Advanced Research Project Report: Climate Services for Energy

World Meteorological Organization

GENEVA GRADUATE INSTITUTE

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Table of Contents

List of Figures

SECTION I

1. Introduction

Climate change has been globally recognized as a threat to human and natural systems as is evident given the rising incidence of climate-related disasters between 1981 and 2022. For instance, between 2020 and 2022, the number of billion-dollar climate-related disasters increased by approximately 9 billion dollars, with the most horrific events concentrated amongst vulnerable populations (Masters 2022). While these events indicate climate variability, they also inflict long-term damage such as disruption to ecosystems, erratic water supply, food insecurity and economic loss (Barros et al 2014).

Given their impact, climate adaptation has become central to the discourse regarding climate change. As per The United Nations Development Programme (UNDP), adaptation can be defined as a "process by which strategies to moderate, cope with and take advantage of the consequences of climate events are enhanced, developed and implemented" (Lim and Spanger-Siegfred 2005). To accelerate attempts at climate adaptation, the Conference of Parties (COP17) to the United Nations Framework Convention on Climate Change (UNFCCC) introduced the National Adaption Plan (NAP) (Munang et al 2013).

One of the core elements of this plan was the introduction of climate services which can be understood as science-based tools that provide user-specific information relating to past, present, and potential future weather conditions (WMO 2022). The information and data obtained from such climate services can then be used by countries or other users to make efficient and sustainable decisions within the relevant sector in which the service operates.

Owing to their technical nature, research and policy have largely been focused on the scientific benefits of climate services such as prediction accuracy, quick risk forecasting and efficient data analysis. Nonetheless, recently, the calls for greater assessment regarding the social and economic impact of climate services have increased amongst investors, experts, and policymakers.

Therefore, this project attempts to assess and understand the socio-economic impact of climate services, especially within the energy sector, in collaboration with the World Meteorological Organization (WMO). The focus on the energy sector stems from the magnitude of investments in climate services for energy, the global support for a green energy transition and the increased resilience of renewables.

Within the WMO, our research is part of a larger project - this year's iteration of the State of Climate Services Report. Since it was first published in 2019, every year, the State of Climate Services Report focuses on climate services targeting one sector and based on the research findings, provides recommendations on how to improve the implementation and effectiveness of climate services for that sector worldwide (State of Climate Services Report 2021, 5).

The report is structured as follows:

- *Firstly*, it introduces integral concepts regarding climate services, followed by an extensive literature review exploring the evolution of these services, the current state of research and existing divergences.
- *Secondly*, it establishes key research objectives and questions, followed by the methodology used, the workplan adopted, the resources consulted, and the limitations faced in the process.
- *Thirdly*, it analyses in-depth, the impact of specific climate services in the energy sector in four countries namely, South Africa, Egypt, Croatia, and China, given the needs of local populations in these regions based on a qualitative analysis.
- *Lastly*, it highlights key learnings from the research process, informed by findings from the case studies. These can also serve as recommendations for policymakers and researchers as they identified critical gaps in the assessment of climate services.

The main contributions to the report are as follows:

- A grid assessment of the socio-economic impact of climate services, based on observations from four countries and other secondary sources (See Figure 6).
- Four detailed and regionally diverse case studies, supported by an overview of contextual challenges and varied needs of end-users in South Africa, Egypt, Croatia, and China.
- Evidence of the positive socio-economic externalities created by specific climate services for a variety of renewable energy sources including hydropower, solar power, and wind energy.

2. Literature Review

2.1 Themes and Concepts

Historically, climate-related risks have always threatened animal and human life. Given the current state of the global environment and the unprecedented rate of climate change we are witnessing, human welfare is increasingly influenced by how prepared we are to manage these risks. Climate services can be understood as an effort to better manage this risk, by providing timely and tailored information regarding natural events to decision-makers (Vaughan and Dessai 2014, 588).

Here it is imperative to distinguish between climate services and weather services. Weather services describe the state of the atmosphere at a given place and time whereas climate services analyse time-series data to estimate trends, departures from average conditions and low-probability scenarios ranging from timescales of seasons to centuries (Vaughan and Dessai 2014, 588).

The concept of a climate 'service' is a relatively new one within the climate community which explains the existence of varied definitions for them (Troccoli 2018, 22). For this project, we employ the one stated in the Global Framework for Climate Services (GCFS) which iterates that climate services refer to those services that provide climate information in a way that assists decision-making by individuals and organizations. Such services require appropriate engagement along with an effective access mechanism and must respond to user needs (GCFS n.d.).

These services work by using high-quality data on temperature, wind, rainfall, soil moisture and ocean conditions as well as maps, risk and vulnerability analysis, assessments, and long-term projections. They also include scenarios from national and international databases, integrating them with non-meteorological data such as agricultural production, health trends, human settlement in high-risk areas, and infrastructure maps. The data collected is then transformed into products such as projections, trends, economic analysis, and services for different communities (GCFS n.d.) (See Figure 1).

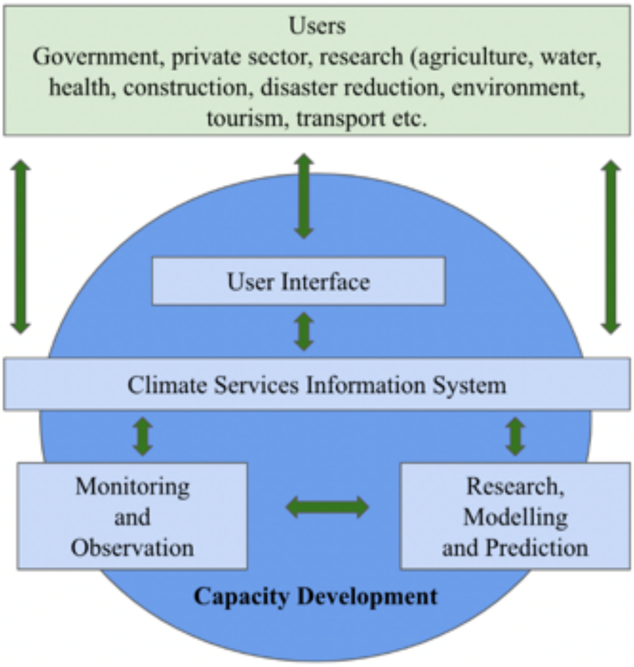


Figure 1: Global Framework for Climate Services (World Climate Conference 2009)

Climate services can take various forms. One of the most widely used services is the Copernicus Climate Change Service (CS3), which has been designed as a user-friendly digital data store (See Figure 2). It comprises observations, historical climate data records, essential climate variable (ECV) datasets, global and regional climate analysis, local projections, and seasonal forecasts (Raoult et al. 2017, 22). Other forms that climate services take forecasting and prediction, data analysis and integration and information packages through websites or bulletins (Vaughan and Dessai 2014, 588).

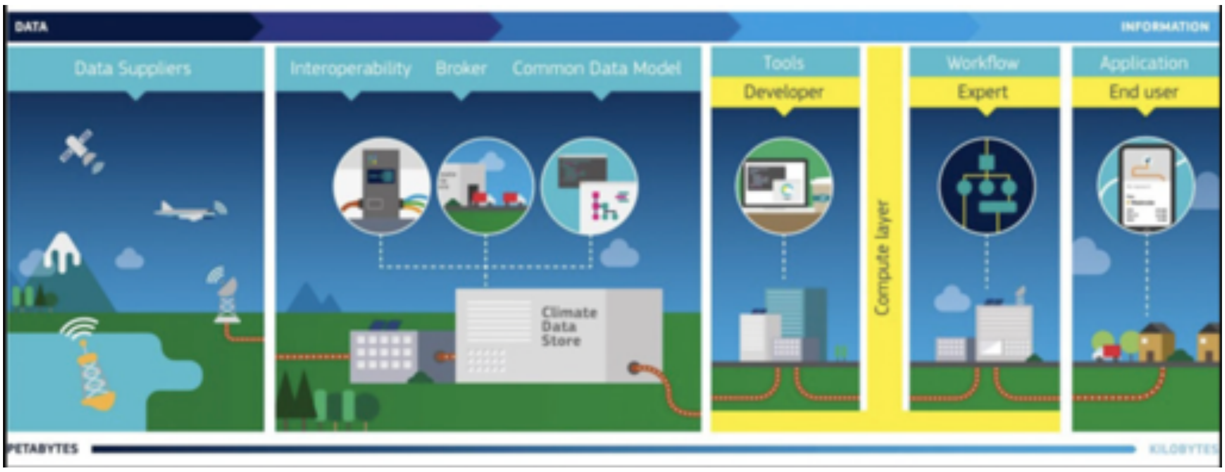


Figure 2: The CS3 Workflow (Buontempo et al. 2020)

The climate service literature identifies a range of different stakeholders that are relevant to this industry such as service providers, service users and coordinating agencies (Vaughan and Dessai 2014, 588).

Climate service providers include those who provide and manage this information. They could operate at the international, national, or local levels within a range of different sectors. Climate service users refer to those who use this knowledge to inform their decision-making. Often, they are also involved in communicating this information to others thus making them providers *and* users.

Climate service coordinating agencies are involved in strengthening the connections between users and providers to facilitate the development of these services in various contexts (Vaughan and Dessai 2014, 588). For instance, the GCFS serves as a global partnership of governments and organizations that produce and use climate information (Hewitt et al. 2012, 831).

As mentioned previously, climate services can be equipped to operate in a range of different sectors. For the purposes of our research, we focus specifically on climate services for the energy sector. The energy sector affects other sectors such as economic development, security, women empowerment, food security and education thus validating the need to improve its efficiency (SE4ALL 2014).

However, the expansion of the energy sector increases these systems' vulnerabilities to weather and climate events (Troccoli et al. 2014, 6). Both renewable and non-renewable energy sources are sensitive to meteorological conditions. Consider the impact of Hurricane Katrina on the Gulf of Mexico's oil production (Troccoli et al. 2014, 6). Therefore, understanding and learning how to manage climate-related risks is crucial to maintain the efficiency of existing energy systems and developing new ones. Depending on the nature of the climate service used, they can not only help manage risks that accompany climate-related events but could also assist in identifying potential prospects for the expansion of renewables and energy access.

The end-users targeted by climate services also vary from one service to the other. They often include a heterogeneous mix of stakeholders from the national, sub-national and community levels (WMO 2015). In the energy sector specifically, end-users may include transmission system operators (TSOs), distribution system operators (DSOs), utilities, policy-makers, researchers and governments.

The type of climate service provided to these users depends on their varying needs. For example, transmission system operators may be concerned with detailed geographical forecasts of wind power and demand at relatively short lead times (hours or days ahead) for the operational management of the power grid. However, long-term investors in infrastructure and system planners would require a longer view of system resilience (years to decades), and energy traders or maintenance planners seeking to position themselves for the coming weeks (Brayshaw 2018, 152).

To effectively study the impact of climate services, one would have to identify key performance indicators. Given the reliance of other sectors on the energy sector, it is only logical to focus on socio-economic factors and include these in the evaluation of climate services. These indicators are largely influenced by specific UN Sustainable Development Goals (SDGs) namely - SDG 7 (Ensure access to affordable, reliable, sustainable, and modern energy for all), SDG 8 (Decent work and Economic Growth) and SDG 13 (Climate Action).

Other factors relevant to the assessment of a climate service include access to the service, awareness about it amongst community members and troubleshooting mechanisms in case of any technical issues. Assessing these aspects is integral as it leads to the identification of areas of improvement to achieve better results in the future. Furthermore, comprehensive, and reliable data on the benefits of climate services is necessary to demonstrate their value to society thereby, scaling awareness and encouraging investments.

2.2 Thesis and the Evolution of Ideas

As elaborated in the previous section, climate services are increasingly recognized as a means to improve decision-making by ensuring access to accurate information regarding weather events and changes induced by climate change. However, since their inception, climate services were embraced not only on account of their ability to manage and integrate scientific data but also to promote innovation, economic opportunity, and ecological balance (Swart et al. 2021, 7).

While these two objectives have received unanimous acceptance today, reaching this unanimity required extensive discourse, scientific research, and monetary investment (Vaughan 2018, 374). This can be understood through the emergence of diverse theories and initiatives which dictated the development of climate services during different periods. This section will discuss two main theories that directed the adoption of climate services, the objectives they prioritized and the organizations they emerged from.

These can be divided into two categories namely the traditional or *silo* approach and the next-generation or *nexus* approach to climate services (Tudose et al. 2011, 754).

As of 2001, development and research on climate models was dictated by the traditional approach which emphasized adaptation and resilience relative to climate risks. This approach focused on the provision of climate data and information management for risk assessments to mitigate threats imposed by extreme events (Dilling and Lemos 2011, 682). During this period, researchers largely focused on terms such as 'information management,' 'risk assessment' and 'adaptation' (Larosa and Mysiak 2019, 16). Thus, climate services in the initial years were driven by an extremely straightforward objective which aimed to reduce disaster risks by relying on scientific data (See Figure 3)

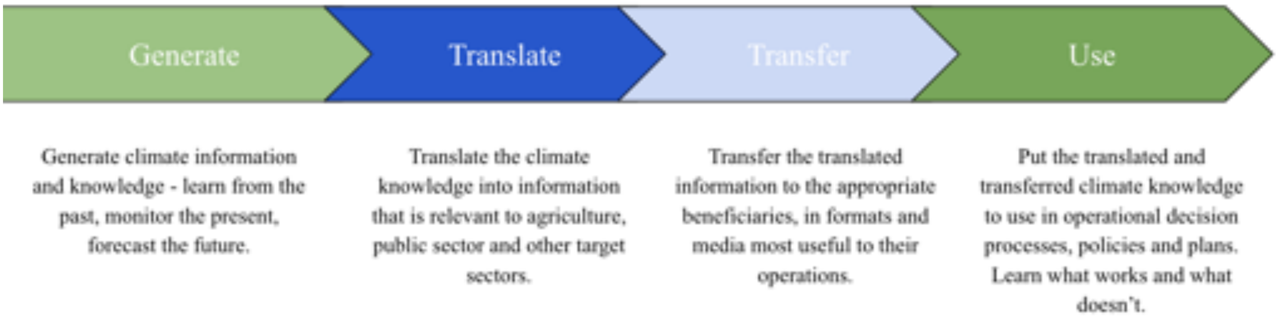


Figure 3: Visual representation of the linear or silo approach (Vogel et al. 2019)

This idea drove the development of the US National Academy of Sciences in 2001 and the department highlighted the need to specialize in data storage, exchange, and computation to provide accurate and stable predictions for risk reduction (National Research Council 2001). On a global scale, by 2009, the WMO launched GFCS to facilitate the advancement of scientific information regarding the climate (Hewitt et al. 2012). Thereafter, these services became integral to sectors such as water and agriculture (Brasseur and Gallardo 2016, 3).

With the development of renewable energy sources and storage mechanisms, these services began to gain priority in the energy sector, especially in regions with significant reliance on renewable sources (Vaughan and Desai 2014, 590). Contrary to common assumption, these services were not only adopted by the public sector but also by the private sector and non-profit organizations as they evolved from simple seasonal forecasts to long-term climate projections (Ranger et al. 2010, 152).

Despite their utility and efficiency, criticism arose within academia regarding the 'silo' approach as it was deemed too narrow and top-down. Critics argued that this restricted the realization of the full potential of climate services by levying excessive focus on their scientific value with adaptation as the overarching objective (Holling 1973, 16).

These discussions highlighted that the scientific representation underlying climate services was detached from social meaning and human experience (Jasanoff 2010, 238). It also deemed this approach simplistic and supply-driven as it only focused on making end-users dependent on climate products without offering means to improve their agency, awareness and resilience (Daniels et al. 2020).

Thereafter, discourse regarding climate services began to shift from this 'linear mode of knowledge production' toward a more 'holistic' interpretation which sought to recognize the evolution of these services and the value they created (Vogel et al. 2019). Although academics voiced these criticisms during the conception of climate services, the community favouring a more holistic approach strengthened with the establishment of the Red Cross Climate Centre. The Centre emphasized the need to focus on how climate information can be used to benefit communities, invoking a discussion on their socio-economic impact (Red Cross 2007).

This resulted in the emergence of the 'next-generation' approach regarding climate services which emphasized the potential contribution of these services to the broader sustainable development agenda. It recognizes the need for the adaptation of these services to the specific contexts within which they operate to address numerous societal challenges (Street 2007, 175). To do so, it is emphasized the scientific information underlying climate services must be linked to social, economic, and cultural contexts, embedded in the needs of the community thus creating a 'nexus' (Tudose et al. 2011, 756).

For instance, climate models assessing rainfall patterns and water flow may be effective in drought prediction. However, patterns of land-use and management, crop rotation and population characteristics must also be taken into consideration for long-term resilience (Tudose et al. 2011, 754). Therefore, climate services must be viewed as a cross-sectoral model as opposed to a linear model for predictive analysis (Venghaus et al. 2019) (see Figure 4).

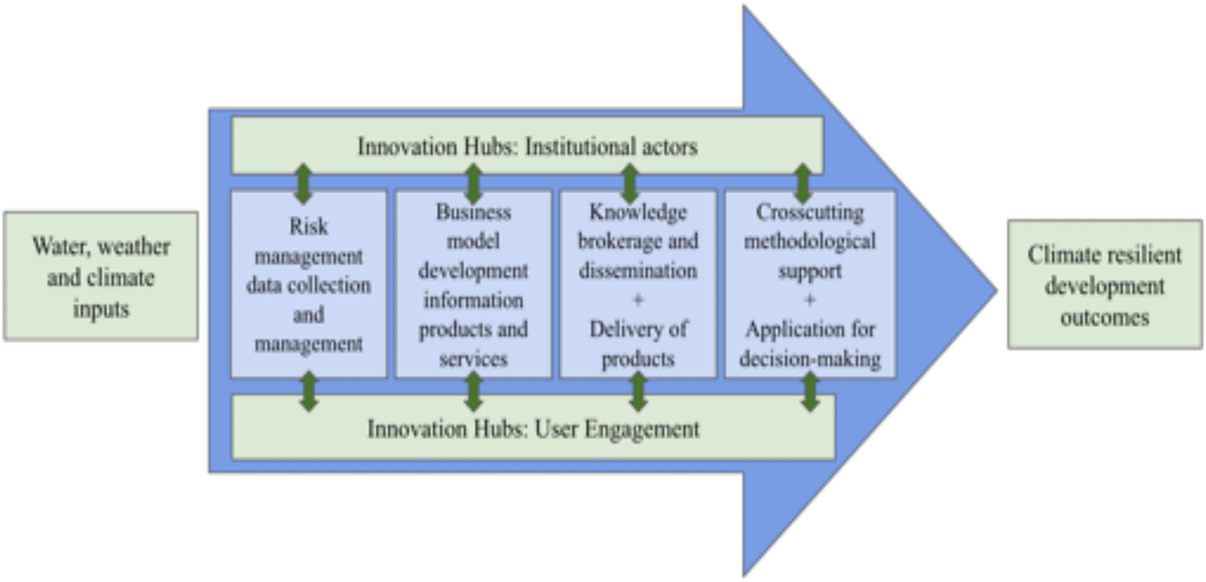


Figure 4: Visual Representation of the Nexus Approach (Swart et al. 2021)

This new interpretation warranted an intra-disciplinary perspective that combined top-down scientific use with bottom-up socio-economic information to ensure that these services catered to the broader needs of society (Jacobs and Street 2020). Integrating these two aspects creates 'added value' by enhancing institutional capacity, collaborative learning, and community agency (Schipper et al. 2016).

This leads to long-term benefits that go beyond risk mitigation by triggering transformative changes in society, policy, and politics (Norström et al. 2020, 187). Subsequently, experts incorporated terms such as 'sustainable development goals,' 'vulnerability,' and 'community-based' in their climate research (Larosa and Mysiak 2019, 16).

Based on this understanding, several service structures have been established to monitor, communicate, and regulate the information provided by these models. International service structures such as the GFCS further encouraged the development of national climate service centres to collect and assess climatological information and generate seasonal outlooks (WMO 2012). National centres had the ability to narrow their focus to specific regions, coordinate stakeholders and disseminate information on federal and local levels thus making them the popular choice (Miles et al. 2006).

While the next-generation approach is progressive and marks a turn in the traditional conception of climate services, its practical execution is not without challenges.

The advancement of nexus-based climate services is impeded by the lack of socio-economic assessments on regional and local levels. This can be attributed to gaps in research regarding which values can be considered economic and social depending on their utility to the end-user (Milner et al. 2011, 211). Furthermore, the absence of a common typology and evaluation framework for the integration of socio-economic contexts inhibits the materialization of holistic climate models (Pfaff et al. 1999, 645).

Nonetheless, despite these challenges, there exists a community, globally and regionally, that actively support the development of holistic climate services. The project discussed later in this report is a testament to the effort that goes into contributing to the next-generation approach to climate services for long-term sustainability.

2.3 The Current State of the Research

Existing research demonstrates that climate services primarily depend on data derived from systematic observations (WMO 2020, 18). These observations assist in the understanding of the current state of global and local weather and climate conditions, as well as future changes. Thus far, most of the research has focused on climate services for water, disaster risk reduction, and agriculture, while there exists little to no research on climate services for energy.

Furthermore, climate research has acknowledged the importance of climate services in ensuring that various societal actors and stakeholders are aware of their vulnerability and exposure to climate change and related disasters (Brasseur 2016). For instance, some research suggests that climate services *can* contribute to socio-economic benefits. This was witnessed in communities in South Asia that were experiencing hazardous weather conditions. In these instances, climate services aided the provision of crucial information that helped manage the present and future climate risks (Daron et al. 2022).

For example, the Asia Regional Resilience to a Changing Climate (ARRCC) Met Office Partnership programme, succeeded in enhancing climate resilience through the implementation of weather and climate services in Bangladesh, Nepal, and Pakistan. However, this was only effective in these countries because they were founded on equitable and sustainable partnerships, focused on increasing knowledge sharing, and worked on strengthening their evaluation systems (Daron et al. 2022).

Nonetheless, the research that does go into depth about the socio-economic benefits of climate services focuses more on disaster risk reduction and is specifically inclined to Small Island Developing

States (SIDS) (Newth et al. 2021). It employs a variety of methodologies for socio-economic analysis such as sectoral modelling and seeks to assess the role of the public and private sectors regarding resource mobilization (See Figure 5) (Newth et al. 2021).

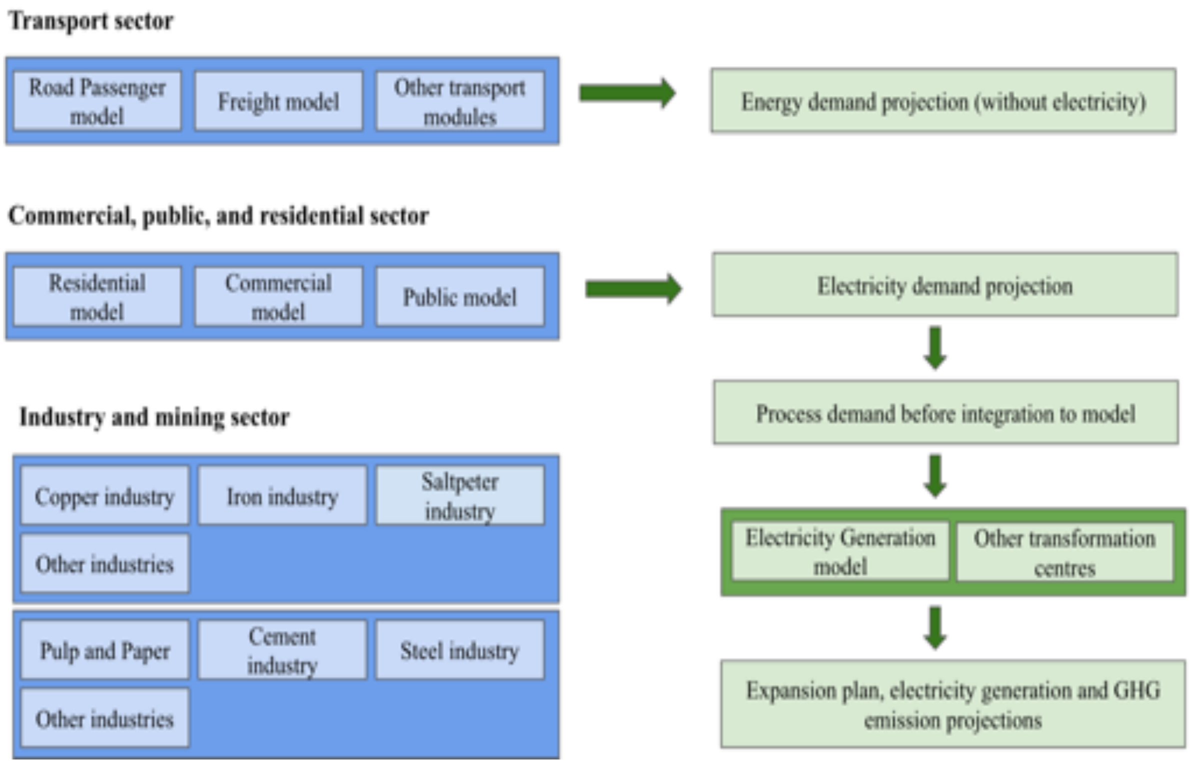


Figure 5: Conceptual framework for sectoral modelling for climate services in energy (Ryan 2019)

Nonetheless, there is still a long way to go in the existing literature that details the application of climate services in various geographic contexts. The lack of scope presents challenges in understanding the benefits and drawbacks of specific climate services per region (Halnaes et al. 2020).

Some of the existing research does question the relevance and need for climate services as a whole, given that there is little evidence available regarding their effectiveness and value for specific sectors (Tall et al. 2018). It is critical to note that this is only the case because the scarce research on climate services leaves evaluation as an afterthought, as opposed to integrating it into the design of climate service programs so that their evaluation is based on impact pathways (Tall et al. 2018). Thus, there is a need for further exploration into climate services and the actual value they can provide within particular systems.

The lack of available research can be explained by the fact that climate services could be more effective and widespread in use if there was a clearer understanding of who the relevant stakeholders and end-users are (Brasseur et al. 2016). There is a lack of clarity, generally due to:

1) Societal actors being unaware of their level of vulnerability to climate change,
2) Climate services and products are not offered promptly, and
3) The climate information is not communicated and disseminated in an appropriate format that can be easily understood and accessed by users (Brasseur et al. 2016).

To facilitate research on climate services, and then ultimately on climate services for energy, these four challenges need to be resolved. For instance, the first issue can be addressed by developing channels that include a diverse range of stakeholders, such as non-government organizations, small businesses, and local government (Brasseur et al. 2016). These entities should be made aware of their vulnerability to future climate disturbances. This also addresses the second issue, implying that if there is a diverse range of stakeholders involved then the manner in which the climate services are developed will naturally adapt to the specific needs of end-users (Brasseur et al., 2016).

The third issue can be resolved by ensuring that the information is contextually relevant and caters to the needs of users as climate services seek to "transform climate-related data into customized products, to advise on best practices, and to develop and evaluate solutions that may be of use for society" (Street et al. 2014). Thus, the information needs to be relevant, communicable, and interpretable.

2.4 Diverging Opinions in the Literature

This paper has extensively discussed the reasons why scholars share consensus regarding the importance of climate services for risk reduction and improvement of socio-economic conditions in beneficiary populations. However, dissenting voices question the validity of climate services as the most efficient and appropriate response, given the other options for mitigation and adaptation, and the varied and sometimes disparate interests of affected stakeholders.

Critics argue that the resources and effort put into implementing and promoting climate services - an adaptation effort in a world already affected by climate change - would be better used for prevention and mitigation. Even the most refined early warning system cannot eliminate the damage done by a natural disaster and does not make up for a lack of resources and capabilities of infrastructure to cope with the damage (Šakić Trogrlić et al. 2022).

Nonetheless, proponents of climate services insist that their benefits are multi-fold, doing more than just preventing disaster risk management but also enabling new industries and economic growth, making them worth their pay (Brooks 2013). Considering the already-apparent impacts of climate change on weather and the observed increase in climate disasters that are otherwise unprecedented in prior climate patterns, climate services are now necessary (IPCC 2014, 50). Redirecting funding to prevention measures is therefore inevitable and beneficial in the long term.

Additionally, there are concerns that climate services are destined to become yet another amplifier of inequalities, as only countries and organizations with sufficient resources will be able to enjoy their benefits. These services will become more critical as climate change increases the risks and damage experienced due to climate-related issues, but their benefits are only available to those who can afford to pay their premium.

Svenja Keele (2019) laments a movement "away from delivering 'climate information' towards producing 'climate services,'" as information which all stakeholders will need to adapt to climate change is siphoned away for service providers to earn profits. While it may be problematic that such duties are being delegated to the private sector, they are nonetheless creating a promising industry to fill the information gap that poses risks to energy infrastructure and disrupts sustainable paths forward (Jennings 2011).

The topic of divergences between indigenous knowledge and modern scientific knowledge receives significant attention across academic fields, and climate services are no different. While the contemporary nexus approach does consider the interests of the end-user, there is no guarantee that it will encompass a wide range of priorities across an entire population.

This can be problematic when purely policy-focused scientific practice leads to decisions that are imposed on the daily livelihoods of local populations, and conflict ensues (Krauss and Von Storch 2012, 224). Early warning systems, for example, have typically focused on the protection of property and lives saved. A proposed improvement to this system suggests making the process more "people-centred" by adding a phase of information dissemination to people at risk, and including them in the process (Dannenmann et al. 2006, 23).

Since then, improvements have been made, but the success of a climate service continues to be measured largely by using the same indicators, while local populations continue to be deprived of vital risk-reducing information (Brooks 2013). An added challenge in communicating such information to target populations is to create trust among users. Otto et al. (2016) suggests the importance of transparency regarding levels of uncertainty and collaboration in information-sharing between users and providers in alleviating such problems for more effective services.

Given the uncertain and inherently time-distant nature of the outcomes of climate services, it is even more essential that the interests of all stakeholders are considered. However, stakeholders hold varied priorities. For instance, local farmers, tend to be more concerned about the short term than any investments that cost them resources today for some potential risk-reducing return in the future (Biskupska and Salamanca 2020, 9). Whatever practices that climate services implement will need to be cautious of any adverse consequences to all population groups, based on a comprehensive understanding of their level of risk-adversity and the socio-economic benefits the service can provide (May and Plummer 2011).

While these debates deserve consideration, none pose an argument against the validity of, or the need for, climate services. The WMO's State of Climate Services Report to which this applied research project contributes to can be understood as an effort to combat these issues. By assessing the socio-economic benefits of existing climate services with positive outcomes, the report aims to encourage other countries and industries to invest in and implement similar services based on their needs assessments.

A successful report which exemplifies the economic savings and social improvements created by climate services can increase the demand for such projects. This would contribute to reducing the cost of existing services through economies of scale and encouraging the development of new services which can compete to lower costs and improve performance. Additionally, highlighting socio-economic benefits can bring donor attention to the need for such projects, to ensure that countries and organizations, lacking the resources to implement them can potentially progress.

3. Research Questions and Objectives

This project aimed to assess the socio-economic benefits created by hydro-meteorological climate services in the energy sector, through an in-depth analysis of several case studies, namely South Africa, Egypt, Croatia, and China. These case studies offered an overview of the current state of climate services in the selected areas and helped identify how climate services generated socio-economic benefits for the end-users. This was integral to address the research gap concerning the socio-economic impact of these services, a subject which remains largely understudied and unexplored.

Subsequently, this research sought to identify success stories and challenges faced in the implementation of climate services in these regions. Highlighting the success stories would contribute to enriching claims that climate services create several positive externalities, providing a strong basis for further investment and policy focus.

The research questions and objectives were as follows:

Overall Research Question
• What are the socio-economic benefits of climate services for energy?
Sub Research Question
• What is the current state of climate services in China, South Africa, Egypt and Croatia? • What are some of the success stories with the implementation of the climate services, and the challenges experienced by the users? • What are the challenges encountered with the implementation of the climate services, and the challenges experienced by the users?
Research Objectives
• To explore the socio-economic benefits of climate services for energy. • To determine the current state of climate services in China, South Africa, Egypt and Croatia. • To highlight the success stories and challenges of the implementation of climate services, and experiences by the users.

Figure 6: Research Questions and Objectives

4. Methodology

4.1 Qualitative Approach

This project's purpose was to contribute to the 2022 WMO State of Climate Services Report by conducting research regarding the socio-economic benefits of existing climate services in the energy sector. Each of the selected case studies comprises a climate service associated with a regional partner, that has worked closely with WMO previously.

For each case study, the student team was provided with a summary of the service, its mode of operation, and any previously reported benefits derived from this service. This case study summary, along with a review of prior State of Climate Services Reports, and background research on the risks and benefits of each type of energy source, formed the basis for the qualitative research and interviews with stakeholders (See Figure 7).

SDG	Goal	Indicator
SDG 7.1	By 2030, ensure universal access to affordable, reliable and modern energy services.	**Indicator 7.1.1:** Proportion of population with access to electricity. **Indicator 7.1.2:** Proportion of population with primary reliance on clean fuels and technology.
SDG 7.2	By 2030, increase substantially the share of renewable energy in the global energy mix.	**Indicator 7.2.1** Renewable energy share in the total final energy consumption.
IRENA Measures (SDG 7, 8, 10)	**SDG 7:** Ensure access to affordable, reliable, sustainable and modern energy for all **SDG 13:** Take urgent action to combat climate change and its impact. **SDG 8:** Promote sustained, inclusive, and sustainable economic growth, full and productive employment and decent work for all. (Relevance with indicators 8.3 and 8.4).	**IRENA Indicators** • Employment. • Access to health and education. • Skill development.

Figure 7: Impact Assessment Grid for indicators used

Thereafter, the data was collected by the student team via interviews with service providers, users, and other stakeholders. This included pointed questions about needs assessments, quantifiable improvements experienced by each party on the preservation of human life, reduced operational costs, and any other factors deemed integral by the student in charge of the case study. The process helped uncover new information on socio-economic benefits, including those related to income, education, employment, community safety, and social support.

4.2 Secondary sources

This project relied on two secondary sources namely, reports published by international organizations and academic publications by scholars concerning climate services, with both sources serving different purposes.

Reviewing academic literature allowed the team to develop and consolidate a theoretical understanding of these services and trace their scientific evolution. Since these services vary depending on the energy sources available in the region, academic articles helped prevent confusion by offering a unified understanding of the potential impact of these services.

However, academic journals reveal little about the practical implications of such technologies and their shortcomings in different landscapes. This compelled us to consult reports to develop a better understanding of the real impact of these technologies and the benefits academics claim they offer.

Following an extensive academic literature review, this research relied on reports published by the World Meteorological Organization (WMO), Intergovernmental Panel on Climate Change (IPCC) and the International Renewable Energy Agency (IRENA). These reports included practical case studies from diverse countries, which facilitated an understanding of how these services benefit other sectors such as disaster reduction, agricultural production, and infrastructure.

Given the focus of the project, these reports also offered ideas concerning potential indicators of socio-economic benefits such as skill development, increased employment, and consistency of energy supply. Since climate services are an emerging field with numerous innovations, a combination of academic sources and organizational reports facilitated the establishment of a solid background which prepared the team for the project.

4.3 Primary Sources

The primary sources across the case studies comprised of interviews conducted by the team members. Interviews were conducted via video calls using Microsoft Teams, and interviewees received an interview quideline and a Sustainable Development Goal (SDG) grid a week prior to the interview. Between one and three interviews were conducted per case study (see Figure 8). The goal was to ensure that insights from different stakeholders were incorporated in the socio-economic analysis of climate services in these regions.

Each interview was led by the student team member responsible for that case study, one or more members of the WMO team, in the presence of other team members or stakeholders. The table below indicates the interviews conducted by students with diverse stakeholders:

Country	Stakeholder	Interviewee
South Africa	Service provider	Henerica Tazvinga - Lead Scientist at South African Weather Service Miriam Murambadoro - Lead Scientist at South African Weather Service Nico Kroese - Manager at South African Weather Service
Egypt	Executive Chairman of the New and Renewable Energy Authority (NREA)	Dr Mohammed El Khayat
	Case study author	Dr Stelios Kazadzis
Croatia	Case study author	Kristian Horvath and team
China	Service provider	Dong Zhao and the team at Beijing Jiutian Weather Corp.
	Service user	Xuesong Zhang, senior engineer at CGN New Energy

Figure 8: Table showing the interviewee for each case study

For simplifying the analysis, the data was then compiled into a Word document and paired with the grid to establish causality between the climate service and its benefits.

4.4 Limitations

This section will explore the challenges faced by the team and the solutions adopted to resolve them. Firstly, as mentioned previously, climate services are an emerging field with frequent developments fuelled by scientific and technological advancements. For instance, some of the technologies analysed in the case study included forecasting and predictive algorithms based on specific properties of climate events.

Given the complex nature of these technologies and the educational background of the team, it was challenging to develop an understanding of how these technologies worked. Hence, the group chose to pursue a strategy that combined academic sources, reports, and interviews with diverse stakeholders to clarify misconceptions and gaps in knowledge. This not only assisted with knowledge-building but also invoked curiosity in the subject, motivating further research and informative discussions.

Secondly, the project was limited by obstacles in the execution of the data collection process, which was extremely time-consuming. Since the research relied extensively on interviews, the challenge of working with interviewees with busy schedules in different time zones created problems in scheduling and coordination.

Thus, the team had to revisit its communication strategy and adopt a more flexible approach. Consequently, we sought to resolve this by offering interviewees multiple time slots on different dates and pursuing them with frequent follow-ups. Moreover, the team also prepared interview guidelines and questions in advance to get the most out of the scheduled meetings. Fortunately, the WMO offered immense support by providing contacts for interviews, assisting with follow-ups and scheduling interviews.

Despite the team's best efforts, we faced a challenging situation which demanded a re-evaluation of the case study selection due to the absence of the information. For instance, initially, Colombia was selected as a case study as the country demonstrated immense potential for climate services and a diverse energy mix making it a promising case study.

However, after interviews with case study authors in Colombia, it was noted that data concerning socio-economic assessments of climate services in the energy sector was confidential owing to an extremely competitive energy market. Despite approaching diverse connections through the WMO, it was realized that energy utilities held this information to maintain their monopoly in specific regions.

This experience served as a great lesson as it taught the team how to face unanticipated challenges and exposed the complex contexts within which advanced initiatives like climate services were developed. Specifically, it led to the awareness of the challenges faced by international organizations in coordinating with and accessing information from different member states.

Most importantly, despite the team's interest in Colombia, it was compelled to close the door on this case study and start the process of identifying a region and conducting research from scratch. Thus, after reconsidering its priorities, the team chose to move away from Colombia and unanimously selected Croatia as an alternative.

Although these challenges delayed the anticipated timeline for the results, they served as a learning experience for the team by encouraging us to improve our knowledge regarding the subject and work on skills concerning coordination and communication, strengthening our ability to work as a team.

SECTION II

Case studies

The report will include detailed analysis on the country context and offer a background of the climate service projects in four countries namely, South Africa, Egypt, Croatia, and China. The analysis will explore the socio-economic benefits delivered by specific services for different stakeholders ranging from local communities to utilities.

South Africa

Upper Blinkwater Smart project

5. South Africa

Context

The Eastern Cape Province in South Africa faces challenges in access to electricity. In response, several renewable energy initiatives have been introduced to improve energy access and create jobs to reduce the poverty levels in the area. The aim of this climate service project was to decentralize the energy system in the region so that the lower-income communities in the area can access clean energy and cut their energy costs by reducing their dependence on fossil fuels (WMO 2022).

Furthermore, the project would assist in reducing the vulnerability of these communities to extreme weather conditions. To achieve this, the Upper Blinkwater Smart project was implemented in a community in the Eastern Cape. This was accomplished through the provision of renewable energy produced from solar photovoltaic panels and diesel generators with battery storage.

This project was successful due to its unique collaboration with the Eastern Cape Province, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, and Upper Blinkwater community, South Africa's Department of Mineral Resources and Energy; the provincial Department of Economic Development, Environmental Affairs and Tourism; South Africa's Council for Scientific and Industrial Research; the South African National Energy Development Institute and the Universities of Fort Hare and Nelson Mandela.

Based on this case study, the team was tasked with understanding and assessing the socio-economic benefits of the Upper Blinkwater Smart system on the community members' lives. The community participated in the process to ensure their buy-in (WMO 2022). This was achieved through the use of questionnaires, workshops, and monitoring of the climate service system performance to provide appropriate and relevant feedback (WMO 2022).

Findings

The project's aim was to assist the community with energy access to improve the lives of the community members through the provision of clean electricity to those who were not connected to the national electricity grid. This was done through a mix of energy interventions largely through solar power but included a hybrid of solar, wind and diesel battery systems to improve consistency.

Firstly, this project was important to implement because the residents of the community began to emigrate due to a lack of access to electricity, which led to schools closing as teachers moved away from the communities owing to the dire conditions. However, since then, the project has acted to positively contribute to SDG 4 on quality education, as improvements in energy access allowed for the re-opening of schools and provided students with the opportunity to study at night, thus improving their access to higher education and increasing their potential for future employment opportunities.

Secondly, prior to the implementation of the project, local communities relied extensively on firewood, cow dung, charcoal, and candles for lighting paraffin to meet their energy needs, resulting in indoor air pollution which led to adverse health effects (see figure 9). To solve this, the mini grid aimed to supply energy from clean renewable sources for the community. However, it is difficult to quantify the number of people that have had their health negatively affected using firewood. Furthermore, the shift to clean energy resulted in households being able to save between $2 and $49 each month from previous paraffin and candle purchases.

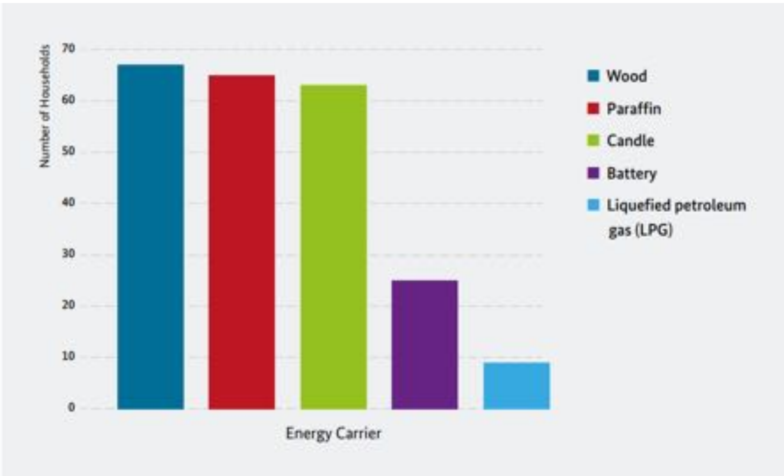


Figure 9: Consumption of energy carriers (GIZ 2020)

Thirdly, the project provided some form of skill development, as they trained community members with the technical skills required to address electrical issues within households. It also contributed to an increase in farming activities through pumping water for irrigation and gardening, which enhanced employment opportunities for community members.

Lastly, the provision of electricity in the community can assist in creating social services in the region. For example, a health care centre can be brought closer to them, as people have previously had to travel long distances to access health care. Thus, several positive externalities are associated with the project even though quantitative data is not largely available.

Egypt

Solar Atlas project

6. Egypt

Context

Egypt's economic development is heavily dependent on the energy sector which constitutes approximately 13% of its Gross Domestic Product (GDP). A close observation of Egypt's existing energy mix will reveal that nearly 92% of its energy demands are met by oil and gas (See Figure 10). To tackle this growing energy demand in the face of climate change, Egypt developed the integrated Sustainable Energy Strategy (ISES) for 2035 that aims to ensure security and stability of supply, emphasizing the role of renewable energy and energy efficiency. Furthermore, the Egyptian government has set renewable energy targets of 20% of the electricity mix by 2022 and 42% by 2035, to be achieved through new investments as well as rehabilitation and maintenance programmes in the power sector.

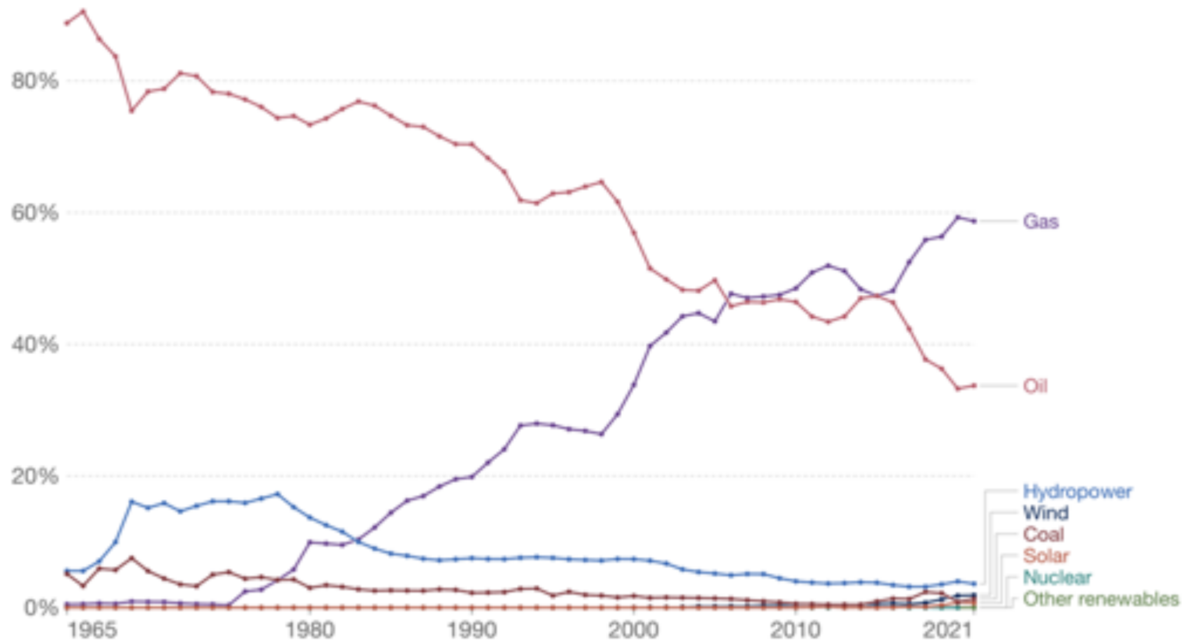


Figure 10: Graph showing Egypt's energy mix through the years (Our World in Data 2021)

In this context, the Group on Earth Observations (GEO) CRADLE initiative developed a pilot activity – the Solar Energy Nowcasting System (SENSE). SENSE uses freely accessible data and state-of-the-art real-time solar energy calculating systems to deliver reliable and high-resolution solar Atlases and broader climatology studies. The climate service that is under assessment in this case study is a Solar Atlas developed by the government of Egypt in collaboration with GEO CRADLE as a part of this pilot activity. The Solar Atlas uses real-time solar radiation data to help identify the potential for more efficient solar energy exploitation in Egypt.

Applications have also been developed within the Solar Atlas that use historical datasets and provide information critical to the operation of solar systems and farms in real time, with high spatiotemporal resolution. The platform upon which the Solar Atlas operates exists in the form of an online website. Based on this case study, the team was tasked with understanding and assessing the potential socio-economic benefits that this Solar Atlas has had on the energy sector in Egypt.

Findings

The study focused on the Solar Atlas project which provides information on solar resources and their application for the management of solar-based electricity power plants and grid integration strategies across three sub-regions namely, Cairo, Alexandria, and Southern Egypt.

The Solar Atlas helps identify prospective areas (in Egypt) where solar parks can be developed. It has also helped guide potential investors in solar energy - to identify which areas could have the highest and most promising solar radiation. The Solar Atlas is expected to mainly serve the small and medium projects under implementation in Egypt.

The service has been used by the government to plan future national investments and for the efficient exploitation of solar energy to successfully implement ISES 2035. This includes the Benban Solar Park, which started its operation in 2018 and is currently the fourth largest solar power plant in the world, with a total capacity of 1650 MW nominal power. The nowcasting of the solar energy potential in real time has also supported the Egyptian energy authorities to better plan solar energy demand. Furthermore, data from the Solar Atlas and the website have helped secure funding close to US$ 2.2 billion for these solar projects in Egypt.

The interviews conducted based on the Egypt case study have highlighted the importance and need for more studies that attempt to quantify the socio-economic impacts of such climate services in the energy sector. Further, some critical gaps still exist in the uptake of climate services in the Middle East – low levels of cooperation between relevant stakeholders, ineffective exploitation of the available resources, a lack of awareness about such services and their benefits amongst local communities as well as limited involvement of the industrial sector.

Croatia

Forecasting system for energy trading

7. Croatia

Context

Croatia holds immense potential for renewable sources such as hydropower, while approximately 52% of the energy is imported from neighbouring countries (ITA 2022). Owing to its location and in a bid to reduce energy imports, the country has made attempts to increase the proportion of renewable sources.

The case study in Croatia focused on the project using the national short-range weather forecasting system ALADIN-HR and forecast verification from the DHMZ/Meteoalarm warning system. It relies on technology to address gaps concerning intermittent energy supply which resulted from the lack of storage solutions, disproportional supply, and volatility in the power system.

To address this gap, the project used forecasting climate services for market behaviour optimization of energy generation and trading, thereby allowing for proportional distribution and supply consistency. This is because climate services offer better predictions of weather-sensitive energy demand which reduces operating costs and multi-risk exposure, increasing the efficiency of power system operations.

The key stakeholders in the project included the Croatian Hydrometeorological Institute (DHMZ) and the HEP Group (Hrvatska Elektroprivreda), the national energy company of Croatia. HEP constitutes the primary electricity provider in the region through public and private facilities. The breakdown of HEP's energy portfolio can be seen below (Figure 11).

Electricity production and procurement	GWh
Hydro power plants	6.785
Thermal power plants	3.537
Krško nuclear power plant	2.709
Purchase of electricity generated from RES	1.424,67
Import	4.674
Total available	**19.130**

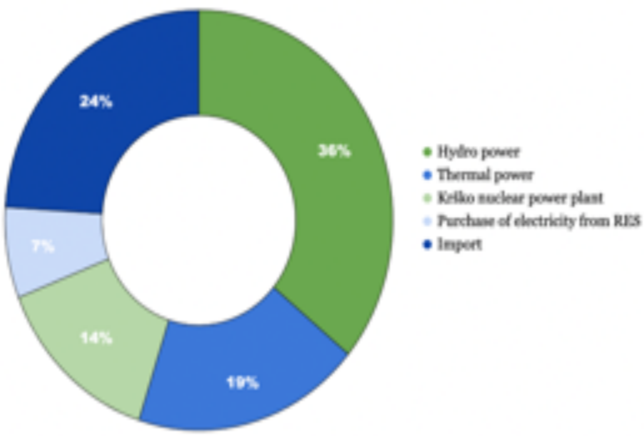


Figure 11: HEP energy portfolio (HEP 2021)

Prior to the project, HEP had witnessed challenges in energy supply owing to cross-border bottlenecks, voltage instability and extreme weather events. This caused supply disruptions, resulting in severe economic costs. For instance, in 2014, an extreme hydrological event left approximately 14,000 households without electricity and caused damage worth 15 million Euros to energy infrastructure.

By utilizing data provided by climate services on past, present, and forecasted weather conditions, HEP could reschedule intraday trades, fill, or recharge reservoirs and regulate its sale or purchase of electricity. This allowed them to start the trading process earlier based on data concerning accurate load and other forecasts critical for trading positions. It would also reduce the energy prices for end-users by saving resources for "peak hours", especially in cases of huge loads, weather, and price volatility.

Based on this case study, the team was tasked with assessing the socio-economic benefits such as price minimization, improved energy supply and better decision-making within utilities based on advancements in the energy trading platform.

Findings

The goal of the project was to ensure consistency in energy supply for the population and prevent fluctuations in electricity prices by relying on energy trading mechanisms. It also included objectives such as improved decision-making by utilities, hedging risks in energy portfolios and limiting the impact of extreme weather events. The energy trading mechanisms have created significant positive impacts on the energy sector in Croatia.

Firstly, the introduction of a trading platform has encouraged efforts to diversify the energy mix, which primarily relied on hydropower. Moreover, in the last decade, there have been increasing attempts to build solar energy, biomass, and wind power nationally. Investments in renewable energy reached roughly 2 billion Euros resulting in 1300 megawatts (Mw) in renewable energy system capacity.

Secondly, the introduction of new sources of energy and trading platform has cumulatively improved the consistency of supply, thereby preventing utilities from arbitrarily increasing prices when the supply is low. Consequently, in the last decade, supply intermittency reduced by roughly 40% thereby, reducing the overall cost of access to renewable energy for an average consumer by 5%.

Thirdly, the energy trading platforms, by encouraging the diversification of the energy mix and resource options for users, have created opportunities for skill development and employment. As per records, renewable energy development in Croatia generated approximately 6000 new jobs in the country. The introduction of the energy trading platform has further compelled businesses to offer skill development and learning opportunities to employees regarding energy efficiency and regulation.

Nonetheless, the sector is not without challenges as renewable energy only contributes to roughly 28.5% of the national energy mix (ITA 2022). This is on account of high balancing costs, which refer to the cost of maintaining an energy plant or system. Since renewable energy sources like wind and solar are intermittent with limited energy storage solutions, the expense of maintaining these sources may discourage utilities, decreasing investments in renewable energy.

This can adversely affect energy trading mechanisms as sources of energy supply may be limited, thereby leading to inflationary pressure on prices. These challenges could hinder the success of the project and should be accounted for in regions which are not investing in the development of the renewable energy sector.

China

Integrated services for offshore wind power

8. China

Context

Beijing is a mega city that requires a continuous and safe power supply. However, extreme weather events such as floods, hail, and rainstorms, threaten the operations of Beijing's power grid. This was witnessed when network failures occurred as a direct result of various meteorological disasters, which have accounted for more than 50% of all power failures in recent years. To address this, advanced information technologies such as multi-source data analysis and power grid lean geographic models were introduced.

On Saturday, 2 July 2022, the Fujing 001 engineering vessel was performing maintenance work on an offshore wind farm off the coast of Hong Kong (Yu 2022) when Typhoon Chaba damaged the anchor chain, sinking the boat and resulting in the death of 25 workers on board (CGTN 2022). Rescue efforts were hampered by the storm's severity. Such disasters further highlight the need for accurate weather predictions and their potential for saving human lives.

China Meteorological Administration (CMA) has integrated meteorological and power grid considerations which have enabled their early warning system to predict accurate disaster warnings for more than ten types of disasters, such as wire icing and water flooding transformer substations. Based on this case study, we were tasked with assessing the socio-economic benefits that the service contributes to the operations of offshore wind farms which are its beneficiaries.

Findings

The project on integrated weather services for offshore wind power production by Beijing Jiutian Weather Corp. was initially requested by wind power plant companies, as they assessed that offshore wind farm operations are costly, high-risk, and dangerous. In 2019, a typhoon within 200 kilometres of a wind farm, forced operators to cut submarine cables, causing massive financial losses. Before the deployment of this system, decisions were made mainly by captains, according to their best judgement and experience. Currently, operation plans are made using climate services, concerning wind and wave predictions for higher accuracy and reliability.

The service aims to address risks to human life, energy stability, and energy providers' income, via an online system. This sends early warnings to decision-makers, offshore wind farm workers, and other stakeholders (government emergency management departments, rescue teams, local meteorology offices, and equipment failure warning systems).

It operates via an online platform, which sends alerts and "intelligent plan advice" through mobile telecom or high-frequency transmission systems (See Figure 12). Alerts are classified as red (immediate danger, all ships take shelter in haven), yellow (everyone should leave the wind turbine, hoisting is prohibited), or blue (need for minor adjustment to activities, stop high-risk activities like gondola work and blade hoisting). Alerts also provide recommendations on how to handle the situation. Situations for which warnings are issued include typhoons, waves, heavy rain, gales, fog, and lightning.

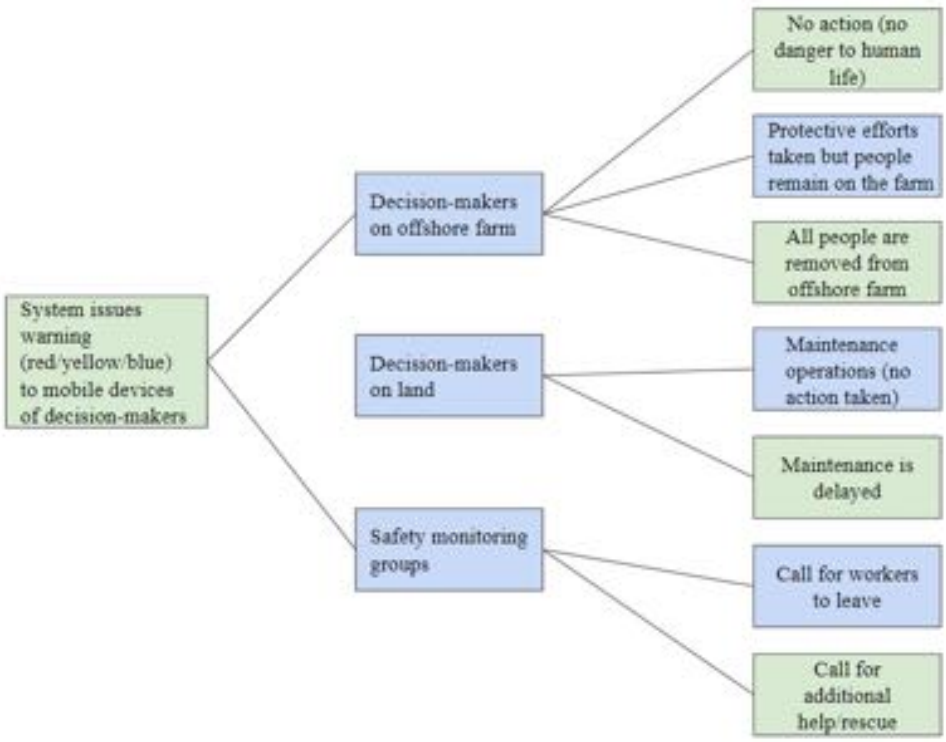


Figure 12: Process chain of early warnings

The users of the platform range between 200 and 500 at any one time (across 20 wind farms), and fall into three categories:

1) workers at sea receive alerts and decide whether to continue to work or to leave,
2) plan makers at wind farms decide how many workers are needed to maintain operations, and
3) safety monitoring groups monitor systems and can call for workers to leave or for additional help in the case of sudden emergencies. The service is tailored to the specific situation and needs of each customer, depending on their operations, types of equipment and so on.

The project's benefits are four-pronged (See Figure 13).

- **Increased safety for offshore wind farm employees:** No safety accidents have occurred since the deployment of the service. However, accidents have always been infrequent, and the service has only been in use since the end of 2020. There is no information on the exact decrease in casualties relative to a baseline because the offshore wind industry is fairly new. The goal is to achieve *zero* injuries. CGN determined their need for this service after a serious accident.
- **Decreased construction costs for offshore wind farms:** The service provided accurate predictions regarding weather conditions ideal for construction to help reduce costs because construction workers use rented equipment, which means time and money are wasted if ideal construction windows are missed. So far, the service has reduced construction costs by 0.5% (11 million RNB/year for GCN with 8 wind farms, around 10 million RMB for Three Gorges). A total of 20 wind farms are constructed by 2 big companies but are run individually by 20 smaller-scale companies.
- **Increased productivity of offshore wind farms:** The service provided accurate predictions of weather conditions ideal for maintenance, which helped decrease the amount of time that wind turbines were inactive (and not generating electricity). This increases the maximum amount of power generated annually per machine. In the case that an ideal maintenance window is missed, maintenance may need to be put off by 7 days. Since the incorporation of the service, there has been an increase in the "trouble-free operation time" of wind turbines by 10 hours per year due to precise predictions.
- **Decreased energy costs for the population:** Accurate prediction windows and timely maintenance reduces power losses caused by failure and shutdown of wind turbines. This means an improvement in the provider's ability to ensure a continuous and stable output of energy from their wind farms, thereby increasing the proportion of wind power in the energy mix. This reduces energy costs and increases market penetration of renewable energy.

Suggestions for future improvements included the following (See Figure 13):

- **Digitization:** The system can be made more effective with the addition of intelligent employee monitoring and automatic generation of maintenance plans.
- **Imperfections** in the mobile application and incompatibility of the web version with mobile platforms should be resolved.

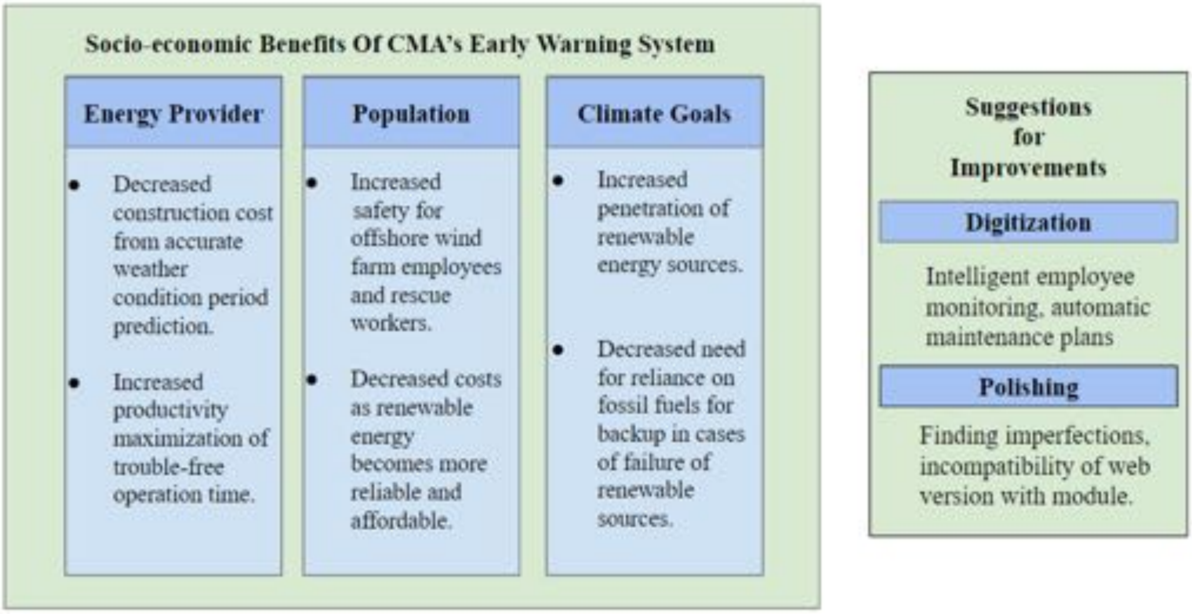


Figure 13: Benefits of CMA's Early Warning System

For the most part, warnings are received on time for stakeholders to react immediately and appropriately, thanks to a high degree of automation of the early warning system. However, on some occasions, decision-makers do not act on received warnings. They may take high-risk actions regardless of the warning, or otherwise act based on information provided by local meteorological predictions instead. A later interview with a user of the service was conducted to gain a better understanding of which factors go into such decisions on the part of decision-makers at offshore wind farms.

The interviewee at CGN New Energy, a user of the system, revealed that over 50% of warnings issued by the system do not result in action by the user. In most cases, the user deems action unnecessary because there are no people on the wind farm at the time. The turbines and other assets are designed to survive extreme weather events and have a safety mode which can be activated automatically or manually. Inaction does not imply ignorance of warnings. Rather, operation plans are made considering multiple factors, including employee shifts, vessel status and urgency of the tasks. Normally, decision-makers adjust the plan based on information from various sources.

SECTION III

9. Comparative Analysis

The case studies exhibit significant differences based on their scale, objectives, the climate services used, challenges faced and their intended impact.

A visualization of the comparative analysis can be found below.

	South Africa	Egypt	Croatia	China
Project	Upper Blinkwater Smart	Solar Atlas Project	HEP Energy Trading Project	Beijing Jiutian Weather Corp
Objective	Decentralize the energy system to expand access to energy	Identify the potential for efficient solar energy exploitation	Price minimization and improved energy supply	Addresses risks to life, energy stability, and energy providers' income, via an online system.
Scale	Community	National	National	Regional
Common Benefits	Enhanced productivity of renewable energy sources (solar farms) + Improved access to energy	Enhanced productivity of renewable energy sources (solar farms) + Improved access to energy	Enhanced productivity of renewable energy sources (Hydropower) + Improved access to energy	Enhanced productivity of renewable energy sources (wind farms) + Improved access to energy
Challenges	Limited economic impact	No significant benefit to end-users	Profit maximization by utilities	Decision-makers may not respond to received warnings
SDG Impact Area	4 QUALITY EDUCATION	7 AFFORDABLE AND CLEAN ENERGY	7 AFFORDABLE AND CLEAN ENERGY	7 AFFORDABLE AND CLEAN ENERGY

Figure 14: Visualization of the comparative analysis

Firstly, differences in the case studies arise from the priorities of stakeholders involved in these projects which in turn determines the adoption of the climate service and its impact. For instance, in the case of South Africa, the introduction of the climate service is based on a trilateral agreement between the Eastern Cape Province, the federal state of Lower Saxony and GIZ Germany. Since the project is largely financed by the government, its objectives are centred around assisting the community by expanding energy access to low-income communities. The same applies to the Solar Atlas Project in Egypt which seeks to expand energy access by identifying potential solar facilities in the region.

In contrast to these community-centric objectives, the goals of projects in Croatia and China are extremely different. Since the key stakeholder and executors of the project here are energy providers who supply electricity through state and private entities, their objectives are more aligned with market forces rather than community support.

For instance, the use of forecasting services by HEP Group in Croatia is motivated by the aim to maximize profits for energy providers by ensuring supply consistency through efficient energy trading, based on forecasts. Similarly, a primary motivation for the adoption of climate services in China is to stabilize the revenues of energy providers such as Beijing Jiutian Weather Corporation by mitigating risks from extreme weather events and supply disruptions.

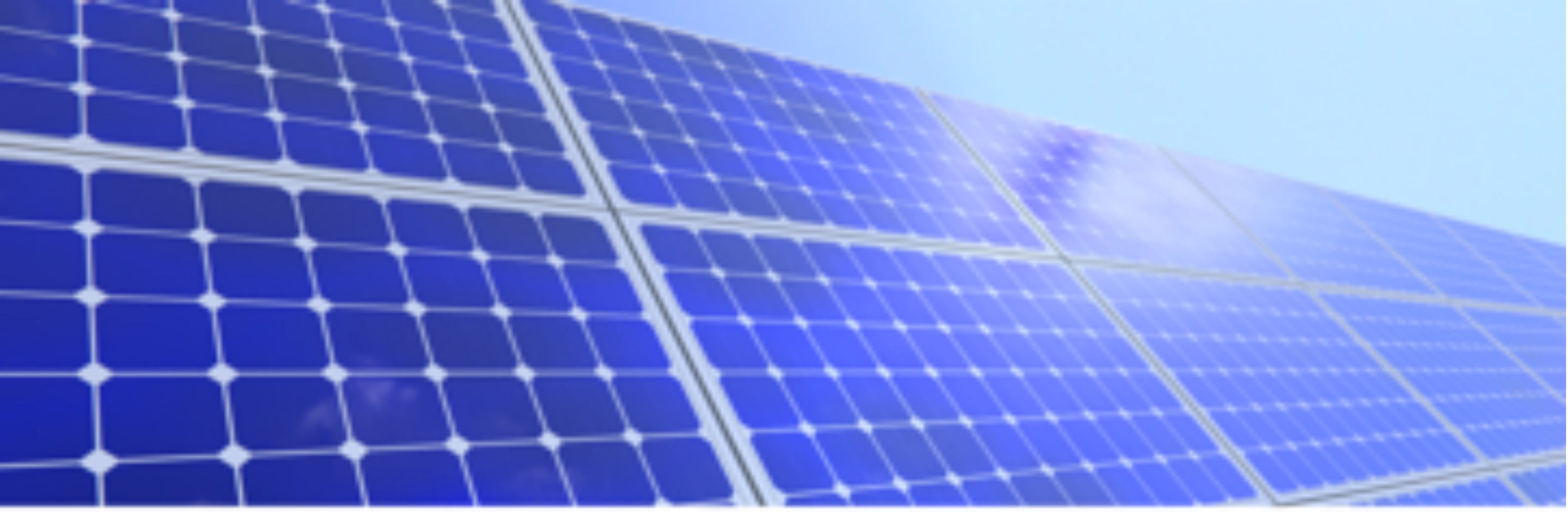
While these generate long-term indirect benefits for the community, the inclusion of privatized stakeholders does significantly change objectives driving the adoption of climate services. However, this only goes to say that these services have wide applications and can cater to extremely diverse objectives.

Furthermore, the data collection process revealed that understanding objectives is critical as these influence impact pathways and leads to the discovery of unintended impact areas. Generally, certain common *economic* benefits were noted across all case studies. A common benefit noted across all studies was the enhancement of productivity of different renewable energy sources.

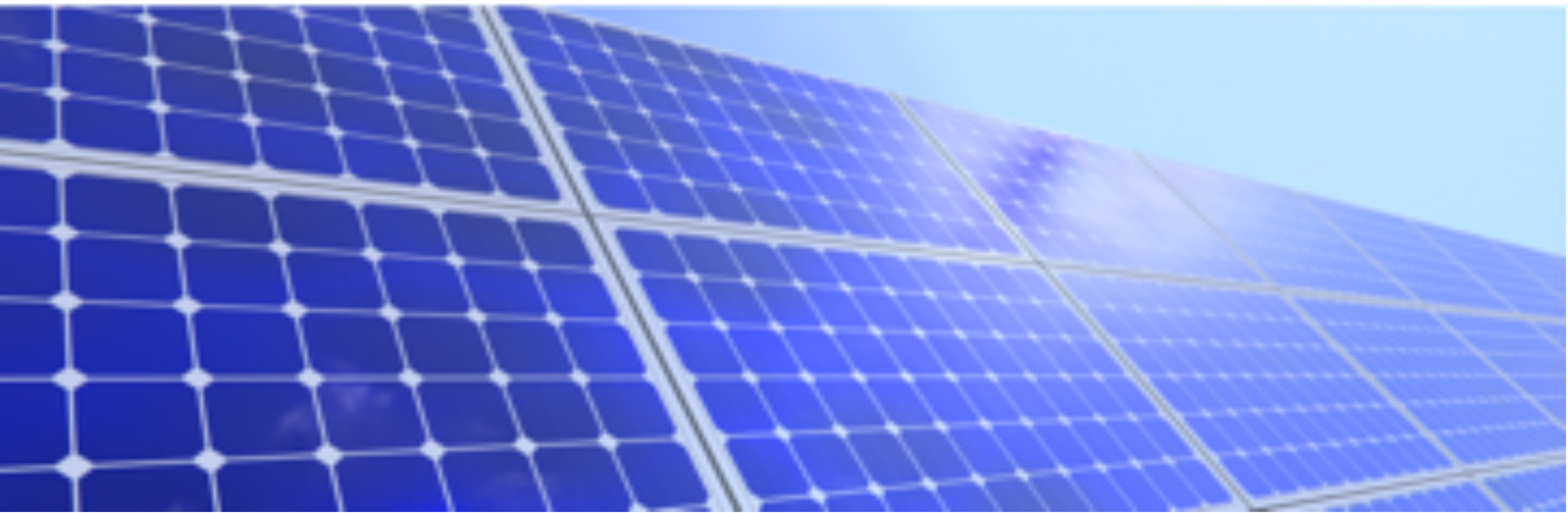
This resulted in improved access to energy for end-users by improving consistency in supply and minimizing disruptions. Notably, the use of climate services in China also reduced construction costs which allowed for greater investments in additional wind farms. Similarly, the energy sector in Croatia also experienced an increase in investments. These outcomes aligned with SDG 7 which focuses on improving access to affordable and clean energy.

Nonetheless, in most cases, an understanding of social benefits in these studies was limited which made it difficult to assess the impact of climate services on end-users. This was partially due to limited assessments of socio-economic benefits by stakeholders and partially because economic indicators such as prices, damages and costs were considered the key performance indicators. Subsequently, in China, Egypt and Croatia, the socio-economic impact on the local community was scarce.

While these obstacles may be specific to these countries, they serve as lessons to stakeholders in other regions who are planning to incorporate these services into their power systems. Furthermore, while these services have created socio-economic benefits in most cases, better monitoring and evaluation of climate services is needed if these benefits are to be realized at scale.



SECTION IV



10. Recommendations

The recommendations are divided into four categories based on stakeholders relevant to the development of climate services namely, governments, electric utilities or providers, international organizations, and civil society.

Governments:

- Facilitate better cooperation between the different stakeholders involved in the functioning of the climate services through platforms, seminars, or conventions.
- Develop instruments to encourage investments towards research and development of climate services for the energy sector through public-private partnerships, public guarantees, or blended finance instruments.
- Improve collaboration and communication with local governments to encourage knowledge transfer and streamline the implementation of climate services at different levels of governance.

Electric utilities or providers:

- Reduce the high costs that are currently being borne by energy producers, as climate services serve as insurance against losses to ensure energy affordability and security. However, their implementation is often inhibited by prohibitively high costs.
- Efforts should be made to increase access of all interested parties to the life-and resource-saving knowledge that is produced by such systems, whether by means of subsidies or decoupling from profit structures.
- Invest in transparent and publicly available socio-economic assessments of climate services whilst encouraging competitors to make similar disclosures.

International organizations:

- Work with end-users to acquire relevant feedback by ensuring the approach is bottom-up and buy-in is acquired from the beginning stages of the project. This feedback could not only help improve research and implementation of climate services but also facilitate the uptake of these services if put into practice.
- Ensure that material such as reports on scientific technologies is simplified and easy to understand to reach a larger audience.
- Collaborate with local authorities and other partners to encourage and report on disclosures regarding socio-economic benefits to save time and resources.

Civil society:

- Offer local expertise and insights to organizations seeking to research and implement climate services.
- Serve as a mediator between electric utilities, end-users, and government officials to integrate knowledge from different stakeholders, which can improve the quality of climate services.
- Engage in awareness-building programs to educate local communities regarding the climate services available in their region, best practices and the benefits created by them.

11. Conclusion

Conclusively, the findings from this project were included in the 2022 WMO State of Climate Services Report which was launched on 11 October 2022, with an attendance of 500 participants with the student members listed as contributors. Following the launch, the Report received 1800 media mentions and reached approximately 35 million people. More significantly, the Report was featured in almost 200 articles and was downloaded roughly 12,000 times from the WMO Library.

Given the magnitude of the positive response to the Report, the WMO raised the issue of the need for socio-economic assessments of climate services at the United Nations Climate Change Conference (COP27) in Sharm el-Sheikh, Egypt November 2022 in Egypt to build a case for greater investments in climate services for energy in diverse markets.

Most importantly, it should be noted that in a world barrelling toward the 1.5-degree mark, there is a need to go beyond mitigation. Renewable energy sources play an increasingly important role in the energy transition, as countries pursue more sustainable options while maintaining energy security and affordability. However, these very energy infrastructures will be highly vulnerable to uncertainties brought by climate change, as rainfall patterns and other climate factors on which they depend continue to change.

This project equipped students with the agency to communicate directly with stakeholders, allowing them to gain perspectives on these challenges associated with climate change and potential solutions to address them. Moving forward, we anticipate exploring creative solutions to improve information sharing, so that more highly effective and much-needed climate services may continue to emerge.

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