sector balance and maturity in Japan hydromet value chain.**



The WISER (Weather and Climate Information Services for Africa) program[57] is funded by U.K. Aid and aims to deliver transformational change in the quality, accessibility, and use of weather and climate information services at all levels of decision making for sustainable development in Africa. The Met Office has been commissioned by the U.K. government to act as fund manager for the East Africa component of the program. It focuses on the Lake Victoria Basin and surrounding region (Burundi, Ethiopia, Kenya, Rwanda, Tanzania, and Uganda) and on service delivery (e.g. seasonal forecasts and official early warnings), directed by user needs which support poverty reduction and development.

3.4 Japan

3.4.1 Overview and Summary

The overall maturity of the hydromet value chain in Japan is advanced, and both the private and public sectors play a major role in the first three elements of the value chain (see Chapter 3.4.2: *Early warning system*). The private sector dominates tailored services and business data integration. The situation in Japan is generally similar to the situation in the U.S. (compare Figure 3 with Figure 5).

The role of the Japan Meteorological Agency (JMA) is defined by the Meteorological Service Act and focuses both on the provision of public services and the promotion/regulation of the hydromet market. In comparison to similar countries (e.g. the U.S.), the NMHS assumes greater regulatory duties and more roles in ensuring the quality of observed data and forecasting services. Although the hydromet market has been deregulated since the 1990s, the weather market in Japan is still more regulated than the weather market in the U.S. For instance, private forecasting service providers must obtain a license from JMA to operate in Japan.

The provision of public services is part of JMA's mandate and is fully funded by the state. Through the Japan Meteorological Business Support Center (JMBSC), JMA provides most of the data, products, and information it produces to the private sector at cost of dissemination for commercial usage. In response to a low utilization rate of meteorological data in industry, the Weather Business Consortium (WXBC) was established. As a joint effort of the public, private, and academic sectors, WXBC aims at promoting the use of weather data for new businesses.

Through international cooperation, Japan is supporting many low- and middle-income countries in Asia and the Pacific Region sharing information, providing capacity building on technical hydromet skills and knowledge.

57 https://www.metoffice.gov.uk/about-us/what/international/projects/wiser.

3.4.2 Services, users, and providers

Hydromet services in Japan are widely used by public and private mass media, the central government, local governments and authorities, the aviation and fishing sectors, and many other economic sectors.

Essential services and channels of communication

JMA provides fundamental weather services such as observations, forecasts, and numerical weather prediction (NWP) and monitors earthquakes, tsunamis, and volcanos. The Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) has oversight responsibility for JMA. JMA has supervision of the Japan Meteorological Business Support Center (JMBSC), which is an incorporated foundation. JMBSC disseminates most JMA data, products, and information—including the gridded NWP data—on a real-time, cost basis to private business users.[58] There are about 300 registered end users.

As of January 2019, Japan had 74 private forecasting service providers licensed by JMA to issue weather forecasts. The private sector provides a variety of integrated services. Licensed forecasting service providers, for example, offer value-added forecasts to the general public and to specific users in many economic sectors (e.g. mobile applications, which are not covered by JMA). Their services are essentially based on the data, products, and information disseminated by JMA (through JMBSC). Among the private forecasting providers are international companies. Some use the data, products, and information generated by JMA together with their own complementary observation infrastructure and forecasting services to meet specific user needs and requirements (World Bank 2017a).

Early warning system

Japan is exposed to many natural hazards, including earthquakes, typhoons, flooding, and tsunamis, and the country's early warning system is well developed. Real-time information on evolving severe weather events includes emergency warnings, warnings, and advisories. JMA is mandated to act as the single authoritative voice with respect to warnings[59] and pushes them to government disaster management agencies, local governments, the media, and the public through various channels. However, the private sector plays an important role in disseminating the warnings issued by JMA to end users.

Surface measurement network

JMA operates an observation network, including geostationary meteorological satellites, and private companies operate their own observation networks to complement JMA's observation networks. The private companies' networks include 1,300 automated weather stations and 20 C-band Doppler radars. One of the private companies, Weathernews Inc. (WNI), operates its own surface observation instruments and compact X-band Doppler radar stations for its commercial activities.

Role of academic institutions

JMA collaborates closely with the academic sector in such areas as the development of NWP models[60] and new meteorological satellite products. The private sector also collaborates with academia. For example, WNI has partnerships with academic institutions, especially in research and development of compact satellites, compact X-band Doppler radars, data analysis techniques, and artificial intelligence.

3.4.3 Legal and policy framework

In Japan, the main regulatory framework for meteorological services is the Meteorological Service Act of 1952. The purpose of the act is «to ensure the sound development of meteorological services», which is understood to include services provided by private companies. It not only regulates the activities of JMA but also includes rules for observations and forecasts that private services have to follow. Further, the act is intended to optimize commercial opportunities for private meteorological services in Japan, such as provision at cost of almost all JMA data, products, and information to the private sector. The act has been amended more than 30 times since 1952, with a 1993 amendment allowing private

[58] To cover operating cost to run servers 24/7; data are free.

[59] Note: Flood warnings for designated rivers with information on water levels or flow rates are issued in collaboration with national and prefectural river authorities (Ministry of Land, Infrastructure, Transport and Tourism and prefectures).

[60] For example, JMA shares its models with academia to get feedback and also conducts joint research activities with academia; JMA has established a new advisory body consisting of model experts to advise on a modelling and development strategy.

forecasting service providers to issue forecasts publicly[61] and opening further deregulation.

Through the amendments, JMA has established a system for verifying observation equipment and for certifying weather forecasters at private forecasting services companies. The act articulates the role of JMBSC to support the sound development of forecasting services by JMA. It also stipulates that, any entity other than JMA conducting meteorological observations intended for announcements and disaster risk reduction must follow given technical standards and that, JMA must be notified of the installation of such observation stations and JMBSC must verify the observations instruments.

Data policy

The Meteorological Service Act provides regulation and promotion mechanisms for the private sector with an open data policy. Since 1995, JMA has provided most of the data, products, and information it collects and/or produces through JMBSC to the private sector at cost of dissemination for commercial usage; further dissemination is allowed.

Assurance of service quality

Many provisions in the Meteorological Service Act pertain to quality issues and requirements for JMA and the private sector. In 1993, when forecasting services by the private sector were allowed, the certified weather forecaster system and a meteorological data and information dissemination system were established to assure quality. In addition, JMA provides training sessions and ample guidance materials for private companies to effectively utilize new and advanced data, products, and information. This helps to achieve higher user satisfaction and/or cost-effectiveness.

Regulations on public-private engagement

The Meteorological Service Act clearly regulates the form of public-private engagement. It specifies the roles and responsibilities of JMA and relevant government authorities, media, and private companies. The act's long history and many amendments have solidified the legal background for public-private interactions.

3.4.4 Funding

JMA establishes, operates, and maintains observation networks and fundamental systems, which are fully funded by the government. JMA's annual budget is approximately USD 600 million. There are no fees, except for aeronautical meteorological services. These fees are partly recovered by the governing ministry for civil aviation (i.e. Ministry of Land, Infrastructure, Transport, and Tourism) and allocated to JMA.

3.4.5 Public-private engagement

Since the early 1990s, JMA has pushed forward its open-data activities; it has disseminated its data and information through JMBSC since 1995. JMA does not provide any commercial services and encourages private companies to utilize JMA's data, products, and information for business use and to offer tailor-made services. Nevertheless, sales of private weather service companies in Japan have slowed since the early 1990s and remained at around USD 270 million between 1998 and 2011.[62] Note that the two biggest companies (Weathernews and Japan Weather Association) jointly occupy the majority of the market share.

The public, private, and academic sectors established the Weather Business Consortium (WXBC) in March 2017 and its members include current and potential meteorological data users. The purpose of WXBC is to promote the use of weather data for new businesses and to take advantage of new technologies (e.g. utilization of big data along with meteorological data, artificial intelligence, and IoT sensor networks) to improve economic outputs. JMA functions as the consortium's secretariat through JMA's newly established Office of Public-Private-Academic Collaboration. WXBC offers seminars, training sessions, idea contests, and matching events based on decisions, discussions, and dialogue. As of February 2019, the consortium had 566 members. A typical example of an emerging commercial application is the project to exploit geostationary meteorological satellite Himawari imagery[63] to effectively harvest pasture grass in Hokkaido, Japan. (For a more detailed explanation, see World Bank 2017a.)

[61] Until 1993, private service providers could issue forecasts to their customers but not publicly.
[62] http://www.jma.go.jp/jma/kishou/books/hakusho/2012/HN2012c1s15.pdf.
[63] http://www.data.jma.go.jp/mscweb/data/himawari/.

JMA's point of view on the future development of PPE

According to JMA, there will be further deregulation in response to technical developments and socio-economic needs. Private services are assumed to evolve due to technical trends such as the availability of big data for private companies. Big data are expected to create more and more opportunities for private sector consulting business.

JMA points out that it has promoted private activities but has also ensured the quality of private forecasting services and observation data by regulation. According to JMA, the main driver of public-private engagement is Japan's firm legal framework. There is a clear understanding of the role and the fundamental services provided by the public sector, and of JMA's intention of leaving room for private activities.

According to JMA, while there are no impediments to private service provision in Japan, a more flexible system for observation instruments would make data gathering and utilization more effective. A similar challenge already has been identified and included in the latest recommendation to JMA by an advisory body dated 20 August 2018 (JMA 2030 Vision). It calls for further integrating the usage of observation data from various bodies by overcoming challenges (e.g. data quality assurance and development of big data utilization technology).

3.4.6 International cooperation

JMA dedicates significant effort to international cooperation through multilateral and bilateral arrangements, operating global and regional centers that are established within the frameworks of WMO and other international organizations. The agency has established procedures to engage in cooperative activities with many NMHSs in developing countries and international organizations through the facilitation of activities, implemented by the Japan International Cooperation Agency (JICA).[64] For more than 40 years, JMA has taken part in the planning of projects, dispatched experts to share skills and knowledge, and conducted annual training courses for staff members of NMHSs.

3.5 Myanmar

3.5.1 Overview and Summary

The overall maturity of the hydromet value chain in Myanmar is low; the maturity of observations and numerical weather prediction is low; the generation of forecasts and the issuing of official warnings can be characterized as intermediate (Figure 6). The value chain is largely dominated by the public sector. The private sector does not yet play an important role in Myanmar, with the possible exception of targeted services generally provided by international companies (e.g. to offshore drilling platforms). Cooperation between the public and private sectors is weak but evolving.

Following 2008 Cyclone Nargis, the country's weather forecast and official warning infrastructure improved, with extensive support from international development partners. Today, ongoing development projects focus on strengthening the infrastructure and forecast capabilities of the Department of Meteorology and Hydrology (DMH), the NMHS of Myanmar. A meteorological services law is being drafted based on WMO good practices with support from international consultants and the World Bank. The draft law is providing an important new foundation for the hydromet value chain and public-private engagement. Not least because of this, Myanmar is in a pivotal situation and a very interesting case study.

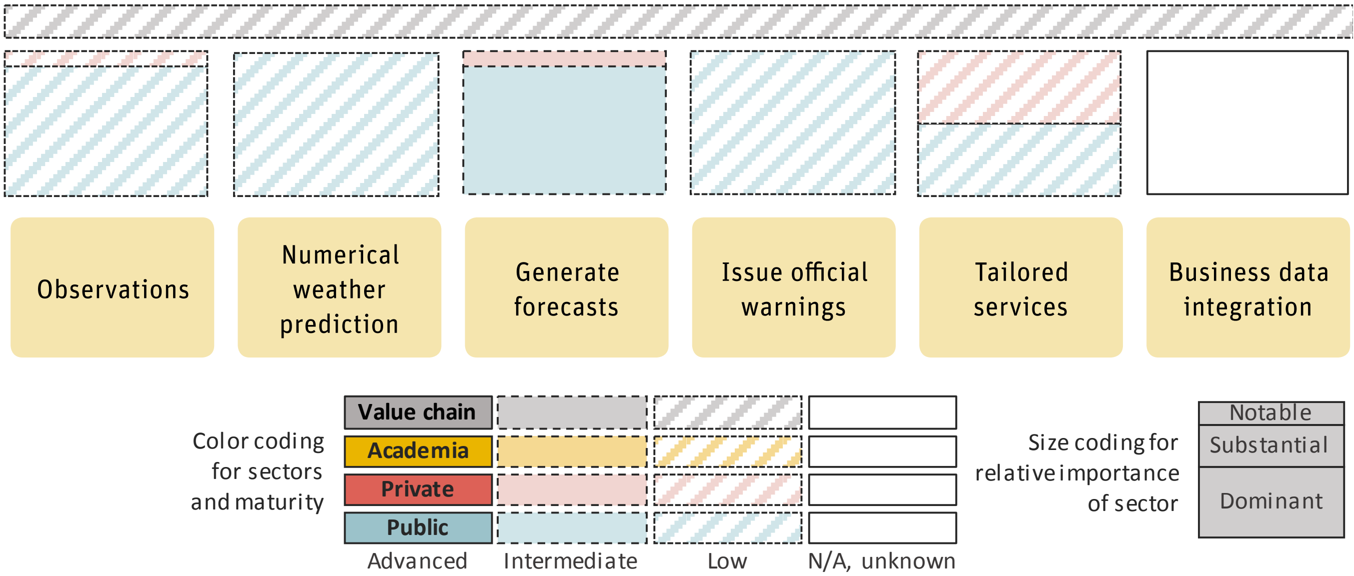
3.5.2 Services, users, and providers

Essential services and channels of communication

Over the past ten years, Myanmar has developed its warning services but has not developed its hydromet services at the pace of comparator countries. An extremely destructive cyclone in 2008, Nargis, hit Rangoon and caused an exceptional loss of lives. This spawned international cooperation and the development of official weather and extreme warning systems. Yet, based on the study's research and interviews, the public is less aware of weather forecasts than in other countries.

64 For further details, see http://www.jma.go.jp/jma/en/Activities/intcorp.html.

Figure 6: **Sector balance and maturity in Myanmar hydromet value chain.**



In 2016, 25 percent of Myanmar's population used the internet, compared to only 0.25 percent in 2010.[65] Social media, especially Facebook, is becoming an essential source of weather information and warnings, alongside newspapers and TV.

In addition, a national monsoon forum is organized twice a year as a technical conference to raise awareness and build capacity. The forum is regularly attended by around 50 experts and is covered by TV stations and newspapers. Depending on the availability of funding, there are also sub-national monsoon forums.

Department of Meteorology and Hydrology

The Department of Meteorology and Hydrology (DMH), under the administration of the Ministry of Transport and Communication, is the main provider of hydromet information in Myanmar. Its primary duty is to provide weather-related information to central and local authorities, although provision of information to the general public has gained importance in recent years. The DMH Meteorological Division issues warnings and forecasts, provides records of climatic data, and monitors significant climate conditions like El Niño.66 DMH has a staff of around 900, of which 150 are based in its headquarters located in Nay Pyi Taw.

According to DMH, Myanmar currently has a network of around 160 automatic and 140 manual weather stations, including tide gauges and agromet stations. Most of these weather stations are owned and operated by DMH; a few stations are operated by research institutes (e.g. Agricultural Research Institute) or private companies. DMH does not use data from other weather station operators. The automatic weather stations (AWSs) largely have been financed by development partners and co-located with manual stations. However, AWSs are perceived as a tool to monitor and check manual observation work, and issues surround the compatibility of different AWS systems implemented by development partners. Projects are being implemented to improve infrastructure, and three radars financed by JICA are in operation. DMH plans to roughly double the number of AWSs and to run limited area numerical forecast models by using ECWMF data.

DMH issues official warnings and disseminates them through its website and mobile providers like MPT or Telenor (see Chapter 3.5.5). DMH regards itself as the single authoritative voice concerning warnings.[67]

Private Providers

Global providers of hydromet information deliver forecasts and other hydromet information for

[65] Statistics from https://data.worldbank.org.
[66] https://www.moezala.gov.mm/meteorological-division.
[67] To the best of the research team's knowledge, this is not yet articulated in law.

Myanmar based on global weather models. There is no information about the popularity of such services compared to DMH's services.[68]

International weather companies generally do not operate local branches in Myanmar. One exception is WNI, which runs an operation center in Yangon. However, WNI is primarily taking advantage of the low operational costs in Myanmar, using the center only to support its global marine business, not to deliver products and services in Myanmar. Without a legal framework governing the hydromet value chain in Myanmar (see Chapter 3.5.3), a comprehensive overview of private hydromet providers is difficult to ascertain.

Another example of private weather information provision is *Site Pyo* (Burmese for «cultivation»). Site Pyo is an application for smartphones targeted at farmers and includes customized weather forecasts and recommendations for ten different crops (e.g. for seed selection, harvesting, and storage) to improve yields. The private telecom provider Ooredoo launched the service. The app and its data usage are free but exclusively available to Ooredoo customers. *Site Py*o is supported by GSMA (a worldwide interest group of mobile providers) under its mNutrition Initiative that is funded by U.K. Aid. By the end of 2016, *Site Pyo* had 150,000 users but did not generate direct revenue (GSMA 2017).

Academic Sector

Both Yangon Technological University and Yangon University offer a degree in physics with a specialization in meteorology and a Ph.D. program with a focus on meteorology in cooperation with DMH. Currently, DMH is evaluating research cooperation with the Norwegian Meteorological Institute (MET Norway).

3.5.3 Legal and policy framework

Myanmar seems to be at a pivotal stage for policy development and a sound strategy is very much needed to strengthen DMH's mission and activities. At present, no meteorological law or legal framework governs the provision and use of hydromet information in Myanmar. However, a meteorological services law is being drafted based on WMO good practices, with support from international consultants and the World Bank. The law is envisioned to define DMH's mandate, regulate the hydromet market, and inform and guide future PPE in hydromet services. It is still in an early draft phase and is expected to be finalized in 2019.

Data policy

Under the current policy framework applied by DMH and the Ministry of Transport and Communication, hydromet data can be sold or given away for free, depending on the beneficiary and the planned use of the data. At present this policy applies to historical observation data from weather stations, not to real-time data from AWSs or radars as such data are not available. Some of the older historical data are not yet digitized, and the process of data retrieval and approval appears to be quite time-consuming. According to DMH, the data are mainly used for research purposes and to support construction work. The government has an internal policy where data must be bought from the originating agency.

3.5.4 Funding

The 2018/19 DMH headquarter (HQ) budget ranges roughly from USD 1.5 million to USD 2 million. About two-thirds of the HQ budget covers the salaries of all DMH employees, whether they are working at HQ or in regional branches. The costs and expenses associated to maintain regional infrastructure are not covered. At the time of writing of this report, the regional budgets were not available.

In Myanmar, public-sector salaries average around USD 120 per month. While the gap between public- and private-sector salaries is uncertain, sources estimated the salary in the private sector to be up to three times higher than in the public sector.

The 2018/19 DMH HQ budget includes an increase of USD 100,000 for maintenance expenses. However, DMH estimates that this is inadequate and that approximately USD 1 million will be required annually to cover the operation and maintenance (O&M) of the new AWSs and radar infrastructure installed by development partners. A very limited budget and the long-term O&M costs of the growing equipment inventory appears to be a critical issue for DMH. Modernization of its infrastructure and equipment is regarded as the highest priority, followed by a concerted effort to increase revenues by selling hydromet products and services to companies.

68 When discussing potential business models, people pointed to free transnational apps; for example, the one provided by year number.

While revenue from data sales amounts to around USD 35,000 per year, no additional revenue appears to be generated through fees. The revenue from data sales goes back to the national government, and not to DMH.

3.5.5 Public-private engagement

Public-private engagement is not yet well established in Myanmar. However, DMH is committed to change this situation and is starting to engage private companies to foster PPE. This led to at least one memorandum of understanding (MOU) with a private company. Examples of PPE in Myanmar follow:

Provision of data and information to individuals, institutions, and companies by DMH

Private companies are encouraged to request information for various purposes (e.g. construction and research). Some of the historical meteorological, hydrological, and seismological data (up to the previous month) can be obtained by individuals, companies, and institutions alike. An extensive case-by-case approval process over hierarchical levels decides whether the data are provided for free or for a relatively small fee.

Cooperation with private providers of weather information

Possible partnerships between private providers and DMH are being discussed, mainly concerning the ground observation network. Private companies would provide technical support to DMH or operate their own weather stations and provide DMH with data; in return, the companies would receive access to DMH's observational data.

Cooperation with private providers of instrumentation and services

DMH regularly contracts companies to provide instrumentation (e.g. water-level sensors and AWSs), according to a private engineering company. At present, DMH receives free lightning detection from five stations run by a private company as a pilot project. Funds for new equipment typically come from development partners. Under the current policy, operation and maintenance of such infrastructure must be carried out by DMH staff.

Sustainable long-term O&M of new infrastructure is recognized as one of the main challenges. While some of the current maintenance of infrastructure is provided under warranty agreements at the supplier's cost, this will not be the case in the future. Moreover, AWSs are often added alongside manual stations without replacing them. Without reducing manual stations and reassigning field-staff to other duties, the cost of operating AWSs will remain an additional expense.

Educating and training DMH staff are recognized as vital. Unfortunately, staff in leadership positions often change positions within DMH and the government, requiring frequent re-education of new department heads.

Cooperation with mobile providers

Mobile phone subscriptions increased dramatically from 0.5 per 100 people in 2007 to 90 in 2017.[69] There are three leading mobile operators: MPT (mainly state-owned), Ooredoo, and Telenor.

Operators must provide official severe weather warnings to their customers via Short Message Service (SMS) as a condition of their operating licenses. They can, however, restrict this service to warnings concerning imminent hazards.

Like many mobile operators worldwide, operators in Myanmar want to grow their revenue by providing content as a service to their consumers. One approach is to provide exclusive free content to their customers (as in the *Site Pyo* example mentioned above). Another approach is to provide paid services (e.g. via SMS services) and share revenues with content partners. Under the latter scheme, mobile operators would not pay for the data provided by DMH or other service providers. To be profitable in the long run, companies must be able to monetize data and information to sustain operations. Value-added services must therefore be profitable by a commercial measure (e.g. customer retention). With respect to basic weather-related services such as forecasts and warnings, mobile providers observe a very low or inexistent willingness to pay in their customer base.

Mobile providers might be able to use rain and flood prediction in support of their operations. Rain requires mobile operators to boost their signal, and floods can hamper

69 https://data.worldbank.org/indicator/IT.CEL.SETS.P2?end=2017&locations=MM&start=2007.

access to and damage their sites. However, there was no indication that such possibilities were being discussed.

There is no formal cooperation between DMH and mobile operators for hydromet data other than the mandatory transmission of official warnings via SMS. This is also true for infrastructure cooperation (e.g. using cell tower locations for weather stations), with the exception that DMH seems to mainly use the MPT network to communicate with its AWSs.

3.6 Indonesia

3.6.1 Overview and Summary

The overall maturity of the hydromet value chain in Indonesia is intermediate and it is largely dominated by the Meteorological, Climatological, and Geophysical Agency (BMKG[70]), the NMHS of Indonesia (Figure 7). The private sector plays a minor role with observations used for tailored services. The law on meteorology, climatology, and geophysics governs the whole value chain and supports the dominating role of the NMHS.

In order to further strengthen its capabilities and to overcome budget pressure, BMKG follows a strategy of developing its non-public services and increasing commercial activities. Public-private engagement is seen by BMKG as a vital part of this strategy. Therefore, a growing range of PPE activities can be observed in Indonesia, from public-private partnerships to finance infrastructure to exchanging data and sharing of infrastructure with the private sector. Additionally, Indonesia uses its regulative oversight to ensure that gas and oil companies buy and use meteorological information provided by BMKG.

3.6.2 Services, users, and providers

Essential services and channels of communication

BMKG is responsible for monitoring and providing information and services on weather, climate, air quality, earthquakes, and tsunamis, and relevant environmental information. BMKG is a government agency with ministry status. In addition to its role in disaster risk reduction and management, BMKG provides weather services to agriculture and agro-industry, fisheries, forestry, tourism, aviation, marine, and land transportation as well as to the general public.

Websites and social media such as Twitter, Instagram, and Facebook are heavily used and are vital channels for weather information and official warnings. Approximately 70 percent of Indonesia's 264 million population is under 40 years old.[71] BMKG has around 4 million followers on Twitter and provides an app for smartphones which includes weather, earthquake, and tsunami information. Weather apps and websites from private providers like AccuWeather or windy.com seem to be very popular.

To mitigate the issue of misinformation on social media, BMKG has created so-called «cyber troops» who handle Frequently Asked Questions related to environmental information and deal with issues such as fake warnings. In some cases, BMKG has requested authorities to block accounts disseminating misleading information.

BMKG regards itself as the primary provider of weather information in Indonesia. However, transnational private providers (e.g. Accuweather, Windy.com, and WNI) as well as specialized private providers (e.g. for offshore drilling operations) are also used by individuals and companies. Some companies (e.g. in the agriculture sector) may use their own observations but only for their own operations, and not for providing hydromet services to others. BMKG regularly runs customer satisfaction surveys to improve information delivery.

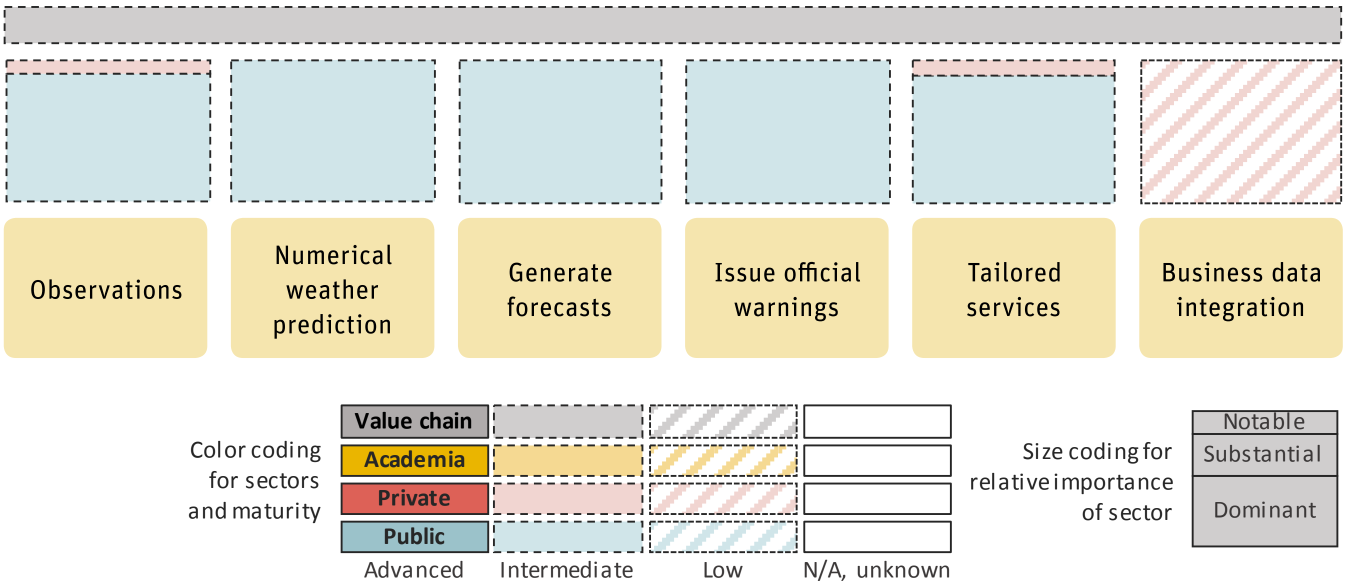
Official warnings

BMKG issues early warnings for weather risks. The National Disaster Management Authority (BNPB) assesses early warnings from BMKG for vulnerabilities and, if needed, issues warnings directly to regional governments and the general population. Regional/local governments issue binding orders if required (e.g. evacuation of an area). In extreme cases, for instance an earthquake or tsunami, BNPB and BMKG may issue warnings directly. The cooperation between BNPB and BMKG is close and based on an MOU.

70 Badan Meteorologi, Klimatologi, dan Geofisika.

71 Total population in 2017: World Bank Data, https://data.worldbank.org/indicator/SP.POP.TOTL?locations=ID. Share of population under 40 in 2015: UNData, http://data.un.org/Data.aspx?d=POP&f=tableCode%3A22.

Figure 7: **Sector balance and maturity in Indonesia hydromet value chain.**



Observation network

BMKG maintains and operates an observation network of around 850 automatic stations for meteorological and climatological monitoring as well as 23 weather radars.[72] BMKG also monitors 160 broadband seismic and 220 accelerometer stations for seismological observations.

Role of academic institutions

BMKG collaborates with universities in Indonesia and abroad. Capacity-building activities for other Asian countries is also envisioned. According to the governing law,[73] research results obtained by collaborating with BKMG can only be disseminated to the public after written approval from the head of BMKG.

3.6.3 Legal and policy framework

The main legal document for hydromet services in Indonesia is the Law of the Republic of Indonesia Nr. 31 from 2009 on meteorology, climatology, and geophysics. A detailed overview of all related regulations and legal documents can be found online.[74]

Data policy

The publication of data from observation stations which were not established by BMKG is prohibited by law.[75] Since 2016 BMKG has operated an open and free data portal for research. However, commercial use and further dissemination of this data are prohibited.

BMKG is interested in the use of its data by private companies and sells climate and weather data upon request and under specific agreements. Around 100 such data licensing agreements are currently in operation. Prices depend on the frequency of the measurements and are calculated using a price table. In BKMG's view, the prices are very low.

Regulation of public-private engagements

The Ministry of National Development Planning (BAPPENAS) is in charge of coordinating and supporting PPE projects. There are different PPE schemes, one of which is public-private partnership (PPP). A PPP is defined as cooperation between the public and private sectors for public interest infrastructure provision. PPP is a finance scheme and not a transfer of public obligations to the private sector. In Indonesia, PPP projects

72 http://www.bmkg.go.id/cuaca/citra-radar.bmkg?lang=EN.
73 Law 31, Article 72.
74 http://hukum.bmkg.go.id/index0.php.
75 Law 31, Article 19.

can be initiated by the government or the private sector. In the latter case (so-called unsolicited projects), a private company submits a proposal to the governing entity. In all cases, PPP projects must follow a procurement process, even if the private sector initiates the project. The main responsibility for the projects lies with the public entity: in the case of hydromet projects, this would be BKMG.

PPP projects in the hydromet domain do not need formal approval by BAPPENAS. However, BAPPENAS has to ensure that BMKG is following the right procedures and therefore provides consulting and advisory services to BMKG. In this context, it is important to note that no PPP project has been implemented by BMKG yet. The project described in Chapter 3.6.5 would be the first PPP for BMKG.

Projects can be backed by the Indonesia Infrastructure Guarantee Fund (IIGF),[76] a state-owned enterprise that provides government guarantees for infrastructure PPPs. To this end, an agreement with the IIGF must be made and the Ministry of Finance must approve the agreement. Moreover, there are two additional possibilities of government support to PPPs: from the contracting agency itself and from the Ministry of Finance's Viability Gap Fund (VGF).[77]

Between 2005 and 2018, around 20 PPPs were processed, mostly large infrastructure projects. A PPP project takes at least 18 months to be approved and can take up to four years.

3.6.4 Funding

BMKG's annual budget amounts currently to USD 160-170 million. With this budget, BMKG must cover operations and maintenance as well as investments in and further development of its products and services. According to BMKG, the budget is not adequate; around USD 200 million per year is required to sustainably operate, maintain, and develop the agency. Furthermore, BMKG points out that large investments (e.g. supercomputer and better observation network) are needed to provide a service on par with what overseas companies provide, especially if BMKG is expected to deliver competitive services to the private sector.

The increased need for operation and maintenance budget arises because the cost associated to new high-tech equipment, which was installed to strengthen the capabilities of BMKG, was underestimated or even overlooked. Additionally, technical agencies are generally under pressure from the government to cover O&M costs by cost recovery or by providing non-public services. Therefore, BMKG is trying to source additional funding through international organizations, industrial partnerships, and commercial activities.

Revenues, such as the sale of data and services, today account only for a tiny fraction of the annual budget.[78] Moreover, more than 90 percent of the revenues are provided by the aviation sector.

3.6.5 Public-private engagement

BMKG started an initiative to strengthen public-private engagement in 2016. The goal is to develop sustainable business models together with private companies. There are two main approaches:

- Sale of data and services by BMKG to companies; and
- Public-private partnerships for infrastructure investments.

The following sections illustrate examples of such engagements.

Oil and gas companies have to buy BMKG data and services

Quite a few oil and gas companies operate in Indonesia. For many years, they used «metocean» services from international companies. A few years ago, the regulatory body SKKMIGAS[79] started to require oil and gas companies to use BMKG weather data and meteorological services (an MOU governs the cooperation between SKKMIGAS and BMKG). A transition period of two to three years was granted to allow for contract changes.

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76 http://www.worldbank.org/en/country/indonesia/brief/faq-indonesia-infrastructure-guarantee-fund.

77 «The Viability Gap Fund is a government-supported contribution for some construction costs that is given in cash to a PPP project that is economically viable but has not been financially feasible. VGF can be awarded when there is no other alternative to make the PPP project financially feasible», http://www.djppr.kemenkeu.go.id/ppp#dukungankelayakan.

78 From the information obtained, the study estimates the value at between 1 and 2 percent of the annual budget.

79 SKKMIGAS is a government entity that monitors the budget of private oil and gas companies. The operation costs directly influence Indonesia's revenues. Therefore, there is an incentive for SKKMIGAS to make sure that the costs are as low as possible and for the company to claim as high costs as possible.

As a result, oil and gas companies pay between USD 15,000 and USD 20,000 per year for BMKG's services, probably less than they used to pay. In practice, they use other meteorological information as well (e.g. from FUGRO or other specialized providers). However, they are not allowed to claim those costs as operational expenses for the calculation of their oil and gas profit-sharing with the government. This new approach carries an additional advantage for SKKMIGAS: Because the binding source of meteorological information is now BMKG, and SKKMIGAS receives the same information directly from BMKG, the control over the claimed operational cost of oil and gas companies can be tightened. This prevents oil companies from overstating operational costs related to bad weather.

Sale of data and services

BMKG sells data and services to private and state-owned companies. The revenues are still very small and BMKG is keen on growing the business. Around 100 agreements for data sales are active and there are a few examples of commercial services (e.g. forecasts to coal and other minerals mining companies). In some cases, forecasts are verified with companies' own weather stations; in other cases, companies provide space for BMKG to place a weather station at a company site in return for better local forecasts.

Exchanging data and sharing infrastructure

BMKG is currently exploring business models involving partnerships with private companies on the basic idea of exchanging measurement data or services against infrastructure provision (place, power, and communication for AWSs). As noted above, some oil and gas companies share data from own observations with BMKG or provide space on their platforms for AWSs operated by BMKG. Because the electricity market has been privatized, BMKG is looking at partnerships with the power sector. However, this is still in a very early phase.

Sale of data through geoinformation platforms

BMKG and other governmental agencies provide data to a geographic information system (GIS) platform operated by the private company esri.[80] What started as a project to unite Indonesia's public geo-information systems under the government's «one-map policy» could evolve into a revenue stream for BMKG in the sense that esri could become a distributor of BMKG data.[81] The cooperation is in an MOU state; at the time of writing this report, the key issue of profit sharing had not yet been discussed.

Weather index-based micro-insurance

A consortium of Indonesian and international businesses, initially led by Mercy Corps, has created index-based weather insurance for smallholder farmers. The insurance scheme is part of a complete package for educating, supporting, and financing farmers. The package addresses the full value chain from initial investment in inputs (i.e. seeds, fertilizer, and pesticides) to profitable sales of the harvest directly to end customers. Importantly, the scheme gives non-bankable smallholder farmers access to finance. Farmers need weather forecasts to determine when to bring out seeds and to plan their activities, including the application of fertilizers and pesticides. The insurer needs accurate and historical local weather data as well as data on the insured crop's weather sensitivity to compute the weather indices as part of their actuarial analysis.

The project is under development, and there is cooperation with BMKG's local offices (e.g. BMKG provides monthly provincial analysis bulletins and rain forecasts for farmers for free). However, high-quality local information is needed to compute the weather index. Historical records are essential for developing micro-insurance products, and high-resolution meteorological data (e.g. precipitation) are important factors in the triggering payouts.

The information required to trigger payouts, for instance to determine whether rainfall passes the index threshold in a given year, is provided by privately funded weather stations installed in the farmers' fields. So far, they have not been tampered with.

The weather index-based micro-insurance project illustrates the strategy of driving the development of weather services from the consumer end and shows the socio-economic impact of accurate weather information. It is an example of a productive use of weather information in an agricultural value chain for smallholder farmers in a developing country.

80 See https://livingatlas.arcgis.com.
81 There are yearly subscription and different levels of membership to fully access the esri platform.

Notably, the loans and insurance are not subsidized, and the project could be characterized as a lean start-up (Ries 2011). Farmers are learning about modern farming and are experiencing its value. They have accepted increases of the insurance premiums from USD 3 to USD 10 to USD 30 per year, as the insurance company adapted its actuarial parameters to the available data. Productivity for corn has increased from 5.2 tons per hectare (t/ha) before the start of the scheme to 6-7 t/ha in the first year to 8-14 t/ha in the second and third years. In 2015 and 2016, the insurance helped farmers to actively mitigate El Niño effects through investments in irrigation. The number of farmers taking out insurance is growing significantly, albeit from a small base (from 200 to 1,200 over a two-year period in 2015 and 2016).

The project also demonstrates commoditization of weather services. Willingness to pay for general weather services is very close to zero despite their potential socio-economic benefits. However, there is willingness to pay (in the form of an insurance) for special services, such as the computation of a suitable weather index.

Private-public partnerships for infrastructure investments

BMKG is negotiating a PPP to finance instrumentation infrastructure. Few details are available because the project was initiated by the private company and is still under negotiation. But in principle, the private company would pre-finance the infrastructure investments while BMKG would run the instrumentation, receive education and training, and pay back the private company over a specified period. The deal would have to be guaranteed by Indonesia's Infrastructure Guarantee Fund (see Chapter 3.6.3).

Community engagement

Measurement equipment for volcanic activity to protect agriculture, mining, and tourism is being paid by raising money locally and is operated by volunteers. The idea emanated from voluntary actions by students.

3.6.6 International cooperation

International and regional organizations with an existing cooperation agreement with BMKG include: KNMI Netherlands (climate data exchange and hydrology); Meteo France International (consultancy, some education and training, and support to implement major parts of the hydromet value chain through a design-build-operate approach); JMA (technical assistance in satellite meteorology, seismology, and tsunami warning); IMD India (agrometeorology and radar meteorology); BoM Australia (Joint Working Group on Meteorology: communications system, technical training); ADPC (climate field school: along with Indonesian Ministry of Agriculture). For earthquake monitoring and tsunami warning systems, BMKG has cooperation agreements with the Pacific Tsunami Warning Centre (PTWC), GTZ Germany, China Earthquake Administration (CEA), and other organizations.

3.7 Ghana

3.7.1 Overview and Summary

Overall, the maturity of Ghana's hydromet value chain is low. The «Observations» and «Tailored services» value chain elements are somewhat balanced between the public and the private sectors compared to other elements (Figure 8). Observation data are mostly collected manually and delivered with a considerable time lag. Further dissemination is not regulated and appears not to be explicitly allowed.

Private activities are not specifically promoted but the NMHS is open to public-private engagement to access additional resources, as government funding is not sufficient. In recent years, the private sector has developed good capabilities and specific forecasts for the agriculture sector in the entire West Africa. Often the services are based on international weather prediction services; there is potential for the NMHS to step up and provide more locally relevant services. Furthermore, transnational non-profit organizations are developing low-cost observation networks which can underpin the data available to the NMHS.

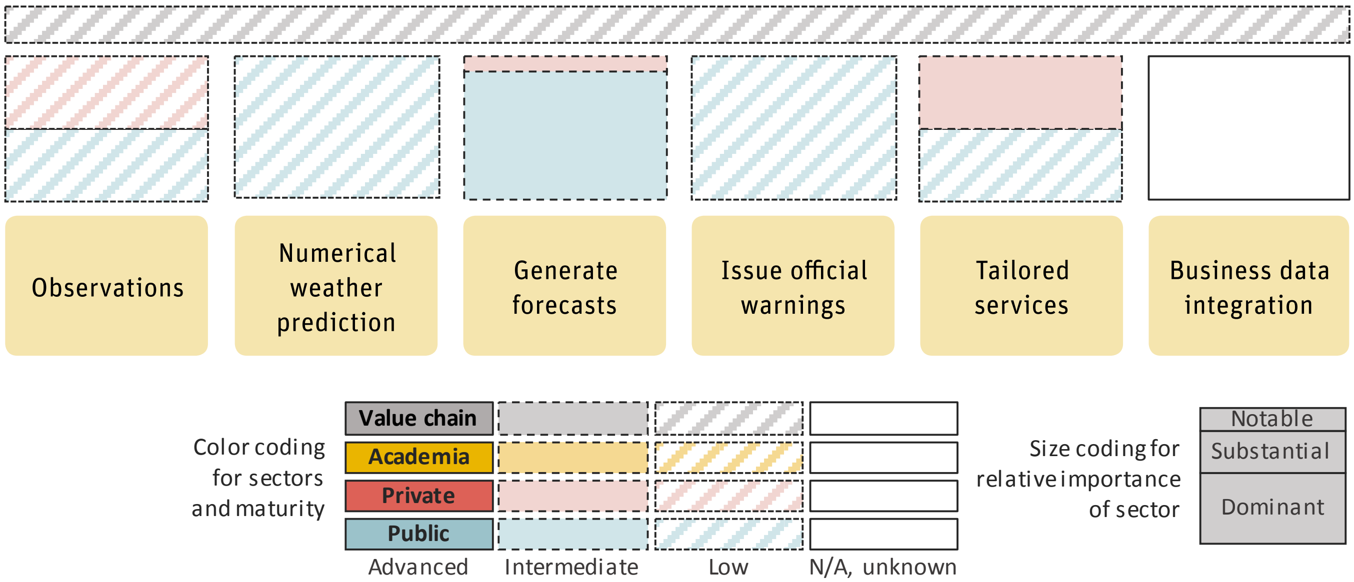
3.7.2 Services, users, and providers

Essential services and channels of communication

The Ghana Meteorological Agency (GMet) is a government agency under the Ministry of Communications tasked with collecting, processing, archiving, analyzing, and disseminating meteorological information to end users.[82] GMet provides weather information for

[82] http://www.meteo.gov.gh.

Figure 8: **Sector balance and maturity in Ghana hydromet value chain.**



official warning services (droughts and floods), marine services, hydrological services, agrometeorology, aeronautical services, and TV weather broadcasting.

Mobile phones have spread very quickly in Africa and are a crucial communication channel to access information, especially among the younger generation. Weather apps based on international weather models like AccuWeather have good reach. GMet has neither a mobile-friendly website with forecasts nor its own mobile application, although it does use Facebook to disseminate its TV weather forecasts.

According to an evaluation of the public weather services (Anaman et al. 2017), users would like more location-specific weather information (by GMet) and warnings issued further in advance.

International service providers do not necessarily have more accurate information but focus on user interface and comprehensiveness. Most apps show local forecast results and give the impression of location-specific information.

Official warnings

The Ghana Hydrological Services Department issues flood warnings based on statistical evaluation and extrapolation of time series measured at water-level gauges. This approach does not allow early warnings to be issued and thus requires more proactive measures. At the time of writing, resources were not available to enhance the existing hydrological and hydraulic models or to make use of the model output from the major forecast centers as inputs. GMet's information on rainfall may not be sufficient to improve this situation.

Observation network

GMet maintains and operates an observation network largely comprising manual stations plus a few automatic stations. In January 2018,[83] the following manual stations were in operation: 22 synoptic, 36 agronomic, 23 climate and 72 rainfall stations. In addition, there are currently 11 automatic weather stations and two (non-operational) radars. In addition, 16 rainfall stations are monitored by the Volta River Authority (VRA) but maintained and run by GMet.

Role of academic institutions

According to GMet, academic institutions do not receive preferential access to meteorological data and are required to pay for data use. However, information from the private sector indicates that GMet sometimes provides data free of charge.

83 Presentation on «Basic network» from Richmond K. Obeng, Ghana Meteorological Agency, 2018.

The Kwame Nkrumah University of Science and Technology in Kumasi and the University of Cape Coast educate meteorologists. The students can participate in national and international trainings provided by foreign meteorological services that cooperate with GMet. A meteorology degree from these universities provides an excellent chance for a job with GMet.

3.7.3 Legal and policy framework

Act 682 «Ghana Meteorological Agency Act» of 2004 is the main legal document for hydromet services in Ghana. It defines the organization and responsibilities of GMet.

Data policy

The use and dissemination of meteorological data are not regulated by the Ghana Meteorological Agency Act. Data can be obtained upon request and registration with GMet and are paid services. It is unclear whether data are provided under a formal agreement that regulates the use and dissemination of the data. Feedback from the public power generation sector indicates that further dissemination of GMet data is not explicitly allowed. GMet appears to be ready to adopt an open data policy, provided public funding sustains the agency's development.

Regulation of public-private engagements

The Ghana Ministry of Finance issued a national policy on public-private partnerships in 2011 (Government of Ghana 2011). One of the policy's main objectives is to encourage and promote local content in PPP projects. A PPP project typically requires a private-sector PPP proponent to submit a local content plan to the contracting entity in response to any request for proposals. The plan needs to demonstrate how the PPP project promotes local industries and the private sector in Ghana. (See Chapter 3.7.5 Delivering metocean services for an example of applying the local content law.)

3.7.4 Funding

GMet is publicly funded and its budget covers O&M costs, investments, and development; however, the budget is viewed as insufficient. About 15 percent of the budget is declared as coming from non-governmental sources. Of this 15 percent, a significant share is assumed to come from international agencies and development partners. GMet is trying to source additional funds through international organizations, cooperation agreements with the private sector, and commercial activities. Although GMet delivers services to the Ghana Civil Aviation Authority (GCAA), it has no share in the revenues earned by GCAA. GMet is lobbying for a legislative change to enforce a claim of 10 percent of those revenues.

Other revenue streams

The 16 rainfall stations deployed across Ghana are operated and maintained by GMet but are monitored by the VRA. VRA is a fully profit-oriented state-owned power company. GMet provides the data to VRA by email and receives a fee based on a five-year contract.

As governmental funding is not sufficient to properly maintain and operate the equipment and to further develop the service, GMet is ready to cooperate with private companies to access further resources. However, there are no substantial revenues from the private sector yet.

Feedback from the private sector suggests that current data and services have little value for most potential customers. In many cases, GMet data and services are not specific enough geographically and are delivered too late to be useful. Customers would be willing to pay for meteorological services if there was an added value compared to the already available foreign services which are based on global forecast models.

3.7.5 Public-private engagement

Current PPE activities are mostly initiated by the private sector. The following sections illustrate examples of such engagements.

Delivering metocean services

GMet is exploring a potential collaboration with a Ghanaian private oil field service provider on a tender for metocean services issued by an international oil company. GMet would supply the meteorological and hydrological information, while the private service provider would oversee the financial, legal, and administrative work and customer relations. Such a partnership would require the formal approval from the Ministry of Communications.

Offshore oil companies could be required to use GMet data and services for weather and tide information, based on local content law. According to GMet, the

NMHS can decide whether or not to request compliance with local content law by foreign companies when it comes to the provision of weather services.

Mobile services to smallholder farmers

Information and consulting services based on mobile phones to smallholder farmers are spreading in West Africa. Most companies are active in multiple countries, covering different elements of the hydromet value chain. Most services are based on the push and pull of information to and from farmers.

Mobile-based services to farmers include daily to seasonal weather, provision of seeds, market information, market access, payment systems, access to finance, and a bundling with insurance, among others. The companies collaborate with mobile service providers (including Vodafone, MTN, and Tigo in the case of Ghana) which are interested in offering value-added services to attract and retain customers. For example, MTN's 15 million subscribers represent a large base of possible customers for these kinds of services. The mobile service providers share the revenues with the value-added services providers, typically retaining 70-80 percent.[84]

Most farming-related services start as demonstration projects initially supported by development partners such as NGOs, development and government agencies, social investors, seed and fertilizer companies, or off-takers of farming products. In some cases, insurance companies are involved to gain access to potential customers, and the farmer service provider receives a provision from the insurance. The challenge in this setup is to create a sustainable business with enough paying subscribers. Usually, the project partners (development partners) pay for the farmer services for the duration of a project or a trial period to let farmers experience the value of the service. Sometimes farmers are required to pay a small fee to become familiar with the idea of paying for the service. Since weather forecasts are usually sent out only during the crop season, there are no customer relations in the dry season and hence the risk of losing customers.

The business models of two companies which provide weather information services to farmers in Ghana and other West African countries are illustrated.

Esoko

Esoko provides primarily market and weather information services to farmers, mostly in Northern Ghana. In addition, *Esoko* provides agricultural tips, crop calendars, market prices, and a platform where farmers can share knowledge and localized information. Weather information is disseminated as recorded messages in the local dialect and give specific farming advice rather than generic weather information. An agronomist interprets the available weather information and translates it into recommended farming actions. As a result of using the service, farmers have substantially increased their crop yield.

Notably, there are no meteorologists on staff; instead, *Esoko* staff receive advice and training from GMet and are thus able to translate the weather forecasts into verbal advice for the farmers. Besides listening to seasonal weather forecasts, customers can subscribe to daily or weekly forecasts. The daily forecasts are provided by aWhere[85] and Toto Agriculture and translated into local languages, but not otherwise substantially modified by *Esoko*. The data provided by GMet are not specific enough for the daily and weekly forecasts and are not offered in the right data format for an automated daily weather information feed. According to Esoko, about 500,000 farmers[86] subscribe to its service in Ghana.

When farmers are required to pay, they purchase airtime from the mobile provider, which shares part of the revenues with *Esoko.* A sustainable fee for *Esoko's* services is approximately USD 0.5 per month. While projects initially rely on partnerships with development partners, the businesses develop towards B2B2C or B2C models.[87] The services are sold to a business partner, such as a mobile provider, farmer association, or organized community.

84 Winrock International, in preparation.

85 http://www.awhere.com/.

86 An unpublished study from Winrock International (2018) mentions that Esoko has reached 1 million customers in ten African countries. Although their main markets are in Ghana and Tanzania, the figure of 500,000 customers in Ghana seems to be rather high.

87 The business-to-business-to-consumer (B2B2C) business model combines the business-to-business (B2B) and the business-to-consumer (B2C) model.

An important feature to attract and retain subscribers is the hotline service through which farmers can ask questions and provide feedback. Customer feedback helps to improve services, evaluate customer satisfaction, and increase utility of the services. Many complaints about forecast errors turn out to be due to location errors. They can be solved by registering the farmer at the correct location or correcting the coordinates of a farm. Location information is often wrong, and Esoko has given its staff an app to test and correct locations whenever they go into the field.

Ignitia

Ignitia's business is based on their proprietary high-resolution weather forecast model. Ignitia provides daily, monthly, and seasonal weather information to farmers, without consulting or other services.

The customer's location is determined via mobile network technology; a text message containing a forecast for the next 48 hours is sent out every morning. An individual can subscribe to the service with short codes (like *455#) or receive forecasts through a farmer organization or development project. Ignitia charges a fee of about USD 0.02 per day for individual subscribers,[88] or about USD 5 per year. If the services are subsidized by a farmer's association or development agency, these actors agree on a one-time payment which gives the farmers forecasts for an entire season. *Ignitia's* services are focused on agriculture. However, they have received requests from other sectors, such as road construction and fishing.

The weather forecast model used by Ignitia was developed by scientists from Sweden and the U.S. It is run in Sweden and is based on a modified WRF model making extensive use of remote sensing data. So far, ground-based measurements are not included for assimilation or model output corrections. *Ignitia* validates the forecast accuracy with three different remote sensing data sets. Their 2016 user survey shows good user evaluations but less intense customer communications compared to *Esoko*. A field team each year is tasked with surveying customers. *Ignitia* reports around 500,000[89] customers who have subscribed with MTN in Ghana and over 700,000 total across West Africa. Ignitia until now has had no substantial interactions with GMet.

3.7.6 Transnational non-profit organizations in West Africa

Organizations and companies are active in large parts of West Africa and interact with governments, NMHSs, and the private sector. Examples of these interactions are presented here.

WASCAL

The West African Science Service Centre on Climate Change and Adapted Land use (WASCAL) has designed a joint research program between a German and a West African research consortium on adapted land use and management under changing climate conditions. WASCAL partners with institutions in ten West African countries, provides climate modeling and assessment, and implements capacity building at schools and universities. WASCAL provides expertise and infrastructure to, but is not involved in the operations of, the NMHSs of member countries. WASCAL is trying to significantly expand its own measurement network of 50 automated stations which are designed to support the research and the operational needs of member NMHSs.

WASCAL station data are open and used to calibrate climate models. A data-sharing framework based on largely standardized bilateral agreements between WASCAL and each member state has been set up, where the NMHSs share observation data with WASCAL and with the other WASCAL members through the WASCAL data platform. In return, WASCAL can share the data from the NMHSs with private companies or other entities outside the WASCAL framework, upon consent of the relevant WASCAL member. In some countries, WASCAL has access to all data from the NMHS; in other countries, the access is limited to synoptic data.

TAHMO

The Trans-African Hydro-Meteorological Observatory (TAHMO) is a public-private consortium jointly led by Delft University of Technology in The Netherlands and Oregon State University in the U.S., with non-governmental status in

88 https://www.resourceaward.org/revolutionary-tropical-weather-forecasting-small-scale-farmers.
89 This figure is based on information from Ignitia and is not confirmed from independent sources.

Ghana, Holland, and Kenya. TAHMO's vision[90] is to develop a dense network of hydro-meteorological monitoring stations in Sub-Saharan Africa—one every 30 kilometers—and to make high-quality data freely available to governments and researchers in near-real time. By applying innovative sensor technology and ICT, TAHMO stations are meant to be both inexpensive and robust. The first station was installed in 2012 and to date 400 more have been installed in Africa. Stations are placed at schools to facilitate their operation and maintenance; a teacher hosts the station and receives free access to its data and to TAHMO teaching material. In addition, stations are integrated in educational programs to enrich the curriculum and to help foster new generations of scientists.

TAHMO strives to work under agreements with national or sub-national governments. Typically, an MOU with an NMHS defines the *modus operandi* in a country. In the case of externally funded projects, TAHMO can have agreements with other government agencies or non-governmental organizations that in turn have agreements with the local governments. Data are free for NMHSs and researchers and available at a fee for commercial use. In Ghana, GMet shares data with TAHMO and contributes to the maintenance of the equipment. In return, GMet receives data from TAHMO stations which are then integrated into its system. Concerns were expressed about potential issues with the calibration of the equipment.

3.8 Germany and Israel: Policy changes related to data access

Germany and Israel both recently experienced a change in the data policy and the corresponding role of the NMHS and private service providers. Because data access is one of the main topics in this study, it is instructive to look at the change process itself and the new regulatory frameworks of Germany and Israel.

3.8.1 Germany

New data access policy

The law on the organization and duties of the German Weather Service (DWD[91]) was revised in 2017.[92] DWD's mandate was extended to cover climate modelling and to safeguard all major infrastructure, including telecommunications infrastructure, from weather and climate risks. The research mandate was upheld. The law now stipulates that DWD has to provide most of its weather and climate data and corresponding services free of charge. However, the technical availability of this information does not have to be guaranteed. Guaranteed service levels are provided at a fee.

According to Article 4(2a) of the act, DWD has to provide free of charge certain services to ministries, provinces, and municipalities as well as certain geo-referenced data and corresponding services to the public. Because almost all meteorological information is geo-referenced, most of DWD's data and services are free (e.g. observation data, weather radar imagery, weather forecasts, and climate data series). This practice is based on the «geo data access law»,[93] which is not specific to the hydromet domain and states that georeferenced data and services routinely generated by government agencies must be made available for free if they are part of a catalogue of themes, must be easily accessible, and must support visualizations. The scope of available DWD data and services, and whether or not they are downloadable for free, is documented in an extensive price list.[94] Even if the legal basis is quite clear, there are currently discussions about the categorization of some services, for example context information provided with official warnings or tailored services like «pc_met» for private pilots. Ultimately, the controversy on the interpretation of the geodata access law might have to be resolved by the courts.

Previous situation

Previously, DWD had to generate revenues to cover some of its cost. Customers paid the federal government rather than DWD directly, precluding a direct connection between the price paid and the services delivered. Data access was always discrimination free, and purchasing the data included the right to redistribute. But the prices were generally too high for the general public and for small private companies. Prior to the new data policy, the data were not used to its full potential.

90 http://www.tahmo.org.
91 National Meteorological and Hydrological Service of Germany (Deutschen Wetterdienst).
92 https://www.gesetze-im-internet.de/dwdg/BJNR287100998.html.
93 Gesetz über den Zugang zu digitalen Geodaten (http://www.gesetze-im-internet.de/geozg/).
94 https://www.dwd.de/SharedDocs/downloads/DE/allgemein/preisliste_2019.pdf.

Triggers and process for changing to an open data policy

According to DWD, they always lobbied for an open data policy. Eventually, the initiative to change the law came from the Minister of Transport in response to new EU regulations and to national initiatives to transform Germany in the digital age.[95] Two important EU directives can be seen as triggers for the amended law on DWD activities and the corresponding data policy: the INSPIRE[96] directive and the PSI[97] directive.

The INSPIRE (INfrastructure for SPatial InfoRmation in Europe) directive aims to benefit European public authorities and others by making available relevant, harmonized, and quality geographic information that supports policies and activities impacting the environment. The directive requires EU members states to share 34 different spatial data themes. INSPIRE is based on a number of common principles:[98]

- Data should be collected only once and kept where they can be maintained most effectively.
- It should be possible to combine seamless spatial information from different sources across Europe and share it with many users and applications.
- It should be possible for information collected at one level/scale to be shared with all levels/scales; detailed for thorough investigations, general for strategic purposes.
- Geographic information needed for good governance at all levels should be readily and transparently available.
- It should be easy to find what geographic information is available; how it can be used to meet a particular need; and under which conditions it can be acquired and used.

The PSI directive is European legislation on the reuse of public-sector information. The directive provides a common legal framework for a European market for government-held data (so-called public-sector information). It is built on two key pillars: transparency and fair competition. The PSI directive focuses on the economic aspects of the reuse of information rather than on access to information by citizens. It encourages the member states to make as much information available for reuse as possible. It addresses material held by public-sector bodies in the member states at the national, regional, and local levels, such as ministries, state agencies, and municipalities, as well as organizations funded mostly by or under the control of public authorities.

The change in policy which resulted in the amended DWD law was based on the standard law-making process in Germany and was completed within one year, largely due to its uncontested nature. DWD and the private sector were consulted at different stages of the legislative process.

Effects of the new policy

DWD now generates less revenue for the federal government, but this is compensated to some extent by less administrative overhead. Since revenues were not being directed to DWD before, DWD's budget did not change with the new policy. DWD's expectations that the private weather market would extend available services have not materialized to date. This situation may be largely attributed to previous regulations, as the amended policy on open data has been in place only for a short time. A market analysis, which is already in preparation, is expected to provide evidence for effects of the new data policy. A first evaluation of the open data policy is due by the end of 2019.

3.8.2 Israel

New data access policy

Israel is a good example of both an NMHS focusing on public services and the application of an extensive free data policy. Under the new framework, the Israel Meteorological Service (IMS) has re-focused its activities on the provision of basic meteorological services for the public, free of charge, while leaving the tailoring of meteorological services to the private sector. The basic meteorological services include forecasts and official warnings (including aviation and marine sectors), climatological reports and

95 https://www.bundesregierung.de/breg-de/service/publikationen/digitale-agenda-2014-2017-727554.
96 https://inspire.ec.europa.eu.
97 https://ec.europa.eu/digital-single-market/en/european-legislation-reuse-public-sector-information.
98 https://inspire.ec.europa.eu/inspire-principles/9.

atlases, climate change monitoring reports, NWP products, observation data (near- and real-time, historical, quality-controlled climatological data), and consultation to government agencies. Products with further added value are entirely supplied by the private sector.

Data and services are provided without any type of charge; moreover, IMS cannot charge for any of its activities, which rules out payment for additional services. There are no restrictions on the use of the data and services provided by IMS, except that the redistribution of original data is prohibited. Its website, however, is currently available only in Hebrew.

Previous situation

Previously, about 75 percent of the IMS operational budget (excluding salaries) depended on revenues from selling data and services, including tailor-made forecasts and climatic analysis, to other public agencies, academia, and the private sector. As a consequence, IMS focused more on revenue generation—business development, answering calls for tenders, and providing services to paying customers—than on public projects. For example, private-sector queries were a heavy burden leaving little time for projects of public interest such as the production of a climate atlas or a wind energy atlas. The revenues from billing data and services had to cover the operational budget, fulfill international obligations to WMO and ECMWF, maintain weather stations, and deploy radiosondes. Due to the unsteady income, payments to WMO were sometimes delayed causing inconveniences. Most of the income came from governmental agencies which struggled with their cost. Hence, most monetary transactions were between public agencies which created high administrative costs but no real profits. Furthermore, the high prices for data and services led customers to use lower quality free data from other sources and discouraged development of applications based on IMS data (see Furshpan 2017).

Triggers and process for changing the policy

Government agencies and the private sector increasingly demanded to lower the prices of data and services from IMS, with companies lobbying in Parliament and ministries. Additionally, a new «open-government» policy[99] put forward by Israel encouraged a change.

In the ensuing negotiations between IMS and Israel's transport and finance ministries, it was recognized that disputes over fees between different government agencies were counter-productive and that it was not appropriate to delay payments to WMO. Additionally, IMS was able to point out the socio-economic value of a change in the funding model and the subsequent provision of free basic meteorological services. As a result of the negotiations, IMS now receives a yearly fixed budget that is more than doubled compared to the previous budget. In return, IMS can no longer charge other agencies for its services and has to make all basic meteorological services available to the public free of charge. The change process took about 1.5 years and ended in 2012.

Effects of the new policy

The private sector now provides a range of value-added services that were previously provided by IMS (e.g. answering meteorological queries that require data processing; producing tailor-made forecasts for specific applications; generating advanced graphic displays of meteorological data; providing meteorological consulting for the private sector; and, providing and maintaining meteorological equipment). According to IMS, the cooperation with other government agencies, especially with the emergency and rescue authorities, is much more effective; the new policies ended inter-agency disputes and improved IMS's reputation. On the operational side, IMS could drastically reduce tasks which required significant time but little technical expertise. Hence, it can now focus on national priorities such as a wind energy atlas or climate change monitoring analysis, which require meteorological skills. Overall, the new data policy resulted in a win-win situation, with the possible drawback that IMS is now fully depending on the ministerial budget for all its activities, including R&D.

Israel's example suggests that, when agreements can be reached within governments, new funding frameworks based on free and open access can benefit the public and private sectors as well as the meteorological services themselves. No comprehensive economic evaluation of the effects of the policy change has been yet undertaken. Such an exercise could lead to useful and more detailed insights.

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99 https://www.opengovpartnership.org/countries/israel.

3.9 Transnational perspective of international weather companies

The continuous advancement of communication technologies, sensors, and computational resources result in an ever-increasing availability of hydromet services, and the falling cost to end users of high-quality information significantly increases the services' reach and impact. The way people receive up-to-date information and conduct business is shifting rapidly toward internet and mobile-based services. In many developing countries, people often use mobile apps of international services providers rather than information disseminated by the NMHS. The NMHS may operate a website with only a few localized forecasts that are of interest to the public. More often, the apps and websites of international providers are simply easier to use and present information better to end users. People also tend to use pre-installed applications. In many cases, forecast models and post-processing for localization of the forecast can produce forecasts of adequate quality for most users. Even if the NMHS forecasts are significantly better in quality and accuracy, many users may prefer the more attractive user interface of an international provider.

In developing countries, international providers could fill gaps in the provision of weather services while in-country capabilities are being built up or could be strategic partners to strengthen the hydromet value chain. The most important observations and learning derived from interviews with international service providers about their transnational experience and perspectives are summarized below:

- **Many of the international weather enterprises cover a large part of the value chain**, some even operate their own measurement networks.
- **International weather enterprises can reach a large number of customers and make profits with very low prices for individual customers**, advertisement, or additional embedded services. Sometimes, international companies provide such services to establish their brand and do not necessarily seek direct profits from B2C streams.
- **Some companies have agreements with the local NMHS for data-sharing and in return disseminate their warnings to the public via apps** (e.g. Accuweather app), effectively helping to enhance the authority of the government's voice. Other companies have no interactions with the local NMHS or governments. Those companies in most cases are not affected by local legal and policy frameworks, as they operate from outside of the countries.

  Especially noteworthy is Meteoalarm,[100] a service that aggregates official warnings from European national weather services. It was developed for EUMETNET with strong support from WMO. End users can simply view their website; weather service providers can access the information via web services and disseminate through their own channels. Meteoalarm seems to meet the consistency weather warning requirements identified in a recent study by Weyrich et al. (2019).
- **NMHSs do not encourage the in-country physical or virtual presence of international weather enterprises when they are perceived as competition**. In some countries, there can be a generally negative perception of profit-driven private companies. In other cases, international providers use market penetration strategies discrediting the capabilities of the NMHS.
- **International service providers would benefit from local data**. Many countries have a conservative data policy which restricts the dissemination of NMHS data and products derived from the data. Additionally, some NMHSs or governments lack experience in interacting with private companies. International weather service providers aim at proving that the benefit of NMHS data to the public is higher when the data are shared. The establishment of a relationship and possibly even a partnership with relevant public entities is a crucial business development issue for the private sector.
- **Some countries have legal impediments for private international service providers**. For instance, China requires a joint venture with a local company.
- **Depending on the regulatory framework and the maturity of business activities, there are different ways for international weather enterprises to cooperate with an NMHS**: (i) agreeing by MOU or business contract to cooperate on managing and improving the meteorological services in a country; (ii) obtaining the permis-

100 http://www.meteoalarm.eu.

sion to render meteorological services as a private service provider; and (iii) purchasing the necessary data from the NMHS.

- **International weather service providers have a large customer base and can often improve their forecast quality due to ample customer feedback**. This is especially true for mobile-based services.
- **A very productive first step is to bring together all stakeholders in a country, specifically the hydromet-related agencies and identify areas of cooperation**. This can open the flow of data between agencies and create synergies that help build the hydromet value chain.

3.10 Models and examples of public-private engagement

Public-Private Engagement has been broadly defined as engagement between the public, private, and academic sectors. The study's research identified a wide and heterogeneous range of PPE that can be summarized as follows:

- **Customer-supplier relationship:** The private sector acts as supplier to the NMHS either by provision of products (e.g. instrumentation) or services (e.g. lightning detection or computing as a service). This model is very common, especially concerning the provision of products. The provision of services is less frequent but recently has gained more attention.
- **Financial partnerships for infrastructure projects:** Co-financing of infrastructure through classic PPPs (e.g. investment projects for roads and airports) is not yet very common in the hydromet domain. One example of such a PPP is in Indonesia. The private company pre-finances infrastructure investments, while the NMHS runs the instrumentation, receives education and training, and pays back the private company over a certain period.
- **Exchange or sharing of infrastructure:** The NMHS and the private sector work together to more efficiently provide observations by: (i) building up separate but coordinated infrastructure and then exchanging observation data (e.g. cooperation between the private and public sectors in Japan); or (ii) sharing a part of the infrastructure (e.g. in Indonesia, the NMHS receives space to install its automatic weather stations on private offshore platforms, cell towers, or plantations and provides data in return).
- **NMHS support for new products and services:** The NMHS supports the development of new products and services in the private sector. For instance, in Indonesia, the NMHS is supporting the development of weather index-based micro-insurance by local companies. The insurance is part of a complete package educating, supporting, and financing farmers. The NMHS provides information as decision making support to the package.
- **Joint and project-based applications for private contracts:** The private and public sectors jointly offer services to other private companies. This is not a typical form of engagement, as the private partner is often a company which is not active in the hydromet domain but is seeking a partnership to complete or strengthen a tender submission. An example is the Ghanaian company which is collaborating with the NMHS for a tender in the offshore oil sector.
- **Cooperation of the private sector with transnational companies:** The private sector cooperates with transnational companies to deliver products and services to local customers (e.g. actionable weather information delivered via mass voice calls to farmers in Ghana).
- **Dissemination of Warnings:** The private sector, such as mobile operators or transnational weather service companies, distribute warning messages on behalf of the NMHS or a public emergency service organization.
- **Provision of open data to the private sector:** The NMHS provides observational data, model outputs, and basic forecasts as, for example, in the U.S. and Japan. This type of engagement is typically the effect of a strong open data policy.
- **Commercial activities of the NMHS:** The NMHS sells data, products, or services. In some cases, this is done by an entity detached to some extent from the NMHS, sometimes by the NMHS itself. This is a supplier-customer relationship that is comparable to the «Customer-supplier relationship» (first on the list), only with reversed roles.

Photo: JIRAROJ PRADITCHAROENKUL.

4. Hydromet value chain development and public-private engagement

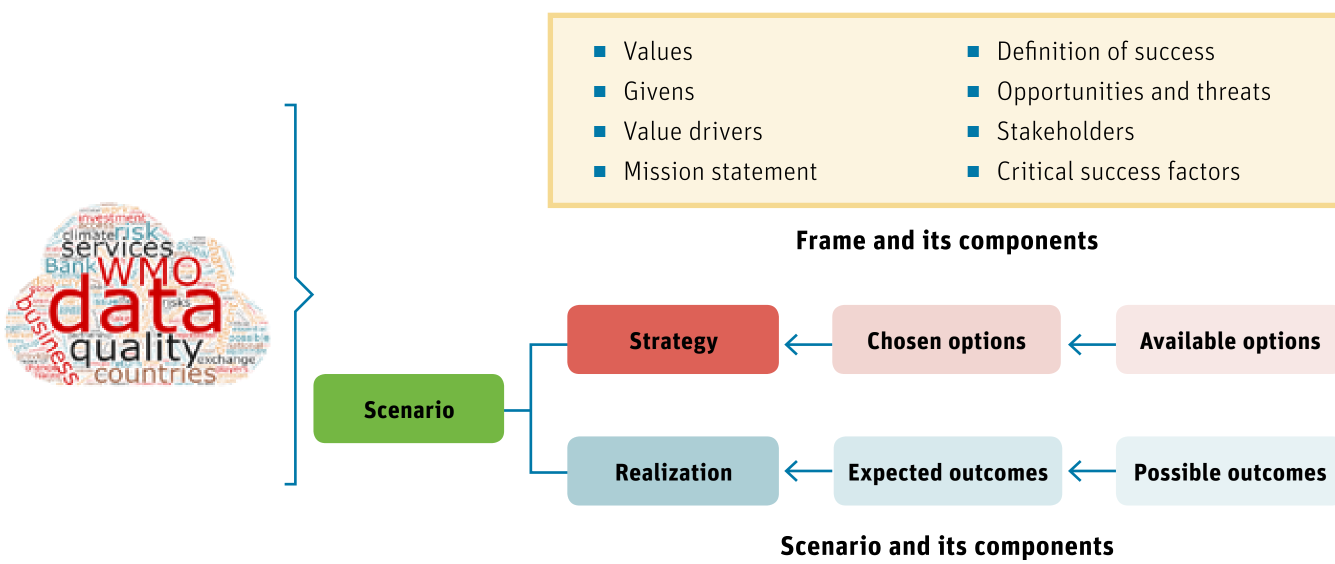
This chapter analyzes possible development scenarios of the hydromet value chain, possible options for PPE, and good practices for development. The analysis should enable practitioners and stakeholders to identify the optimal options for their specific case, make informed decisions, and address prerequisites early in the process.

The analysis follows scenario-based planning methods, using the concepts of «frame» and «scenario». A frame describes the context in which a scenario is defined and comprises elements such as values, givens, stakeholders, success factors, and others. Each scenario is constructed by selecting the options which will define the strategy and identifying the outcomes which will define a possible realization. Figure 9 shows a schematic of the elements comprising frame and scenario. Note that only the frame components in bold typeface will be used in the analysis. More information on scenario-based planning and the notions of frame and scenario are provided in the annex.

Each scenario is defined after selecting a set of options. Pros and cons of each option can be intrinsic to the option, namely they are independent of the country (or the context) where the option is applied, or they can be country-specific. As a result, options rejected for an advanced value chain may be valuable in a low-maturity value chain, and conversely, options suitable for an advanced value chain may be too ambitious or simply irrelevant for a low-maturity value chain. Therefore, frames and scenarios of hydromet value chain development projects will vary from country to country.

This chapter is organized as follows: Section 4.1 discusses the aspects which are common to all scenarios. Section 4.2 presents three reference scenarios: jump-starting a low-maturity value chain, strengthening the NMHS in an intermediate value chain, and optimizing an advanced value chain. Section 4.3 describes good practices for the development of a sustainable hydromet value chain or of a successful public-private engagement.

Figure 9: **Putting interlinked issues into a coherent structure that can be used in planning a hydromet value chain improvement project. The frame captures the wider context; in this chapter only the bold frame components are used. Scenarios link possible strategies to possible realizations. See the annex for more detail.**



4.1 Aspects common to all scenarios

4.1.1 Common frame elements: values, value drivers, and givens

Core values are the fundamental principles that guide the provision of hydromet services. They must always be considered in decisions that affect a development project. Not all stakeholders have identical goals, and some of their specific goals may conflict. Agreeing on the core values is what maintains a project's purpose when conflicting goals arise.

Table 9 presents a list of core values for providing hydromet services. The protection of lives and property is part of any government's core mandate; the provision of adequate government hydromet services and ensuring fair and universal access to information services that are critical for the protection of lives and property can be considered part of this mandate. Creation of additional economic benefits is one of the ultimate goals of an NMHS, whether directly or indirectly through the services provided to the private sector. The impacts of weather service data policies on national security need to be carefully assessed, as measures overly restricting the open exchange of data may severely hinder international cooperation and ultimately the quality of weather forecasts («weather does not stop at borders»).[101]

Table 9 | **Core values for providing hydromet services (common to all scenarios).**

Protect lives and property	**Values**
Create additional socio-economic value	
National security	

Value drivers are activities that increase the value of a project's outcome. One could see value drivers as the main «levers» to create value—increasing the presence of value drivers creates more core value. Table 10 gives examples of generic value drivers for hydromet services; more value drivers are listed in the context of individual scenarios.

Table 10 | **General value drivers (common to all scenarios).**

International cooperation	**Value drivers**
Public/private sector cooperation in value chain	
Development projects	

Givens describe facts, assumptions, and decisions that have been made and boundary conditions that affect an initiative. Table 11 lists givens common to all scenarios. An important given is **technical advances have enabled the private sector to offer hydromet services that could once be provided only by NMHSs**. This opens up possibilities, in particular for less developed countries, to benefit from public-private engagement to efficiently strengthen the provision of weather and climate services. For example, local forecasts have improved by combining local station data, global numerical weather model output, and simulated historic data through machine learning.[102]

Table 11 | **Given situation (common to all scenarios).**

The need for hydromet services is growing (e.g. due to more extreme weather, higher vulnerability due to population growth and urbanization, and climate change).	**Givens**
The lack of observation data over large areas (e.g. oceans, Sub-Saharan Africa and polar regions) due to the absence of developed NMHSs and the lack of international agreements to fill these gaps is a big challenge.	
Today's global NWP models match or exceed the skill of the previous generation's regional models.	
Relatively inexpensive observation methods such as sensors and automatic weather stations combined with modern post-processing techniques that can significantly increase the quality of nowcasts and short range forecasts are becoming available.	
Machine learning methods become available that allow assimilation and post-processing to take advantage of mass cheap sensor data and the extremely large output of global modeling systems.	
Open data policies stimulate private-sector development.	
Technical advances have enabled the private sector to offer hydromet services that could once be provided only by NMHSs.	
WMO and World Bank Group are developing guidance for public-private engagement.	

101 Sharing of GPS data exhibits similar properties. The solution here is the technical ability to degrade the openly accessible signal such that adversaries are at a disadvantage.

102 See for example https://www.meteoblue.com/en/blog/article/show/37493_More+and+higher+accuracy.

4.1.2 Common options and trade-offs for public-private engagement

Besides the «classical» public-private engagement options where one side is the supplier and the other side is the customer of hydromet equipment, data, or services (e.g. those discussed in Chapter 3), there are interesting options for public-private engagements with a stronger emphasis on partnership (i.e. where there is a give and take between participants). These are summarized in Table 12 and Table 13, respectively. Note that options are generally not exclusive of each other.

Table 12 | **Pros and cons of supplier-customer-type options for public-private engagement (common to all scenarios).**

Option	Pro	Con	Alternative / Mitigation
Direct payment: agency-to-agency (not PPE but a form of partnership)	Customer agency has influence on supplier agency to make supplier's product more pertinent.	Distraction instead of improvement because the focus is on financing instead of on service delivery and impact. Supplier agency has ways to side-step demands.	MOU between agencies clarifies customer's needs and supplier's capabilities. Budget strategically allocated by government.
Direct payment: private sector-to-NMHS	Customer has influence on NMHS to make supplier's product more pertinent.	NMHS competes with the private sector, stifling the hydromet value chain.	Non-public services are not provided by the NMHS.
Direct payment: private sector-to- government for NMHS services	Customer has influence on supplier to make supplier's product more pertinent. Supplier prioritizes services for which there is demand.	Incentives do not work in practice, as money and service flows do not overlap.	Non-public services are not provided by the NMHS; fees for defined public services; and feedback mechanism for continuous improvement of services.
Fees for public service	Straightforward cost recovery.	Overhead in setting and collecting the fee; stifling of private and non-profit sectors.	Only apply to targeted services (e.g. basic aviation meteorology services).
Outsource	Drive efficiency of public service provision.	Potential loss of quality, oversight, and capability building; dependency on supplier.	Vibrant private sector with competing providers. Set quality targets and use more than one supplier.
Open data	Stimulate private and academic sectors as well as small companies and not- for-profit organizations.	Could amount to hidden subsidy of non-public services; free-ride issue with foreign countries; and uncertainties concerning data which are not produced by the NMHS itself but outsourced to the private sector.	Restrict open data to public services; clearly define the scope (e.g. data/services routinely produced by NMHS as part of its public services); and restrict dissemination of data through license agreements with the private sector.

Table 13 | **Pros and cons of partnering-type options for public-private engagement (common to all scenarios).**

Option	Pro	Con	Alternative / Mitigation
Dissemination of official warnings by the private sector	Maximize the reach of official warnings.	Overhead to negotiate and implement, dependency on the private sector.	Automate and facilitate the dissemination of official warnings.
Rely on transnational company to provide public services	Immediate availability of services.	May limit in-country capacity building.	Time-limited contracts and local content requirements to support capacity building.
Co-finance infrastructure with PPP projects	Risk-sharing facilitates financing of infrastructure projects.	Project setup may be complicated and costly, overhead costs for oversight, less control.	Adjust PPP project controls to reflect relatively low investment numbers. Only apply in cases where interests are clear and well aligned.
Share infrastructure	Lower cost, access to privately owned sites (e.g. drilling platforms).	Costs for coordination and oversight, less control.	Rely on own infrastructure.
Joint development of new products and services	Lower total cost and better understanding of requirements and possibilities.	Inefficiencies because of organizational overhead.	Good R&D governance, finance own R&D.
Joint offering of non-public services	Lowers the public budget needed to operate the NMHS.	Blurs the line between public and non-public services; distraction for NMHS; and may result in an unfair competition advantage for the participating company.	Only apply in cases where this produces capacity building. Ensure a level playing field for other companies.

4.1.3 Common options for governance and funding

Table 14 summarizes options and decisions on strategic governance of the hydromet value chain that are common to all scenarios. One important decision, the scope of public services, depends on what a country considers public interest and must be considered on a country-by-country basis. Therefore, it does not appear in the reference scenarios. (See Chapter 2.2 for guidance on approaching such decisions.)

Table 14 | **Strategic governance options and decisions (common to all the scenarios).**

Option	Decision
Well-defined role for NMHS, focused on provision of public services	Laws, policies, and regulations
Open data: share all national surface-based weather data and basic services freely without charge	Data-sharing policy
Share data internationally in line with WMO Resolution 40	
Government agency (e.g. NMHS) or similar	Provision of public services
Partial outsourcing to the private sector	
Private sector	Provision of non-public services
(International) quality targets for public services	Quality assurance policy
Market mechanism for quality assurance of non-public services	

- **Laws, policies, and regulations.** They establish a well-defined role for the NMHS in line with how a country wishes to organize its hydromet value chain. They create certainty for businesses in the private sector.
- **Data-sharing policy**. Open data is key to enabling the private sector to provide non-public services. For international cooperation, follow WMO standards.
- **Provision of public services**. Governments are mandated to provide oversight on public services. Oversight can be entrusted to an agency (e.g. the NMHS), which can be supported to various degrees by the private sector.
- **Provision of non-public services**. These are left to the private sector to maximize economic efficiency (as detailed in Chapter 2.2).
- **Quality assurance policy**. As part of government oversight, public services are assigned targets to meet for the service quality. Regulation of the quality of non-public services is left to market forces and professional liability laws, as it is standard in most developed countries. If they are not effective, then exceptions should be made, especially in the area of weather information that feeds into safety-related activities such as official warnings.

Table 15 summarizes strategic options and decisions on funding public hydromet services. The options also have been discussed in Chapter 2.2.

- **Investment.** Forms of co-investment can be discussed, where both the state and a private partner invest cash. In addition, a private partner can pre-finance equipment it provides, knowing that it will be paid off over a period of time. This will typically involve some guarantee by the state to buy data as a service over a sufficiently long period from the private partner.
- **Financial risk-sharing.** When co-investing, the state can guarantee part of the investment to reduce the risk for the private partner within reason.
- **Revenue streams.** The state funds public services through regular taxes and, where applicable, fees.
- **Operations and maintenance.** The state funds operations and maintenance. There may be opportunities to leverage private-sector capabilities.

Table 15 | **Strategic public services funding decisions and options (common to all scenarios).**

Option	Decision
State invests cash	Investment
Private partners invest cash	
Private partners pre-finance equipment that they provide[103]	
State takes a share of financial risk	Financial risk sharing
Private partner takes a share of financial risk	
Regular taxes	Revenue streams
Fees on selected public services (e.g. basic aeronautical meteorology services)	
State budget for operations and maintenance	Operations and maintenance
Explore opportunities where the private sector can operate equipment and recover cost by rendering non-public services while giving inexpensive access to data for public services	

[103] An equipment manufacturer does not sell its equipment but pre-finances it and recovers the investment by charging for its use.

Table 16 | **Reference scenarios (green) formed by combining frames capturing different given situations (ochre), possible strategies (red), and desired realizations (or future situations, blue).**

Scenario	Jump-start	Strengthen	Optimize
Given situation	«Immature»: The value chain has low maturity. Public services have significant gaps. National services have no advantage over international offerings.	«Intermediate»: The value chain meets a few of the country's needs. The NMHS is spread thin, providing public services and non-public services to recover cost.	«Advanced»: The value chain serves the country's needs. Public service cost/value ratio needs to be optimized.
Strategy	Establish a value chain and unlock existing potential.	Prioritize a well-functioning NMHS focused on providing public services and enabling the national private sector to provide non-public services.	Reduce public service cost without sacrificing quality.
Realization	The public and private sectors co-operate in a sustainable hydromet value chain of intermediate maturity. Development partners and transnational companies support the provision of public services.	A strong NMHS provides public services and enables the private sector to provide non-public services in a sustainable hydromet value chain of intermediate to advanced maturity.	The public and private sectors cooperate in an optimized advanced value chain that minimizes the cost of public services without loss of quality.

4.2 Reference scenarios

Options for public-private engagement must be assessed for each country in the context of its hydromet value chain maturity, its laws and regulations for the provision of hydromet services, and the way it provides public services. Three scenarios—Jump-start, Strengthen, and Optimize—illustrate how the available options change with a given situation. Each scenario combines a typical given situation with a possible strategy to achieve a desired realization for hydromet value chain development. Table 16 summarizes the given situation, strategy, and realization for each scenario.

These scenarios are simplified examples that focus on key aspects; they can be expanded with input from hydromet experts and stakeholders. For example, specific development projects need more detail to develop actionable plans.[104] The three above scenarios have the same overall context, or «frame». Specifically, the values and the givens listed in Table 9 and Table 11 are common to all scenarios.

4.2.1 Scenario «Jump-start»

Mission statement: Take advantage of private-sector capacity to jump start the value chain while laying the foundation for a sustainable NMHS.

Given situation

In the Jump-start scenario, the current hydromet value chain has low maturity. The NMHS provides basic public services; the observation infrastructure has significant gaps. An underfunded NMHS struggles with capacity, sustainable operations, and maintenance of equipment. However, the NMHS does provide aviation meteorology services. Part of the NMHS staff is not motivated and, given the opportunity, capable individuals leave the service and even the country.

The national private hydromet sector is not developed. A few high-value hydromet services are rendered by transnational companies (e.g. metocean services for offshore oil exploration and production). The general public uses transnational services (e.g. popular international websites and apps for weather forecasts).

[104] The more-detailed scenarios in the annex can serve as a starting point.

Small companies, some supported by NGOs, find ways to tailor, enrich, and deliver hydromet information to make an impact on their customers' lives. Notably, the skill profiles needed by those companies are more closely related to their customers' areas of expertise (e.g. farming) combined with service tailoring and delivery (e.g. ICT technologies and customer support) rather than to hydromet disciplines.

The specific givens for Jump-start are listed in Table 17.

Table 17 | Specific givens in Jump-start.

Low-maturity value chain	**Givens**
Private-sector companies start identifying and servicing customer needs	
Talent leaves the public sector for other countries	

Value drivers and definition of success

In this scenario, the big challenge is to set the right priorities to jump start a sustainable hydromet value chain. The main value drivers (the «levers» to create and enhance value) in Jump-start are hydromet value chain effectiveness, public service sustainability, level of cooperation among government agencies and between the public and private sectors, and capacity building (Table 18).

Table 18 | Specific value drivers in Jump-start.

Effectiveness (impact) of value chain	**Value drivers**
Sustainable public services	
Cooperation among government agencies	
Public / private sector cooperation in the value chain	
National capacity	

The definition of success guides project teams to prioritize tasks. In Jump-start, the definition of success steers project teams toward working at the right level of government to bolster basic public hydromet services and to engage with the private sector to make the overall value chain work (Table 19).

Table 19 | Specific definition of success in Jump-start.

The government views hydromet services as strategic and engages accordingly with its stakeholders.	**Definition of success**
Basic public services are provided sustainably after development support for operations and maintenance ceases.	
Official warnings have good accuracy and reach affected people.	
One or more small hydromet-related companies are successful.	

Options

Only ten years ago Jump-start would have required to first work on the supply side of the value chain, typically by trying to strengthen the NMHS. Today's availability of quality global weather model results, transnational delivery channels, and weather services APIs[105] allows development projects to rapidly plug gaps along the value chain in parallel with building up public hydromet services. This allows NMHS development to focus on areas where it can make a difference in services because of its local presence (in contrast to transnational companies and operators of global systems and models).

The strategy in Jump-start can leverage these global developments, considering that most impacts of the hydromet value chain are created at the user end. Demand has to be stimulated with effective initiatives that clearly demonstrate the advantages of systematically using hydromet information. Good take-up of hydromet services in turn underlines their value and the need to further improve them (e.g. using global forecast model output).

- **The strategy must address governance, public service funding, capacity building, the technical approach, and accompanying measures.** These illustrative scenarios only highlight a few specific options from all these areas (Table 20). A more comprehensive set of options is listed in the annex.

[105] For example, web services offered by private companies and public institutions.

Table 20 | **Specific strategic decisions and options in Jump-start.**

Option	Decision
Share data through appropriate regional mechanisms (i.e. regional specialized meteorological centers, regional climate centers)	Data-sharing policy
Government agency (e.g. the NMHS) with significant technical support from transnational companies / agencies	Provision of public services
Request instruments extended warranty plus several years of maintenance	Operations and maintenance
Development partners finance operations and maintenance[106]	
Train in country, on the job; embed trainers in workforce for several months at a time	Training
Train teams rather than individuals, especially if sending them abroad	
Train on the job before sending staff for training abroad	
Train more people than needed and accept that some will move on	
Inexpensive robust stations[107]	Surface-based observations
Data aggregation via regional hubs	Observation data-sharing architecture
Data aggregation via mobile operator service	
Use software-as-a-service third party post-processing chain	Post-processing

106 A development partner finances operational expenses to sustain operations for the duration of a project and potentially for an additional transition period.
107 «Robust» stations are reliable stations with good accuracy, sufficient for weather forecast but not necessarily for climate analysis. They are often less costly than WMO-certified stations.

- **Data-sharing policy.** An open data policy has maximal benefits when jump starting a hydromet value chain. In addition, sharing data with regional organizations is a good way to engage with them for mutual support and alignment.
- **Provision of public services.** Leveraging available technical solutions allows the NMHS to move fast. Care must be taken to build NMHS capacity at the same time and not to become dependent on outside support in the long run.
- **Operations and maintenance (O&M).** Covering the cost of O&M can be a chicken-and-egg problem: without proper maintenance public services are unreliable and the hydromet value chain cannot develop. Without a visible hydromet value chain, it can be difficult to convince the government to properly budget for O&M. A good tactic could be to request an extended warranty plus maintenance period. This would increase the initial investment but would provide reliable equipment and incentivize vendors to train in-country staff. It also would align with some development partners' rules that do not permit O&M funding. In general, however, in Jump-start, development partners have a role to guarantee O&M for a certain period.
- **Training.** Many simple measures can be applied to improve training and help the NMHS to retain employees (see Table 20).
- **Surface-based observations.** The combination of global NWP output and inexpensive weather station data for post-processing can significantly enhance the value chain. This should complement the use of WMO-compliant stations feeding into global assimilation, which is a more complex and lengthier task.
- **Observation data-sharing architecture.** The emerging gold standard for sharing observation data is the WMO Integrated Global Observing System/ WMO Information System (WIGOS/WIS),[108] which is more attuned to today's data landscape than Global Telecommunications System (GTS). However, sharing observations in compliance with WIGOS may be a costly and complex approach, which should be complemented by more easily achievable and more sustainable solutions for data aggregation. For example, partnering with mobile operators who want to extend

108 http://www.wmo.int/pages/prog/www/wigos/index_en.html.

their service portfolio to ICT operations services. This might require coming up with a simplified approach that could evolve into WIGOS compliance later.

- **Post-processing.** New technologies involving multi-model ensembles accessible through web services open an easily accessible way of using station data for state-of-the-art post-processing and using the results in the hydromet value chain.

Table 21 | **Strategic actions and goals for accompanying measures in Jump-start.**

Option	Goal
Coordinate with NGO initiatives	Increase hydromet value chain impact
Coordinate with start-up initiatives	
Apply scenario-based planning	Agile project management
Facilitate lean start-up projects	

- **Increase hydromet value chain impact.** NGO projects and start-up initiatives usually have good access to in-country talent and are very customer-oriented in their operations. There is significant potential to stimulate hydromet services demand and to raise the profile of the hydromet value chain by making sure a development project is well connected to the demand side. This does not require a large capital investment, but adequate coordination support and expertise must be provided. For example, projects such as *Esoko* in Ghana do not scale by themselves but avail of (proving) in-country talent. For this option to work, development partners must find ways to leverage this talent on a bigger scale.
- **Agile project management.** Jump-start requires a substantial amount of trial-and-error in a multi-stakeholder environment. Traditional project planning and management methods cannot handle this. Scenario-based planning and a lean start-up approach are much better suited and have proven successful in many industries.

Realization

The Jump-start strategy aims at reaching a realization (a future situation) that is briefly characterized in Table 22. Note that the realization is built around uncertainty, acknowledging that plans may not work out as intended. See the annex for additional detail

.

Table 22 | **Realization outcomes aspired to in Jump-start.**

Outcome	Uncertainty
Low to intermediate	Value chain maturity
Private companies are providing non-public services	Market development
Fully funded, including maintenance and operations	Sustainability of public services funding

- **Value chain maturity**. While a development project should aim at reaching the next maturity level, it may be more realistic to expect building a good basis for reaching that level in the future.
- **Market development.** One or two national private companies providing non-public services are a respectable outcome in Jump-start.
- **Sustainability of public services funding.** Public services are sustainably funded after financial support from a development project has tapered off.

4.2.2 Scenario «Strengthen»

Mission statement: Strengthen the NMHS and focus it on providing public services, thus laying the foundation for the private sector to efficiently provide non-public services.

Given situation

In the Strengthen scenario, the current hydromet value chain is intermediate, dominated by an NMHS that is pushed by government policy to extend its non-public paid services. However, there is no significant broadening of the hydromet services offering, and the NMHS finds it hard to compete with transnational companies when it comes to customer satisfaction. There is a public hydromet services infrastructure but the NMHS struggles with maintenance, lack of upgrades, and some deterioration. Given the opportunity, staff tend to leave for better paid positions, most often found in the private sector. Government policies and the resulting competition between the public and private sectors are keeping the national private sector small.

The national private sector is not well developed as hydromet regulations make providing hydromet services by and large unattractive to business. On the demand side, companies are looking for ways to leverage hydromet information. For example, they package weather index insurance with agronomical advice and financing to help smallholder farmers increase their productivity. The NMHS provides some of the hydromet information, and transnational companies fill the gaps (e.g. with climatological analyses for weather index calculations). The general public use transnational services (e.g. popular international websites and apps for weather forecasts) not necessarily because of better forecasts but because they are more attractive and easier to use than what the NMHS provides.

The specific givens for Strengthen are summarized in Table 23.

Table 23 | Specific givens in Strengthen.

Intermediate value chain	**Givens**
NMHS pushed to provide non-public services to cover costs, effectively competing with the private sector	
Talent leaves the public sector for private companies	

Value drivers and definition of success

In Strengthen, there is the opportunity to strengthen the NMHS such that it provides advanced public services and becomes an enabler for a national private sector that provides advanced non-public services. The main value drivers are focusing the NMHS on the provision of public services and increasing the hydromet value chain impact by leveraging the private sector (Table 24).

Table 24 | Specific value drivers in Strengthen.

Clearly defined role of NMHS, focusing on public services	**Value drivers**
Public / private sector cooperation in the value chain	
Profitable private enterprise	

The definition of success emphasizes the NMHS capability to provide public services, measured by its capacity to grow and extend the basic system and services. Public services are seen as enablers for non-public services provided by the private sector, and the definition of success suggests monitoring the hydromet market growth (Table 25).

Table 25 | Specific definition of success in Strengthen.

NMHS has budget and capacity to safeguard the basic system and services.	**Definition of success**
Official warnings have state-of-the-art accuracy and reach everybody affected. The warning system is resilient.	
Hydromet market grows.	

Accordingly, the Strengthen strategy prioritizes a well-functioning NMHS focused on providing public services and enabling the national private sector to provide non-public services. It aims to stimulate the national weather market and allow the private sector to develop, not leaving the field to transnational companies. The rationale behind this strategy is that developing a private hydromet services sector creates more socio-economic benefit than reducing the cost of public services. As in Jump-start, transnational companies can help plug gaps in the hydromet value chain. Table 26 highlights some of the strategic options specifically chosen in Strengthen. A more comprehensive set of options is listed in the annex.

Table 26 | Specific strategic decisions and options for Strengthen.

Option	Decision
Focus NMHS role on provision of public services	**Laws, policies, and regulations**
Facilitate co-investment by NMHS and the private sector	
Monitor hydromet market development	
Partial outsourcing to national private companies	**Provision of public services**
State takes a share of financial risk	**Financial risk-sharing**
Private partner takes a share of financial risk	
NMHS makes in-kind contributions	**Investment**
Private partner pre-finance equipment that they provide	

- **Laws, policies, and regulations**. Public hydromet services are the foundation of an effective hydromet value chain: focusing the NMHS on this role is a pre-condition to succeed. Set the right level of controls for co-investment by the NMHS and the private sector. Monitor the activities of private companies in the hydromet market to quantify its growth.
- **Provision of public services**. The NMHS can leverage private-sector capabilities as long as it sets and moni-

tors the right quality targets for public services.

- **Financial risk-sharing**. When co-investing, the state can guarantee part of the investment to reduce the risk for the private sector within reason.
- **Investment**. The NMHS can enter a partnership for a required investment and make in-kind contributions such as staff-hours and expertise. The private partner can pre-finance equipment they provide, knowing that it will be paid off over a period of time.

Realization

The Strengthen realization can be briefly characterized as in Table 27. (See the annex for additional detail.)

Table 27 | **Realization outcomes aspired to in Strengthen.**

Outcome	Uncertainty
Intermediate to advanced	**Value chain maturity**
Private hydromet sector develops	**Market development**
Observation network runs stably and grows further	**Sustainability of public weather station network**

- **Value chain maturity**. While a development project should aim at reaching the next maturity level, it may be more realistic to expect building a good basis for reaching that level in the future.
- **Market development**. Analyzing a weather market and assessing its development can be difficult in many countries where little or no data are available. In Strengthen, monitoring the market is part of the strategy.
- **Sustainability of public weather station network**. The aspiration is to expand the observation network.

4.2.3 Scenario «Optimize»

Mission statement: Optimize the cost of public services by leveraging synergies with the private sector.

The Optimize scenario comprises an advanced value chain and a well-defined role of the NMHS. It is relatively compact, as it represents a much simpler situation than Jump-start and Strengthen.

Given situation

In Optimize, the NMHS has a clearly defined role of delivering public services and enabling non-public services by the private sector. Transnational and national companies provide non-public hydromet services. The public, private, and academic sectors complement each other on a level playing field. The private sector is strong with sustainable companies, some of them large, some of them with an international presence. New customer needs are met quickly given the stable backbone of a public hydromet services infrastructure. The use of hydromet services grows as more organizations find ways to benefit from them. The overall socio-economic benefit is substantial, including the associated tax revenues. However, there is constant pressure on the NMHS budget which requires it to lower its cost. Also, with new technological developments, the skill profile for NMHS staff is changing and curricula have to adapt.

The NMHS plays an important international role, sharing observation data, NWP output, NWP model source code, and other tools with the international community. Both developing and developed countries benefit from this practice. In addition, the NMHS cooperates with organizations providing training in other countries.

The specific givens for Optimize are listed in Table 28.

Table 28 | **Specific givens in Optimize.**

Advanced value chain	**Givens**
Well-defined role for NMHS, focused on provision of public services	
Thriving market meets new customer needs quickly	

Value drivers and definition of success

Key value drivers in Optimize are economic efficiency of the hydromet value chain and research and development capacity (Table 29).

Table 29 | **Specific value drivers in Optimize.**

Economic efficiency of value chain	**Value drivers**
R&D capacity	

The definition of success focuses an improvement project on public service cost reduction while the private hydromet services sector is still growing (Table 30).

Table 30 | Specific definition of success in Optimize.

NMHS efficiency is increased.	**Definition of success**
Consumer satisfaction increases.	
Public heeds severe weather warnings.	
Private hydromet services sector grows.	

Options

The Optimize strategy is to optimize public service cost without sacrificing service quality. In addition to streamlining NMHS operations, lower cost can be achieved by maximizing the benefits that private sector and competition can bring. The strategy is summarized in Table 31.

Table 31 | Strategic actions and goals for accompanying measures in Optimize.

Option	Decision
Measure the socio-economic impact of the hydromet value-chain.	Laws, policies, and regulations
Explore opportunities where the private sector can offer observation data at lower cost than it would cost the NMHS to operate the equipment.	Operations and maintenance
Integrate observation networks of different agencies.	Observation systems
Leverage data-as-a-service.	
Leverage IoT data.	
Leverage low-cost satellites.	
Use private-sector cloud computing.	High-performance computing infrastructure

- **Laws, policies, and regulations**. It is important to measure the socio-economic benefit of public services. There is a broad academic literature on this topic and examples of such assessments in various field of the hydromet value chain (see Freebairn and Zillman 2002; Frei at al. 2014; and von Grünigen et al. 2014).
- **Operations and maintenance**. The service partner may have economies of scale and scope not available to the NMHS. However, for an advanced NMHS in an advanced value chain, the risk of becoming overly dependent on a private-sector service partner is low.
- **Observation systems**. Different agencies run networks that should be integrated to make all data readily accessible as part of public services. New technologies are becoming available but still need to be developed and tested. They can be expected to provide cost-saving opportunities without loss of quality.
- **High-performance computing infrastructure**. This is an example where a specialized company can have better economies of scale and scope.

Realization

The Optimize realization is characterized in Table 32. (See the annex for additional detail.)

Table 32 | Value chain outcomes aspired to in Optimize.

Outcome	Uncertainty
Hydromet market is growing, transnational companies are successful in other countries.	Market development
Internet of Things devices and inexpensive satellites further improve local forecast accuracy.	Observation systems
Government agencies integrate their observation networks.	Level of cooperation

- **Market development**. Market growth can be assessed, for example, by measuring the tax revenue attributable to the use of public hydromet services, including open data.
- **Observation systems**. Internet of Things devices and inexpensive satellites further improve local forecast accuracy.
- **Level of cooperation**. Government agencies integrate their observation networks.

4.3 Good practices

Good practices for the development of a sustainable hydromet value chain or of successful public-private engagement have been identified through country case studies. While the list of such practices described below is not exhaustive, it includes key aspects a country may need to consider when exploring effective public and private engagement. These «good practices» are broadly categorized into governance, funding of public service, capacity building, infrastructure, and development support, reflecting the design of development projects. Table 33 provides a summary of the good practices discussed below.

4.3.1 Governance

- **Prioritize hydromet services as strategic public service by government.** The government needs to allocate budget to its public services according to its strategic priorities. Leaving agencies to fend for themselves and compete directly with each other and with the private sector creates damaging friction.
- **Role of the NMHS seen as an enabler for a well-functioning hydromet market.** An NMHS that focuses on public services can help stimulate the private sector and thus multiply the socio-economic benefit that it could create just by itself. Missing this point means stifling the private sector.
- **Clear regulations.** The definition of the NMHS' mandate and the data policy are two especially important aspects of regulation in the hydromet domain. Moreover, because the hydromet value chain is interlinked, what is public and what is non-public service must be clear. Otherwise, for private companies, the risk to engage is too high. Clear regulations help to build trust between sectors.
- **High awareness in government of the benefits of public hydromet services.** In many countries, NMHS managers do not receive sufficient government support for creating sustainable hydromet value chains. This may be due to a number of factors, and the lack of awareness is a common one.
- **Investment project processes and controls suitable for the hydromet domain.** Co-investment often implies that the government directly or indirectly supports an investment, which requires proper governance. However, co-investment typically falls into the remit of institutions designed for large public-private partnership (PPP) projects such as road building or dam construction. The existing associated controls and administrative overhead are typically disproportionately large for the much smaller hydromet projects, resulting in inadequate project lead times.

4.3.2 Funding of public services

- **Sufficient and sustainable budget.** This may apply to all public hydromet services cost, including investment and R&D budget, among others. In particular, some governments underestimate the crucial importance and relatively high cost of maintaining observation networks. Development partners typically do not finance maintenance and operations, although this is critical for the sustainability of observation networks once a development project has finished.
- **Realistic expectations of what a low-maturity NMHS can deliver outside its core competencies.** There can be unrealistic expectations of what products and services a low-maturity NMHS can design and deliver. Creating good weather forecast and tailoring weather information for a particular user group require very different skills. It is tempting to extend the scope of NMHS activities to generate income from non-public services. However, this spreads the NMHS thin with tasks for which it does not have the appropriate skill profile. The difficulty of designing hydromet products and services and also delivering them is easily underestimated. *Esoko* in Ghana, for example, employs an agronomist to formulate recommendations for farmers based on the weather forecast as well as field technicians to help farmers with properly registering their farms with the service. The company relies on the Ghana NMHS for meteorological advice.
- **Minimize non-public services by the NMHS to recover cost.** An NMHS offering non-public services in competition with the private sector can have distorting effects on the market and impede the development of a vibrant private market. At the same time, because the NMHS acts and is perceived by the private sector as a competitor, PPE becomes inherently more difficult.

  These negative effects can be mitigated, to a certain extent, by strong competition laws and an independent regulator that ensures a level playing field between the public entity and the private sector. Such setups can also be found in other industries where services were historically provided by the public sector, which lost the exclusivity but still owns a major stake in an important player of the industry. One such example is the telecom industry in Germany and Switzerland. While there are analogies between the telecom and the hydromet domain, such as massive technological shifts, diminishing natural monopolies, and a changing public-sector role, the hydromet domain relates more directly to public health and safety. Therefore, many hydromet services are public services and will likely remain so in the near future.

If non-competing (public) and competing (non-public) services are produced within the same organization, ensuring a level playing field becomes very challenging in practice. Because the line between public and non-public services is often blurry, assigning a specific cost to the non-competing or the competing part of the organization is not always clear-cut. Preventing such distorting cross-funding is costly and in practice, often not fully possible because of an information asymmetry between the regulator and the regulated entity. The regulated entity has more information on its own operations (e.g. details concerning the allocation of costs to public and non-public services). This inherent information asymmetry harms not only market fairness but also the perception of market fairness, and with it the willingness of the private sector to engage.

4.3.3 Capacity building

- **Empower the NMHS to hire its own staff**. In some countries, staff are assigned to the NMHS by the government. Then, if low priority is given to the NMHS, successful career paths tend to lead out of it. In this situation, it is very difficult to create attractive career paths within the NMHS. The same is true if the NMHS has no assurance that people will return to the agency after training (e.g. in regional centers).
- **Create attractive career paths**. Without attractive career paths, the NMHS cannot retain key personnel. Public-private engagement becomes a threat as NMHS employees leave to the private sector on a one-way street. At the same time, it is very important that young generations see potential future job opportunities in the hydromet domain. PPE and a strong private sector would lead to job creation, and potentially incentivizing young generations to study topics relevant to the sector such as meteorology or remote sensing.
- **Provide robust training in development projects**. Development projects often focus on providing new infrastructure to developing NMHSs at the expense of training. Training is often too short, lacks follow-up, and is narrowly scoped in support of particular project objectives. Development projects should support training programs to systematically and holistically build, maintain, and update NMHS infrastructure.

4.3.4 Infrastructure

- **Ensure projects are fit-for-purpose**. The importance of adequate infrastructure for NMHSs to carry out their mission (especially communication, data storage, and computations abilities) is difficult to overestimate. It is thus easy for development projects to target ambitious results, and these results tend to focus on infrastructure. This can detract from the changes that need to be embedded in an organization and incur the risks of newly installed systems quickly deteriorating once a development project is finished. Typical examples include the acquisition of too ambitious AWS networks, weather radar installations, and NWP systems. Rather, cost-effective and fit-for-purpose infrastructure needs to be considered.
- **Establish a standard for lower cost weather stations**. Many lower cost weather stations are used in individual projects where they can significantly improve the local forecast. With advances in post-processing and assimilation techniques, they could be used in a strategic mix, complementing WMO-compliant top-quality stations. However, there is no guiding quality standard that would provide manufacturers with specifications and users with selection criteria for suitable low-cost weather stations. With such a standard, countries could more systematically benefit from lower cost solutions with confidence.

4.3.5 Development support

- **Focus development activities on the entire hydromet value chain, and not just on the NMHS.** Traditionally, the NMHS provided all hydromet services. In developed countries, hydromet services developed over many decades, using sound budgets. Today, focusing on the entire value chain opens the door for using private sector capacities to increase the impact of hydromet services.
- **Keep the development investment budget at an appropriate level.** Somewhat surprisingly, a development budget can be too high at times: in some cases, this is an incentive for formulating an infrastructure-focused project; in other cases, it is used to implement, in parallel, multiple small-scale and fragmented projects without addressing key bottle necks in the value chain. Many measures aimed at jump starting a hydromet value chain are not necessarily costly, and the administrative

overhead can be kept low to promote agility and fast convergence toward good solutions. Too high a budget can change the dynamic from looking for solutions to looking for the best ways to spend the available funding. This is counterproductive, especially if there is a lack of capacity to specify how to allocate the budget.

- **Appropriate operations and maintenance (O&M) budget.** O&M is critical to sustain development and to build capacity. Development partners are not inclined to support O&M, being viewed as the government's responsibility. Concerns also arise that such funding creates government dependency on development financing for recurrent cost. Therefore, in the least developed countries, it is crucial that the transition from funded development to sustained operations be planned and managed over a sufficiently long period of time. While it is important that governments commit to sustainable operation of public hydromet services, development partners may need to find a better way of ensuring such commitment. The current approach does not seem to be working. In fact, it may miss out on promising opportunities to improve capacity building.
- **Ensure flexible development project design and support technical specification capacity.** Finding the best way to build an effective hydromet value chain is a trial-and-error process, somewhat similar to starting up a company. It is often not possible to formulate a detailed project plan upfront and then implement it. Rather, flexible project planning and management methods have to be applied that can support the start-up process.

The good practices of development support discussed above closely relate to the good practices of governance support.

Table 33 | Good practices that foster the development of a sustainable hydromet value chain and successful public-private engagement.

Good Practices	Area
Prioritize hydromet services as strategic public service by government	**Governance**
View the role of NMHS as an enabler for a well-functioning hydromet market	
High awareness in the government of the benefits of public hydromet services	
Recognizing the need for a clear legal frame	
Investment project controls are scaled adequately for the hydromet domain	
Sufficient and sustainable budget	**Funding of public service**
Realistic expectations of what a low-maturity NMHS can deliver outside its core competencies	
Minimize non-public service by NMHS	
NMHS is empowered to hire its own staff	**Capacity building**
Create attractive career paths	
Provide sufficient training	
Build fit-for-purpose infrastructure	**Infrastructure**
Create a standard for lower-cost weather stations	
Focus development activities on the entire hydromet value chain instead of just the NMHS	**Development support**
Keep the investment budget at an appropriate level and include an appropriate maintenance and operations budget that covers transition to sustained operations	
Flexible development project design with adequate technical specification capacity	

High water marks at Cochem, Germany. Photo: Stanislava Karagyozova.

5. Conclusions and Recommendations

This study focuses on public-private engagement (PPE), its models, and possible ways to foster its development, especially in developing countries. PPE can neither be fully understood nor adequately improved without a detailed analysis of the hydromet value chain. In this study, cases from developed and developing countries are analyzed. While learning from reference developed countries was crucial, organizations and people fostering the development of the hydromet value chain in developing countries remain the focal audience.

The analysis is based on public information, on around 60 explorative and half-structured interviews with public entities, private companies, industry associations, and independent experts. The conclusions and recommendations presented in this chapter summarize the findings and evidence detailed in the previous chapters.

5.1 Conclusions

The socio-economic benefits of the hydromet value chain are underestimated

The socio-economic benefits of a well-developed hydromet value chain are by now well documented in an extensive literature, but are still underestimated by governments,—especially, but not only in, developing countries (see Chapter 4.3.1: **Governance**). Consequently, the development of the hydromet value chain at the country level is often not sufficiently prioritized, and regulatory policies are developed mainly considering their effects on the NMHS or related public entities. Moreover, some governments leverage the direct economic value of hydromet information by selling data, products, and services to the private sector to lower the public funding needed for their NMHS (see Chapter 3: Case studies). The resulting economic pressure on the NMHS indirectly shapes the development of the hydromet value chain, with undesired effects on a strategic level often not considered by the governments.

Economics principles should determine service delivery models

Services generated within the hydromet value chain are largely information goods with particular economic properties. The economic properties must be taken into consideration, especially when designing the regulatory framework that governs the delivery models for different hydromet services. Following a discussion of the key economic principles, such as cost structure, economies of scale and scope, and natural monopoly, practical guidelines are provided to choose the optimal service delivery model for different hydromet services (see Chapter 2.2: *Economics of the hydromet value chain*). While applying economic principles «mechanically» would underestimate the complexity of the topic and the role of country-specific preferences, the existing institutional, legal, and administrative environment and the current allocation of responsibility in a specific country, it is also true that the economic principles underlying those choices are generally applicable and should always be taken into consideration. Also, the choice of the service delivery models needs to be consistent. If the government changes its view frequently as to what it considers a public service, it makes private investments too risky. It is also important to note that economic principles suggest that public services should be publicly funded, while more tailored products can be produced and sold by the private sector.

Government commitment to the hydromet domain is a smart investment for safeguarding the public

The development of a vibrant value chain hinges of government commitment. The private sector can flourish when governments support a public entity to provide public hydromet services. Development partners would be well served dedicating time and resources to raise awareness of national governments of the socio-economic benefits of a working hydromet value chain. A government may receive support from development partners to start the process, but ultimately the government is responsible for sustained (through operations and maintenance) public services.

Understanding the characteristics of a hydromet value chain is essential for developing PPE

One of the key findings of this study is that PPE depends on the country-specific characteristics of the hydromet value chain (meaning, a narrow focus on PPE does not lead to useful insights). To effectively leverage PPE, first understanding the country's whole hydromet value chain is indispensable. To this end, three aspects are crucial: First, *maturity* of the hydromet value chain (how mature is the hydromet value chain and each element of the value chain in a given country?); second, *sector balance* (to what extent do the public, private, and academic sectors contribute to the hydromet value chain?); and third, *policy framework* which shapes the hydromet value chain. Chapter 3: Case studies documents those three aspects for a selection of countries, and the reference scenarios in Chapter 4: *Hydromet value chain development and public-private engagement* characterize typical cases.

The approach to hydromet value chains varies considerably among countries

The case studies show considerable differences between the countries analyzed, between and within developed and developing countries. The main differences can be summed up as follows (for more details see Chapter 3: *Case studies*): The hydromet value chains in the U.S. and Japan are quite similar. However, the hydromet market is more regulated in Japan, and the Japan Meteorological Agency has a double role as a provider of public services and regulator. The U. K. has a different model of operating the national meteorological service (Met Office). Due to its status as a Trading Fund, the Met Office is required to operate on a commercial basis and to meet financial targets set by its owners. This shapes the hydromet value chain in the U.K., particularly the Met Office's dominance in tailored services. Within the developing countries, Indonesia has a more advanced hydromet value chain and pushes PPE more than Myanmar and Ghana. Due to budgetary pressures and the need to sustain recent and future investments in infrastructure, the focus of the Indonesian NMHS (BMKG) on PPE prioritizes revenue generation. While both Myanmar and Ghana have a less mature value chain, the private sector plays a more important role in Ghana than in Myanmar. The legislative process started in Myanmar should result in a legal framework which will provide an important new foundation for the hydromet value chain and PPE alike.

Developing public-private engagement requires a broad and systematic approach

The definition of PPE is not universally agreed, and stakeholders use the term in different ways. To capture this heterogeneity, this study defines PPE as any kind of engagement between the public and private sectors (Chapter 3.10: *Models and examples of public-private engagement*). In contrast to WMO's definition, this study does not restrict the direction of the engagement, namely the engagement can be from the NMHS to the private sector or vice versa. The case studies demonstrate the viability of robust, heterogeneous PPEs: *customer-supplier relationship, financial partnerships for infrastructure projects, exchange or sharing of infrastructure, NMHS support for new products and services, cooperation of the private sector with transnational companies, dissemination of warnings, provision of open data by the NMHS, and sale of data or services by the NMHS to the private sector.*

This study also identifies conditions that appear to be needed for the development of a sustainable hydromet value chain or of successful public-private engagement. These conditions are present in the areas of governance, *funding of public services*, *capacity building*, and *technical* and *development support*. They are summarized as good practices and are discussed in detail in Chapter 4.3: *Good practices*.

However, the development of PPE requires a broader and more systematic approach beyond good practices: PPE options must be assessed for each country in the context of its hydromet value chain maturity, its legal framework and regulatory environment, and the way it provides public services.

To this end, this study used a scenario-based approach that can be further built on in any country. Three simplified scenarios («Jump-Start», «Strengthen», and «Optimize») focus on key aspects that evolved as evidence accrued in the case studies (see Chapter 3: *Case studies*). Each scenario combines a typical given situation with a strategy to systematically develop the hydromet value chain (see Chapter 4.2: *Reference scenarios*).

The academic sector is an important vehicle for PPE growth in the hydromet domain. Research and development ensure the ability to innovate value chain elements. Taking advantage of scientific advances, evaluating the performance of models and of nowcasting approaches, being rigorous about data quality, developing and testing new forecast products from observations and models, and building, evaluating, and testing new approaches for better effectively communicating with the public and specialized users should be regarded as one of the critical enablers of the hydromet value chain. The availability of human resources with required skillsets increases the chain's sustainability.

Key elements of the regulatory foundation for PPE are the NMHS mandate/duties and the data-access policies

Alongside exogenous socio-economic factors, the role of the NMHS and data-access policies exert a pivotal impact on the interaction between the public and private sectors. If the role of the NMHS is not clearly defined and if there is no clear distinction between public and non-public services, the development of the value chain and vibrant and purposeful cooperation between the public and private sectors is hindered. The cases of Germany and Israel (Chapter 3.8.1: *Germany* and Chapter 3.8.2: *Israel*) show that there is a realistic possibility for substantial policy changes and a reassessment of the NMHS' role, service delivery models, and the modalities of cooperation between the public and private sectors. However, change generally needs some form of pressure from a governing body (e.g. EU directives driving changes in Germany), from the private sector (lobbying for a level playing field), or from the NMHS itself (seeking to improve its funding situation).

Consistency of severe weather warnings is critical

The recent increase of private providers and channels for accessing weather information and warnings has given rise to the coexistence of public and private weather information providers. It is driving a vibrant debate and presenting a key challenge in the relationship between the public and private weather sectors. This coexistence can lead to inconsistent warnings, with low perceived quality and (thus) low effect (see Chapter 2.1: *Hydromet value chain*). No universal approach to severe weather warnings can be applied to all situations, and countries generally use unique systems (Chapter 3: *Case studies*). In countries where public and private providers coexist, strong coordination or regulation (e.g. by establishing mandatory standards for visualization and classification of warnings) can ensure consistency and public trust. Trust reinforces the system's effectiveness, particularly for official warnings. Severe weather warnings must reach everybody, especially the most vulnerable.

Development projects should focus on improving the whole value chain

Many development projects focus on NMHS infrastructure and capacity, instead of the whole value chain. Even if development partners do emphasize the importance of the whole value chain and the service delivery, the main challenge is keeping the right focus during the implementation of the project and prioritizing investments that yield socio-economic benefits given the present maturity of the value chain. Adequate infrastructure, particularly communication, data storage, and computational abilities, is critical for NMHSs to carry out their mission. However, if incentives favor high disbursement volumes, projects tend to end up focusing too much on the capital-intensive equipment side. In fact, in immature value chains, project budgets are sometimes too big, as the organizations involved do not have the capacity to productively absorb the available funding. At the same time, in developing countries, it is increasingly more important that development projects consider how domestic and transnational companies could play a role in the hydromet value chain, including in provision and maintenance of the infrastructure, and effectively contribute to its improvement.

While these effects are to a certain extent inherent to development projects, which are bound by the mission of the responsible organizations in the framework of development cooperation, it would be beneficial to explore possibilities to reshape the setup of future development projects. The findings of this study can help inform this process and align the incentives of future projects. Additionally, closer cooperation with NGOs should be explored (see, for example, Scenario «Jump-start»).

5.2 Recommendations

The following recommendations are based on the conclusions of this report. The recommendations are grouped in:

- Country-specific strategy;
- Institutions and policies;
- Dialogue and awareness-raising; and
- Development projects.

Country-specific strategy

1. **Develop country-specific approaches to foster public and private engagement and to develop the hydromet value chain.** The approach for a specific development project can be developed using one of the three reference scenarios («Jump-Start», «Strengthen», or «Optimize») as a starting point. Note that any country-specific approach must be designed considering the regional and global nature of hydromet systems (e.g. observations and forecasting).

2. **Develop an overall strategy at the country level to maximize the socio-economic benefits of the full hydromet value chain.** The strategy should be developed by the executive branch of government or a regulatory body, with technical inputs from the NMHS. The separation of roles helps to eliminate bias, ensuring that the strategy maximizes the benefit for the whole country and not only for the NMHS. Additionally, it raises the topic to a higher level, which can foster the government's commitment.

Institutions and policies

3. **Support the development of a transparent legal and regulatory framework.** A stable institutional environment is crucial to implement the hydromet strategy, for private-sector development and a sustainable PPE. A regulator should be designated, and its role needs to be defined as needed.

4. **Properly and sustainably fund the NMHS according to its role as defined in the hydromet strategy**. Not least, this adds stability to the hydromet market, which is necessary for private-sector development.

5. **Aim for open and free access to all data and public services produced by public entities** to increase the socio-economic benefits of the hydromet value chain, often via the value added by the private sector.

6. **Consider minimal regulation of the non-public hydromet services market**. While non-public hydromet services are tendentially less crucial to the safety of people than public hydromet services, some form of regulation (e.g. quality standards or mandatory harmonization) may be needed to ensure public safety, especially concerning severe weather warnings issued by private weather companies. Moreover, as in other markets, governments may choose to enforce regulations to protect the consumers (e.g. in the case of market failures due to asymmetric information between suppliers and customers). Other than that, leave the development of non-public services to market forces.

7. **Minimize the role of public entities in the provision of non-public hydromet services** when the private sector is able to provide them. Consider phasing out the production of non-public services that are also produced by the private sector. If non-public hydromet services are provided by public entities or state-owned companies, an independent regulator must ensure a level playing field between the private and public sectors. This is especially challenging if public and non-public services are produced within the same organization. From a regulatory perspective, it is certainly a complex task which requires strong institutions and a well-developed legal framework, often not available in developing countries. Depending on the legal framework, several approaches can be used (e.g. Trading Fund in U.K.), but note that measuring the practical success of an approach is often controversial.

8. **Ensure the consistency of severe weather warnings,** either by designating a single authoritative voice as the only authorized warning service provider (e.g. the NMHS) or by fostering a better coordination between the warning providers by establishing mandatory standards for visualization and classification of warnings. The meteo-alarm service of EUMETNET is a good example of coordination between warning providers within the EU.

Dialogue and awareness-raising

9. **Develop a structured, continuous, and open dialogue between the public, private, and academic sectors.** This is essential to promote trust between the sectors and to clarify the boundary between public and non-public services, ultimately fostering PPE. Besides the efforts in individual countries, platforms like the «Global Weather Enterprise Forum» are powerful and effective to promote the dialogue between the sectors on a global level.

10. **Invest in awareness-raising**, especially concerning the socio-economic benefits of hydromet services in general and their specific benefits for businesses.

Development projects

11. **Shape future development projects based on the guidelines laid out in recommendations 1-10.** The following specific activities help to apply the principles in a development project:
    - *Use scenario-based planning to align stakeholders and to create project plans that can be easily adapted to changing circumstances*. The insights of this study can be used to establish actionable plans for specific cases and pilot projects.
    - *Embrace a lean start-up approach* (Ries 2011), especially for immature hydromet value chains, to identify and leverage in-country talent and other resources, to maximize learning of all stakeholders, and to ultimately design fit-for-purpose development projects.
    - *Prioritize and support the review or the development of sound policy frameworks*. Make sound policy frameworks a prerequisite for a development project or establish such a framework at the beginning of the development cooperation.
    - Build *the commitment of governments* by cost-benefit analyses showing the hydromet value chain impact and by supporting the NMHS in raising its profile.
    - *Focus the incentives for development partners* on sustainable hydromet value chain impact rather than investment volumes.

5.3 Next steps and need for further research

This study establishes guiding principles for cooperation between the public and private sectors, adding to an already broad fundament of studies that cover organization and development of a hydromet value chain to maximize its socio-economic benefits for the population impacted. These guiding principles can be useful when preparing actionable plans for specific development projects.

Several topics could not be covered in detail and should be the subject of further research:

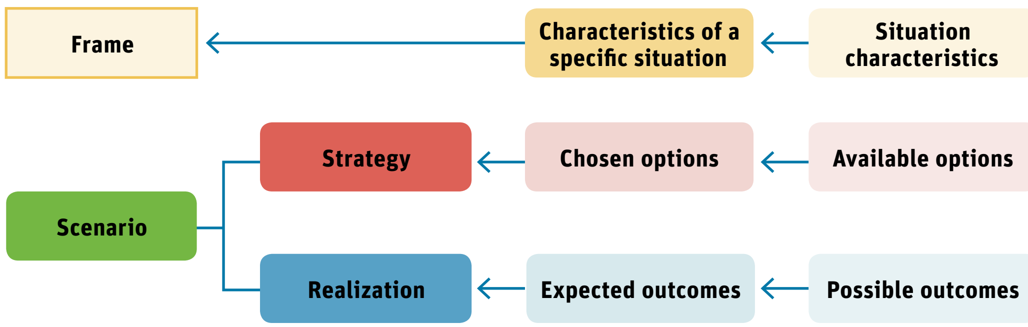
- *Exchange mechanism for global coverage data:* Remote-sensing data with global coverage, particularly satellite data, will become even more important in the future. A global data-exchange mechanism with appropriate sharing of cost and value could help with sustained financing of remote observation technology. Research would investigate if and how existing mechanisms (e.g. by WMO or EUMETSAT) could be further developed or supplemented to meet future needs without ruining the existing free and unrestricted international data-exchange scheme built in a fine balance.
- *Mechanisms for cost sharing along the hydromet value chain*. An example is sharing cost and benefits of weather stations, in particular lower cost stations that can be used for local weather forecast improvements, and that do not have to meet the stringent technical and organizational requirements of weather stations used for assimilation or climatology.
- *Making development projects agile*. The big advantage of agile planning and management methods is that organizations can rapidly adapt to changing circumstances.

Raging river in winter. Photo: Jodijacobson.

Annex: Scenario construction

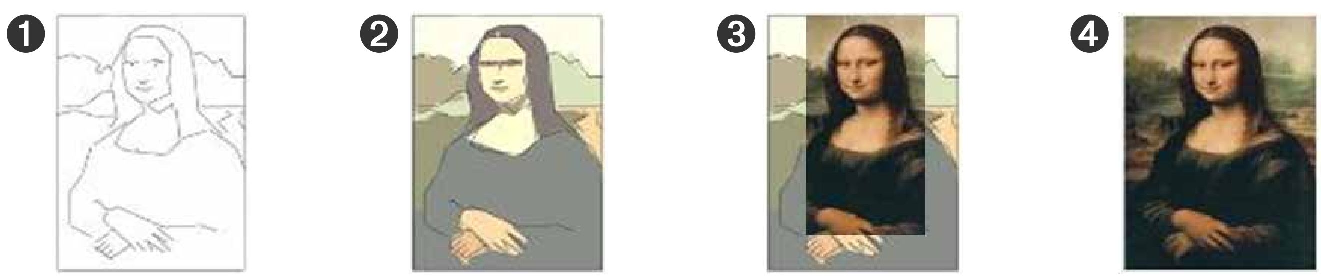
The analysis of the models of PPE in hydromet services was conducted using scenario-based planning methods (SPE 2016). The analysis is based on the description of a project «frame», or context, and a «scenario» and starts with the identification of current situations, available options, and possible outcomes. The concepts of frame and scenario are further developed below. Characteristics of specific situations were included into the frame. A scenario is made up by a strategy and a realization: options were chosen to define a strategy and expected outcomes were selected to define a realization (Figure 10).

Figure 10: **Frame (top), scenario (bottom), and their respective components give structure to complex interlinked issues.**



In general, this is best done in an iterative process that allows project teams and stakeholders to regularly review the emerging full picture as more details are being worked out. Figure 11 illustrates this iterative approach.

Figure 11: **Iterative approach to painting a picture in four iterations (after http://itsadeliverything.com).**



This annex shows how the three scenarios and frames presented in Chapter 4 (Table 34) were composed from the underlying situation characteristics, available options, and possible outcomes. Note that:

- The scenarios were constructed to be illustrative, not to represent any specific recommendations.
- The topics listed cover a wide range but are by no means complete. They are also not discussed in detail beyond what is covered in Chapters 1 to 3.
- It is impossible to completely analyze every single topic upfront, once and forever. The value of scenario-based planning is in always analyzing topics in a well-defined context. This is also key to the iterative approach.
- Situation characteristics are used in the definition of the frame, typically as the frame's givens; they do not represent the full frame. Additional frame components include the mission statement that expresses the purpose of a specific development project.
- Some topics appear both as a characteristic of a current situation and an expected outcome; this reflects the different maturity levels of the hydromet value chains in different countries.

Table 34 | **Reference scenarios (green) formed by combining frames capturing different given situations (ochre), possible strategies (red), and desired realizations (or future situations, blue). The symbols are used in the tables below to show which scenarios are linked to which given situations, strategies, and realizations and, hence, the underlying topics that those capture.**

Scenario	Jump-start	Strengthen	Optimize
Given situation	«Immature»: The value chain has low maturity. Public services have significant gaps. National services have no advantage over international offerings.	«Intermediate»: The value chain meets a few of the country's needs. The NMHS is spread thin, providing public services and non-public services to recover cost.	«Advanced»: The value chain serves the country's needs. Public services cost needs to be optimized.
Strategy	Establish a value chain and unlock existing potential.	Prioritize a well-functioning NMHS focused on public services and enabling the national private sector to provide non-public services.	Reduce public service cost without sacrificing quality.
Realization	The public and private sectors cooperate in a sustainable hydromet value chain of intermediate maturity. Development partners and transnational companies support the provision of public services.	A strong NMHS provides public services and enables the private sector to provide non-public services in a sustainable hydromet value chain of intermediate to advanced maturity.	The public and private sectors cooperate in an optimized advanced value chain that minimizes the cost of public services without loss of quality.
Symbol	●	■	✻

The variability of different frames, available options, and possible outcomes are summarized in overview tables that are designed as shown in Table 35. The leftmost column links each topic to the scenarios in which it appears. The center column names the topic, and the right column groups topics. The background color reflects whether a table refers to the frame [i.e. frame items grouped into frame components (ochre)] or to the strategies [i.e. options grouped into decisions (red)] or to the realizations [i.e. outcomes grouped by uncertainties (blue)].

Note that some items are not assigned to any scenario. This appendix is intended to serve as a starting point for development teams, and the items are included because they can become pertinent in a specific situation.

Table 35 | **Setup of tables that list frame items, available options, or possible outcomes.**

Symbol	Item	Grouping
● ■ ✻	Frame item for all three scenarios	**Frame component, such as «Value drivers»**
●	Frame item for «Jump-start» scenario	
● ✻	Frame item for «Strengthen» and «Optimize» scenarios	
● ✻	Option chosen in all three strategies	**Decision, such as «Data-sharing policy»**
●	Option chosen in «Jump-start» strategy	
	Option not applicable in any of the strategies	
● ■ ✻	Outcome expected in all three realizations	**Uncertainty, such as «Market development»**
●	Outcome expected for «Jump-start»	
	Outcome not expected in any of the three realizations	

Frame

Framing a scenario, strategy, or decision describes their context and systematically maps out all the issues that affect them (Figure 12).

Figure 12: **Frame components.**

- Values
- Givens
- Value drivers
- Mission statement
- Definition of success
- Opportunities and threats
- Stakeholders
- Critical success factors

Values

Values are the core values a project or strategy is designed to create or support (Table 36). They must always be considered when making decisions that affect the project. Not all stakeholders have identical goals, and some of their goals may conflict: agreeing on the values stated in the frame maintains a project's purpose when conflicting goals arise.

Table 36 | **Values. Applicable items are marked for the «Immature» (●), «Intermediate» (■), and «Advanced» (✻) scenario frames.**

Symbol	Frame item	Frame component
● ■ ✻	Protect lives and property	Values
● ■ ✻	Create additional socio-economic value	
● ■ ✻	National security	

Givens

Givens are external factors affecting a project (Table 37). They are categorized as:

- **Facts** that are known to be true and to not change with time.
- **Assumptions, which** are believed to be true but have not (yet) been proven true. Assumptions must be explicitly stated, particularly in multi-stakeholder projects, to avoid potential costly misunderstandings between participants.

Table 37 | **Givens. Applicable items are marked for the «Immature» (●), «Intermediate» (■), and «Advanced» (✻) scenario frames.**

Symbol	Frame item	Frame component	
● ■ ✻	The need for hydromet services is consistently growing (e.g. due to climate change)	Facts	Givens
● ■ ✻	The hydromet value chain generates socio-economic benefit through provision of both public and non-public services	Assumptions	
● ■ ✻	NMHS faces budget constraints	Boundary conditions	
●	Private companies start identifying and servicing customer needs		
	Public services have significant gaps		
	The value chain meets a few of the country's needs		
	The value chain serves the country's needs		
	Public service cost needs to be optimized		
	The NMHS is spread thin, having to provide public services as well as non-public services to recover cost		
	National services have no advantage over international offerings		
●	Talent leaves the public sector for other countries		
●	Low-maturity value chain		
■	Intermediate value chain		
✻	Advanced value chain		
● ■ ✻	The WMO Executive Council is developing guidance for public-private engagement	Decisions already taken	

- **Boundary conditions**: external factors that may change with time, independently of the actions of the project participants.
- **Decisions already taken** cannot be changed within the scope of the project.

Value drivers

Value drivers enhance the outcome of an initiative (Table 38). One could see value drivers as the main «levers» to create value—achieving good results when working on value drivers creates more core value.

Ideally, value drivers are matched by PPE partners' individual values or value drivers. For example, to protect lives and property, a government should increase the effectiveness (impact) of the hydromet value chain, which is thus a value driver. A private company may focus on profitability as value driver, which contributes to a sustainable hydromet value chain, ultimately matching the government's value driver.

Mission statement

The mission statement summarizes in one sentence the essence of a project. Note that it is often more efficient to draft a rough mission statement and develop it further throughout the iterations.

Definition of success

The definition of success describes the expected accomplishments of a project (Table 39). It includes meeting the minimum requirements plus some stretch goals. It should state how to measure success, forming the basis for key performance indicators. WMO document 1129 on service delivery (WMO 2014) and the Sendai indicators[109] can give guidance in this context.

Table 38 | **Value drivers. Applicable items are marked for the «Immature» (●), «Intermediate» (■), and «Advanced» (✻) scenario frames.**

Symbol	Frame item	Frame component
●	Effectiveness (impact) of value chain	Value drivers
●	Sustainable public services	
●	Cooperation between government agencies	
●	National capacity	
● ■ ✻	International data exchange	
● ■	Public / private sector cooperation in value chain	
■	Clearly defined role of NMHS focuses on public services	
■	Profitable private enterprise	
	Maturity of value chain	
	Organizational efficiency of public service	
✻	Economic efficiency of value chain	
✻	R&D capacity	

109 https://www.preventionweb.net/drr-framework/open-ended-working-group.

Table 39 | **Definition of success. Applicable items are marked for the «Immature» (●), «Intermediate» (■), and «Advanced» (✻) scenario frames.**

Symbol	Frame item	Frame component
●	The government views hydromet services as strategic and engages accordingly with its stakeholders	Definition of success
●	Key public services are provided sustainably after development support for operations and maintenance ceases	
●	Official warnings have good accuracy and reach affected people	
●	Official warnings have state-of-the-art accuracy and reach everybody affected. The warning system is resilient	
●	Transnational private sector fills gaps in public services for an agreed period	
●	One or more small hydromet-related companies are successful	
■	Private hydromet services sector grows	
■ ✻	The NMHS has budget and capacity to safeguard the basic system and services	
	Private sector helps to fill gaps in public services	
✻	Public services are economically efficient	

Opportunities and threats

An opportunity is a possibility to create additional value; threats to the project must be monitored and mitigated. The following is a sample of typical opportunities and threats:

Opportunities

- **Create a tiered standard for weather stations and sensors** that do not meet the international rigorous requirements for climate analysis but that add value if properly used for NWP or local applications.
- **Take advantage of private weather station networks** to improve forecast results through suitable post-processing.
- **Take advantage of new types of earth observation data**.
- **Development partners bridge the gap between «grassroots» innovation and institutions** by fostering structured communication and filling small financing gaps.

Threats

- **Unfair competition between public and private entities** destroys potential value.
- **Under-funding can fragment and affect coordination of a national or global observing system**.
- **An overbearing transnational company might lock in a country** with a low-maturity value chain.
- **A minor pool of exclusive observation data could grow and monopolize the market** hindering competition and innovation.

Stakeholders

Stakeholders are the parties who are affected by an initiative and can influence it. Every project must account for key stakeholders' needs, interests, concerns, and expectations. Examples of stakeholders in hydromet development projects are listed below:

Public sector

Government, NMHS, other government agencies

Private sector

Hydromet sector companies, the Association of Hydro-Meteorological Equipment Industry (HMEI), PRIMET, mobile phone network operators, GSMA mAgri

Research and education

Universities, public and private research institutions

International development partners

World Bank, other international organizations, NGOs

International hydromet organizations

WMO, ECOMET, ECMWF, EUMETNET, EUMETSAT, regional centers (e.g. AGRHYMET, WASCAL, and SASSCAL)

Customers of hydromet services

Government agencies, private companies of any size, private associations

General public

Individuals, NGOs, public associations

Media

Social media, web portals, TV, radio, press

Critical success factors

Critical success factors are conditions that must all be met to ensure success. Failing to meet any one of them jeopardizes the entire project. Examples include:

- Shared values, transparency, and shared insight; for example, an impartial platform to facilitate dialogue among the public, private, and academic sectors to build trust; and
- Sufficient investment for sustainable operations and maintenance budgets.

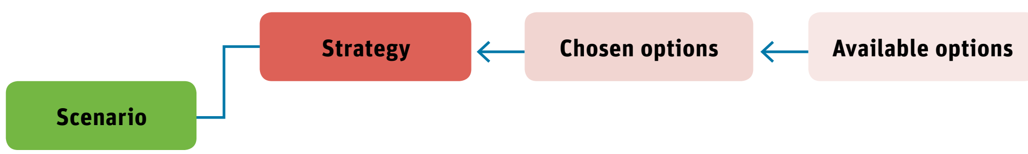
Options – decisions – strategies

The options selected among the available ones define a strategy, which contributes to create a scenario (Figure 13). Options are grouped into five major areas:

- Governance;
- Capacity building;
- Public services funding;
- Public services technical approach; and
- Accompanying measures.

Within each area, options are further grouped into decisions, which define narrower categories. The five option areas are briefly described below.

Figure 13: Chosen options define a strategy that forms part of a scenario.



Governance

This category includes options for setting up the right legal framework, policies, other regulations, and business drivers (Table 40).

Table 40 | **Governance options and associated decisions (right column). Choices are marked for the «Jump-start» (●), «Strengthen» (■), and «Optimize» (✻) strategies.**

Symbol	Option	Decision
	General fair market laws	Laws, policies, and regulations
● ■ ✻	Well-defined role for NMHS, focused on provision of public services	
■	Facilitate co-investment by NMHS and the private sector	
■	Monitor hydromet market development	
✻	Measure the socio-economic impact of the hydromet value-chain	
	Independent agency monitors compliance with regulations	
● ■ ✻	Open data: Freely share all national surface-based weather data nationally	Data-sharing policy
● ■ ✻	Share data internationally in line with WMO Resolution 40	
●	Share data with regional associations such as WASCAL	
	No data-sharing	
	Share data internationally with selected partners under a specific contract	
	Independent organization measures and publishes standardized quality indicators for internationally shared data	Quality assurance
● ■ ✻	(International) quality targets for public services	
● ■ ✻	Market mechanisms for quality assurance of non-public services	
	Observations, public forecasts, official warnings, international cooperation for weather and climate	Scope of public services
	Safeguard aviation	
	Safeguard marine operations	
	Safeguard communication systems	
	Safeguard energy supply	
● ■ ✻	Government agency or similar	Provision of public services
	Commercial arm of government agency	
	State-owned enterprise	
	Grant monopoly to private company	
●	Government agency with technical support from transnational companies / agencies	
■	Partial outsourcing to national private company	
	Partial outsourcing to transnational company	
● ■ ✻	Private sector	Provision of non-public services
	Government agency	
	Commercial arm of government agency	
	State-owned enterprise	
	Transnational company	
	NMHS provides selected non-public services such as aeronautical meteorology	
	Grant monopoly to private company	
	NMHS enables provision of non-public services such as aeronautical meteorology	

Funding public services

Table 41 lists options for funding public services.

Table 41 | **Options for funding public services and associated decisions (right column). Choices are marked for the «Jump-start» (●), «Strengthen» (■), and «Optimize» (✻) strategies.**

Symbol	Option	Decision
● ■ ✻	Regular taxes	Revenue streams
● ■ ✻	Fees on selected hydromet services (e.g. basic aeronautical meteorology services)	
● ■ ✻	State budget for operations and maintenance	Operations and maintenance
● ■ ✻	Explore opportunities for the private sector to offer observation data at lower cost than it would cost the NMHS to operate the equipment	
●	From revenues paid directly to the public-sector provider	
●	Development partners finance operations and maintenance[110]	
	Instrument suppliers price includes several years of maintenance	
● ■ ✻	State takes a share of financial risk[111]	Financial risk-sharing
● ■ ✻	Private partner takes a share of financial risk	
	Development partner takes financial risk	
● ■ ✻	State invests cash	Investment
	Development partner finances capex	
	State makes in-kind contributions[112]	
● ■ ✻	Private partner invests cash	
● ■ ✻	Private partner pre-finances equipment that it provides[113]	

110 A development partner finances operational expenses to sustain operations for the duration of a project and possibly for an additional transition period.

111 For example, through some form of a PPP construction project.

112 The state enters a partnership for a required investment and makes in-kind contributions such as providing expertise or manpower for operations.

113 An equipment manufacturer does not sell its equipment but pre-finances it and recovers the investment by charging for its use.

Capacity building

Table 42 lists capacity building options. Note that options can appear in more than one decision.

Table 42 | **Options for capacity building and associated decisions (right column). Choices are marked for the «Jump-start» (●), «Strengthen» (■), and «Optimize» (✻) strategies.**

Symbol	Option	Decision
●	Train in country, on the job, embed trainers in workforce for several months at a time	Training
	Train at international center	
●	Train teams rather than individuals, especially if sending them abroad	
●	Train on the job before sending staff for training abroad	
●	Train more people than needed and accept that some will move on	
	Use dual training approach, mixing practical work with training periods	
	Adjust curricula for new demands on skill profiles	
	State budget	Funding for training
	Development partner	
	Private sector	
	Student fees	
	Train more people than needed and accept that some will move on	Retain public sector staff
	Create national professional society	
	Raise profile and public recognition of hydromet services	
	Use social media to help create a community	
	Create attractive career paths in hydromet sector	

Technical approach for public services

The technical decisions listed below have an interdependency with decisions about governance, capacity building, and public services funding. Note that the options for running NWP systems were not used in any of the scenarios (Table 43).

Table 43 | **Options for technical approach for public services and associated decisions (right column). Choices are marked for the «Jump-start» (●), «Strengthen» (■), and «Optimize» (✻) strategies.**

Symbol	Option	Decision
	WMO-compliant stations	Observation systems
●	Inexpensive robust stations[114]	
	Low-cost stations[115]	
	Upper air stations	
✻	Leverage IoT data	
	Satellites	
✻	Leverage low cost satellites	
	Rain radar	
	GTS	Observation data-sharing architecture
	WIGOS	
	Cloud solution	
●	Data aggregation via regional hubs	
●	Data aggregation via mobile operator service	
	Data aggregation via vendor's hub	
	Develop global, regional, or local models	Numerical weather prediction
	Run global model(s)	
	Run regional model(s)	
	Run local model(s)	
	Use outputs of others' global models	
	Use outputs of others' regional models	
	Use others' local models	
	Develop proprietary post-processing chain	Post-processing
	Install and operate other organization's post-processing chain	
●	Use software-as-a-service third party post-processing chain	
	Maintain own computing infrastructure	High-performance computing infrastructure
✻	Use private-sector cloud computing	

114 «Robust» stations are reliable stations with good accuracy. Data types, quality and collection protocols are adequate for weather forecast but not necessarily for climate analysis. They are often less costly than stations in compliance with the WMO standards.

115 Low-cost stations may be less accurate or reliable than robust stations but are less expensive, allowing more to be installed. If used in conjunction with higher quality stations they can provide useful information, «filling in» between higher quality stations. They can also be useful in local applications.

Accompanying measures

The hydromet value chain is enabled by, and depends on, a country's institutional capacity, the capacity of its workforce, and its infrastructure, specifically for power and ICT (Figure 1). Table 44 lists accompanying measures that may be required to address gaps in those enablers.

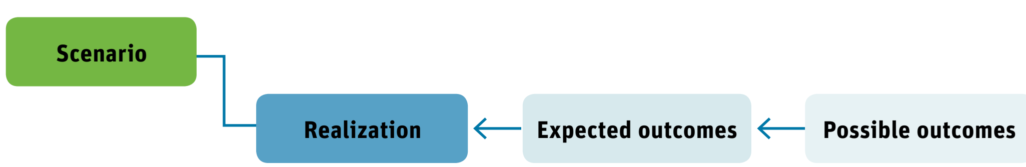
Table 44 | **Strategic actions and goals for accompanying measures. Choices are marked for the «Jump-start» (●), «Strengthen» (■), and «Optimize» (✻) strategies.**

Symbol	Option	Decision
	Lobby for clear regulations for providing public and non-public hydromet services	**Improve governance**
	Organize inter-agency round-tables to foster collaboration	
	Provide contract templates for public-private engagements	
	Organize agency round-tables to foster collaboration	**Stimulate supply side collaboration**
	Engage with national, regional, and/or global associations	
	Involve private-sector representatives in planning phase	
	Invest in power infrastructure	**Bolster enabling infrastructure**
	Invest in ICT infrastructure	
	Partner with mobile mast operators	
●	Coordinate with NGO initiatives	**Increase hydromet value chain impact**
●	Coordinate with start-up initiatives	
	Organize inter-agency round-tables to foster collaboration	**Raise NMHS profile**
	Train people responsible for the funding of public hydromet services	
	Run information campaign for weather services	
●	Apply scenario-based planning	**Agile project management**
●	Facilitate lean start-up projects	

Outcomes – uncertainties – realizations

Expected outcomes and their associated uncertainties define a realization, which is a component of the scenario (Figure 14). Expected outcomes for a realization are suitably chosen from all possible outcomes. They are grouped into two major areas: value chain and capacity building. Within each area, outcomes are further grouped according to the type of uncertainty that they entail.

Figure 14: **Expected outcomes define a realization that forms part of a scenario.**



Value chain outcomes

Table 45 lists possible outcomes for a value chain.

Table 45 | Value chain realization outcomes of various uncertainties (right column). Outcomes are marked for the Jump-start (●), Strengthen (■), and Optimize (✻) realizations.

Symbol	Outcome	Uncertainty
●	Low	**Maturity of value chain**[116]
● ■	Intermediate	
■	Advanced	
	Companies start identifying and servicing customer needs	**Market development**
●	Private companies are providing non-public services	
■	A private hydromet sector develops	
✻	Hydromet market is growing, transnational companies are successful in other countries	
	Thriving market meets new customer needs quickly	
	State-funded but operations and maintenance are not sustainable	**Sustainability of public services funding**
	NMHS pushed to cover costs through profits from providing non-public services	
●	Fully funded, including maintenance and operations	
	No or very few public service weather stations	**Observation systems coverage**
	Some but not enough public service weather stations	
	Good coverage with public service weather stations	
	No or very few private weather stations	
	Clusters of private weather stations	
●	IoT devices and inexpensive satellites further improve local forecast accuracy	
	Private weather stations complement public service weather stations	
	Observation network deteriorates after initial investment	**Sustainability of public weather station network**
	Problems with keeping upper air stations and weather radars up and running	
■	Observation network runs stably	
	Observation network grows further	
✻	Government agencies integrate their observation networks	**Cooperation**
	Government agencies operate different networks and do not exchange their data	
	NMHS competes with the private sector	
	NMHS cooperates with the private sector	
	Limited or no communication and/or data exchange	**Alignment of interests**
	Some communication and/or data exchange between hydromet value chain stakeholders	
	Good alignment of interests among national hydromet value chain stakeholders	

- **Value chain maturity.** Assessment of the maturity of a value chain is complex. We use the criteria summarized in Table 3 to classify the maturity of a value chain as not available, low, intermediate, or advanced.
- **Market development.** Analyzing a weather market and assessing its development may be difficult as little or no data are available in many countries. Nevertheless, qualitative or semi-quantitative observations can be made and used in the value chain assessment.

[116] Compare Figure 1.

- **Sustainability of public services funding** is usually easy to assess, as are surface station coverage, sustainability of the national weather station network, and the level of national and international cooperation.
- **Alignment of interests** between the national value chain stakeholders can be hard to assess without open discussion between them. Misalignment can be a latent threat which becomes visible only when a project has already run into problems.

Capacity outcomes

Table 46 lists possible outcomes for capacity, which need to be monitored during a development project.

Table 46 | **Capacity realization outcomes of various uncertainties (right column). Outcomes are marked for the Jump-start (●), Strengthen (■), and Optimize (✻) realizations.**

Symbol	Outcome	Uncertainty
	Low-maturity public service provider	**Capacity of public service providers**
●	Intermediate public service provider	
■	Advanced public service provider	
	Low-maturity national private sector	**Capacity of national private sector**
●	Intermediate national private sector	
■	Advanced national private sector	
	Existing staff underperform and block positions	**Capacity building**
	Public-sector staff leave for the private sector	
	Talent leaves country	
●	People learn and then teach («teach-the-teacher»)	

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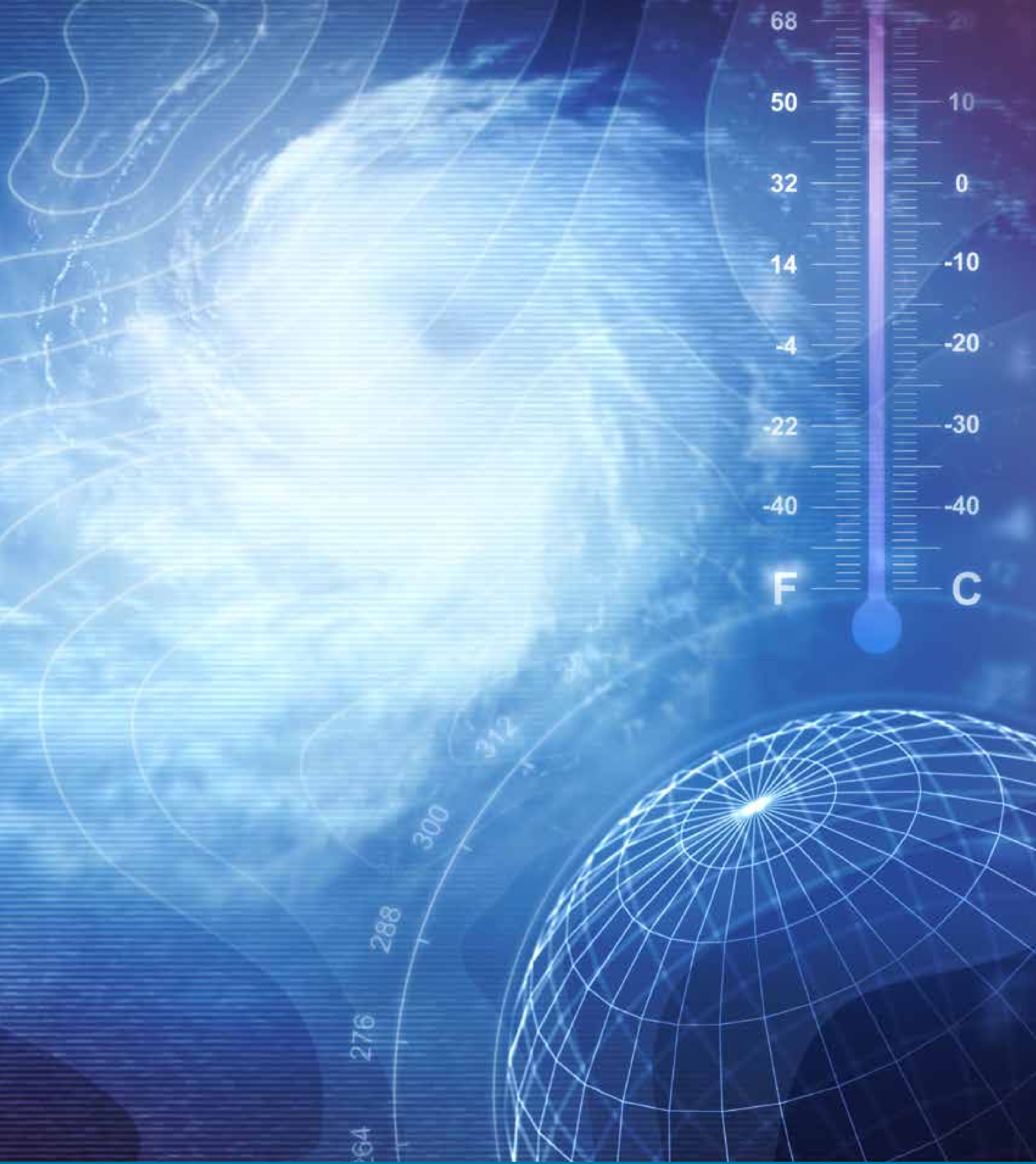
Freshwater mud distribution pattern of the Mississippi River. Photo: Elen11.



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