Energy Exemplar to the User Interface Platform of the Global Framework for Climate Services
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Chairperson, Publications Board
World Meteorological Organization (WMO)
7 bis, avenue de la Paix
P.O. Box 2300
CH-1211 Geneva 2, Switzerland
Tel.: +41 (0) 22 730 84 03
Fax: +41 (0) 22 730 81 17
E-mail: publications@wmo.int

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Executive Summary

The need

Energy systems are the driving force of economic and social development, and investments in them represent a sizeable portion of a country’s gross domestic product. Energy is essential to all aspects of human welfare, including access to water, agricultural productivity, health care, education, job creation and environmental sustainability. Furthermore, emissions (such as carbon dioxide) from the energy sector account for the largest share of global anthropogenic greenhouse gas (GHG) emissions. Emission reduction targets under the United Nations Framework Convention on Climate Change are expected to significantly increase demand for energy from renewable sources, which are highly sensitive to climate, as well as to lead to requirements for energy-efficiency measures. Energy sector planning and operation are markedly affected by meteorological events. With an ever-growing global energy demand – currently about 13.7 billion tonnes of oil equivalent, an increase of about 30% in the past 10 years – expanding energy systems are increasingly exposed to the vagaries of weather and climate. Although this is certainly the case for renewable energy sources such as wind power, solar power and hydropower, and for electrical distribution and transmission systems, traditional energy sources can also be severely affected by extreme weather and climate events. Thus, by properly taking into account weather and climate information, the resilience of energy systems to weather extremes, climate variability and climate change can be considerably improved. Climate services can help to support increased development and use of renewable energy sources.
Improving climate services can help to meet these challenges by giving decision-makers enhanced tools and systems to analyse and manage risk, under current hydrometeorological conditions, as well as in the face of climatic variability and change. This Energy Exemplar explains how improved climate services can benefit the energy sector. It illustrates a vision as to how the development and application of targeted climate products and services through the Global Framework for Climate Services (GFCS) can help to improve the efficiency and reduce the risk associated with hydrometeorological hazards that affect energy systems. The main focus of this Exemplar is to address climate services needed to support:

1. Greater climate resilience and adaptation across the energy sector, due to the fundamental importance for development;
2. The important role of efficiency and reduction of energy consumption with consequent emission reduction in support of mitigation targets;
3. The growing renewable energy subsector, given both the apparent climate sensitivity of renewable energy sources and the policy priority accorded to them due to their GHG emission reduction benefits.

**Mission**

By developing user-tailored weather–water–climate services in close cooperation with the energy industry, GFCS will enable better management of the risks and opportunities arising from extreme events, climate variability and climate change. GFCS will ensure that the resulting science-based climate information leads to improved planning, policy and operational activities.

**Principles**

The GFCS Energy Exemplar will be implemented according to three (sequential) principles:

Take stock – GFCS will take stock of relevant current activities in the area of meteorology/climate and energy, in order to have a detailed overview of the state-of-the-art.

Harmonize activities – GFCS will assist in the coordination of available activities whenever there is a perceived benefit for doing so by a range of stakeholders. GFCS is not meant to replace current activities, but to provide a harmonization platform, with the aim of allowing stakeholders to increase their awareness of available data, tools and energy policies.

Provide multiple benefits – GFCS will provide a platform for collaboration among energy sector stakeholders with a need for improved climate services. GFCS will facilitate the implementation of new complementary projects.

It should be emphasized that in order for these principles to be effectively applied, and hence for the Energy Exemplar to be implemented in a successful manner, strong leadership is required. Such leadership should be shared via partnerships among the World Meteorological Organization (WMO) and counterpart organizations representing the energy industry.
Global Framework for Climate Services

The World Climate Conference-3 (Geneva, 2009) unanimously decided to establish GFCS, an initiative led by the United Nations and spearheaded by WMO, to guide the development and application of science-based climate information and services in support of decision-making (http://www.gfcs-climate.org). GFCS had four initial priorities: agriculture and food security, water, health and disaster risk reduction. Given that climate and energy are intrinsically entwined, energy was subsequently considered as a candidate to become the fifth priority sector. Energy itself plays a significant role in the other areas of activities (pillars), as a driver for improving them.

GFCS is supported by: a network of technical experts; national, regional and global specialized centres and services; and international partners. Its implementation plan spans five pillars:

1. **User Interface Platforms** – forums for forging the stakeholder relationships needed to define needs and respond to requirements for climate information and services in particular sectors and contexts;

2. **Climate Services Information System** – for producing and distributing climate data and information tailored for policy and decision support;

3. **Observations and Monitoring** – for generating the necessary data for the development of climate services;

4. **Research, Modelling and Prediction** – for advancing the science needed for improved climate services and climate-related outcomes;

5. **Capacity Development** – for supporting the systematic development of the institutions, infrastructure and human resources needed for effective climate services.

Work in each of these areas will be undertaken to support the specific needs of the energy sector. Owing to their high sensitivity to climatic factors, renewable energy sources such as wind power, bioenergy, solar power and hydropower and their connecting infrastructure will receive particular attention.
Areas of focus

Work to be undertaken during the implementation of the Exemplar reflects the following project stages of a generic energy system, namely from planning to construction, to operation and maintenance, including also the balancing of supply and demand:

1. Identification and Resource Assessment;
2. Impact Assessment (including infrastructure and environment);
3. Site Selection and Financing;
4. Operation and Maintenance;
5. Energy Integration.

Benefits to energy sector stakeholders

This Exemplar will benefit all energy industry activities influenced by meteorological events, those industries whose aim is to reduce harmful emissions and those enterprises that want to improve energy efficiency and saving. Thus, the aim of this Exemplar is to improve industry resiliency and efficiency while also contributing to mitigation targets.

GFCS will provide a coordinating mechanism to allow energy sector stakeholders to acquire wider access to relevant climate expertise, information, tools and energy policies beyond those currently accessible. While some energy stakeholders are well versed in the use of climate information, a considerable share of the stakeholders, especially in developing countries, cannot afford to have climate specialists in their ranks. Similarly, engagement with energy sector stakeholders will enable hydrometeorological specialists to better understand and respond to the sector’s needs. In either case, information gathering and sharing is a worthwhile investment in this burgeoning area of the relationship between energy and meteorology. GFCS will allow stakeholders to contribute their services and tools into the system; it will also offer the opportunity to suggest improved ways to exchange information and/or request specific services or training.

Timeline and funding opportunities

GFCS is already under way. The activities of the first four priority areas – agriculture and food security, disaster risk reduction, health and water – are progressing according to the following three phases: initial – phase I (2015–2017), implementation – phase II (2017–2019) and consolidation – phase III (2019–2023). Given that the governance structure of GFCS was established in the initial phase, activities of the Energy Exemplar will be integrated in the Priority Needs for the Operationalization of the Global Framework for Climate Services (2016–2018).

WMO has set up a GFCS Trust Fund, which has attracted contributions from a number of countries. It helps to fund some initial projects and cover some administrative costs. Moreover, GFCS provides an organizing structure for framing initiatives and contributing to improved energy-related outcomes. This may generate incentives for self-funding as well as opportunities for obtaining funding from third parties.
Building on existing expertise and structures

GFCS seeks to promote support for its vision and activities at national, regional and global levels, building on existing partnerships and avoiding duplication. This principle can be implemented through active engagement in the working mechanisms, programmes and activities of the energy sector. While energy companies generally have a good appreciation of weather and climate information, technology and science advancements mean that this information is becoming broader and more sophisticated. The challenge for GFCS is to enable effective communication between a science-led provider community and a business-driven sector. Decision-making will take place whether or not adequate climate information is available. However, improved climate services, such as those that may be developed on the basis of this Exemplar, could aid decision-making by reducing risks or costs.

Therefore, in order for this Exemplar to be truly effective, strong partnerships are required with key international organizations, that recognize the benefit of developing climate services and which can assist in communicating and engaging with private sector companies active in the energy industry.

Evaluating and monitoring progress

A principal challenge faced by GFCS in its initial stages will be to demonstrate its ability to add value. In this sense, the risks associated with implementing GFCS priority activities include organizational complexity, leadership and management, resourcing, and support for coordination among international agencies and individual companies active in the energy sector. To manage these risks, this Exemplar proposes establishing monitoring and evaluation practices, to assess the success of activities in its priority categories, and to measure overall improvement in climate knowledge and communication among technical experts, energy practitioners and decision-makers at all levels. These are incorporated in the Priority Needs for the Operationalization of the Global Framework for Climate Services (2016–2018) and monitoring and evaluation framework.

Conclusions

The energy industry is a complex sector that is undergoing major transformation, involving an increasingly diversified supply base (for example, with the widespread adoption of rooftop solar systems) and decreasingly predictable demand patterns. A major consequence of this is that weather and climate are becoming increasingly critical to the balancing of energy supply and demand at any one time, for a range of timescales. By leveraging the power of improved, user-friendly climate services, GFCS has a clear opportunity to beneficially contribute to this transformation of the energy system. Sustained, effective leadership and coordination are crucial if climate services are to be embraced and adopted by the energy industry.
1. Introduction

1.1 Objective, scope and functions

The goal of this Exemplar is to illustrate how the development and application of targeted climate products and services through the Global Framework for Climate Services (GFCS) can advance efforts to better integrate climate information into the planning and operations of the energy sector. This will enable improved sustainability, resilience and efficiency of energy systems under ever-changing weather and climate conditions.

Underpinning the development of the GFCS Energy Exemplar is the decade of Sustainable Energy for All (SE4ALL). The vision of SE4ALL is for governments, businesses and civil society to work in partnership in order to make sustainable energy for all a reality by 2030, underscoring the importance of energy issues for sustainable development and the post-2015 development agenda. As noted by the United Nations Secretary-General Ban Ki-Moon at the launch of SE4ALL in September 2011, the world faces two urgent and interconnected challenges related to energy.

1 http://www.se4all.org/
One challenge is related to energy access. Nearly one person in five still lacks access to electricity. More than twice that number, almost 3 billion people, rely on wood, coal, charcoal or animal waste for cooking and heating. This is a major barrier to eradicating poverty and building shared prosperity. Sustainable, reliable energy provides new opportunities for growth. It enables businesses to grow, generates jobs and creates new markets: children can study after dark; clinics can store life-saving vaccines; and countries can become more resilient, with competitive economies. With sustainable energy, countries can build the clean energy economies of the future. Transforming the world’s energy systems will also lead to new multitrillion-dollar investment opportunities.

The second challenge, where modern energy services are plentiful, the problem is different: waste and pollution. Emissions of greenhouse gases (GHGs) from fossil fuels are contributing to changes in the Earth’s climate, which are causing widespread harm to lives, communities, infrastructure, institutions and budgets. Climate change puts us all at risk, but it hurts the poor first – and worst.

Access to energy is inextricably linked to improved welfare and human development, as energy services have a direct impact on productivity, health, education and communication (Johnson and Lambe, 2009). An illustration of interactions is given in Figure 1.

![Figure 1. Interactions among impacts of climate change on the energy sector and other sectors](image-url)
It is also worth noting that as stated in the *Implementation Plan of the Global Framework for Climate Services* (WMO, 2014, p. 13): “The natural evolution of Framework-related activity will see other sectors come into focus. As an example of a sector that is likely to be considered as one of the next priority areas, the energy sector is recognized for its importance in sustainability and in climate adaptation and mitigation. This sector is particularly sensitive to weather and climate and is therefore an experienced user of climate information”.

### 1.2 Public and private sector engagement

As a sector that is both revenue generating and of immense strategic importance in underpinning national economies, the energy sector engages a wide range of public and private sector stakeholders. Creating partnerships that provide benefits to all parties is key to these engagements and is fundamental for sustainable development. Annex 7 provides recommendations and tools for facilitating public–private sector engagement in the development of climate services. Key roles within the public sector include that of National Meteorological and Hydrological Services (NMHSs) in delivering weather and climate information to all sectors of the economy including energy. Governments regulate the sector, and can ensure free and unrestricted exchange of the data needed for the provision of climate services, ensuring that all private stakeholders can benefit equally from the data and products within the public domain. The private sector, on the other hand, plays key roles both as consumers of climate services and also in the production of specialized climate-related products and services for particular private sector applications. Several NMHSs have already developed a significant presence in the energy industry. For example, in the United Kingdom of Great Britain and Northern Ireland, the Met Office has created the Climate Service UK, which is a framework that provides support and advice for energy private sectors to manage climate-related risks and opportunities. Case studies include partnerships with offshore wind energy industries for resource assessment, providing accurate weather information for gas industries to manage demand and providing advice to businesses on operational and logistical strategies. Another example is the Swedish Meteorological and Hydrological Institute partnership with a leading provider of market data in the European energy markets to create a platform for weather and climate services tailored for energy traders.

### 1.3 Meeting energy demand through a mix of energy supplies

Global energy production derives from different resources each contributing in different measures to the total primary energy supply. The current energy mix is roughly thus subdivided: 80% from fossil fuels, 13% from renewable energy sources (other than large hydropower plants), 5% from nuclear energy and 2% from hydropower plants larger than 10 MW (WER, 2016). Numbers vary slightly when different sources are considered (Figure 2), which can also be due to the sector evolution, but the overall picture is essentially the same. A further subdivision, by energy subsectors, is required in order to identify specific issues in each subsector, and to ultimately develop appropriate and relevant climate services. However, given the large number of energy subsectors – coal, oil, natural gas, nuclear, hydro, bio, peat, waste, wind, solar, geothermal, wave, tidal and ocean currents – it would be impractical to expand on each of these in this Exemplar (thorough coverage of all the main subsectors is given in WER (2016)).

Note also that the subsectors listed above are normally referred to as resource endowments, as opposed to: energy supply (for example, thermal plants, wind and solar power plants, liquid biofuels), energy transmission, energy distribution and transfer, energy infrastructure and energy use (Schaeffer et al., 2012). As a way of providing a few examples, select energy subsectors – wind power, solar power, hydropower and thermal power – are discussed in Annex 1.
In a sector-wide sense, the target is to always achieve sufficient energy supply to match the (variable) demand. Also, aside from the strong constraint of the overall energy demand, the level of supply from each individual source is determined by its relative price. Thus, if, for example, a single source had sufficient capacity to meet demand at any one time, a mix of sources would normally be used nonetheless, as there are constraints other than supply availability, represented by factors such as market mechanisms or network bottlenecks. It is therefore important to view the individual energy supply elements as part of the bigger, demand-constrained, picture.

1.4 Climate service considerations and products for the energy industry

In order to develop relevant and appropriate climate services for the energy sector, a thorough assessment of the way in which climate events affect the energy sector needs to be carried out. A basis for assessing these impacts, as well as a number of examples, is presented below, based on a growing number of publications in this area.

As the sector producing the largest share of anthropogenic GHG emissions – in 2010, 35% of direct GHG emissions came from energy production – the energy sector could substantially contribute to emission mitigation options. While there is a distinct link between GHG emissions and climate change, this document does not deal with policy options for mitigation. Rather, the main focus of this Exemplar is to address the climate services needed to support:

1. Greater climate resilience and adaptation across the energy sector, due to the fundamental importance for development;

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The price of individual supplies is the result of a combination of factors, including subsidies to renewable energy sources as well as to oil-based fuels, carbon price and level of demand.
2. The important role of efficiency and reduction of energy consumption with consequent emission reduction in support of mitigation targets;

3. The growing renewable energy subsector, given both the apparent climate sensitivity of renewable energy sources and the policy priority accorded to them due to their GHG emission reduction benefits.

For the latter, while currently only a small portion of energy comes from renewable sources, international policy processes are under way that provide incentives to significantly increase the share of the renewable energy subsector, owing to climate change concerns. Already, improving technologies and decreasing costs of production have led to renewable energy sources becoming cost competitive with traditional energy generation sources in several parts of the world (REN21, 2016). As this segment of the sector has undergone rapid expansion, the meteorological products and services it needs are less clearly articulated and less well served than those for traditional energy generation sources.

After describing below how climate can affect energy from an industry-wide perspective, an attempt is made to provide a schematic of the types of services required by the energy industry to address impacts related to climate phenomena. The schematic conforms to the five pillars of GFCS. In addition, in order to understand better how climate is linked to energy systems and to define in more detail the type of services needed for energy systems, focused discussions about specific energy subsectors are presented in Annex 1.

1.5 Impacts of climate on the energy sector – leading organizations raising the alarm

Energy services and resources will be increasingly affected by climate change: changing trends, increasing variability, greater extremes and large interannual variations in climate parameters in some regions. Although energy systems already take account of some climate risks in their operation and planning, adaptation measures can further reduce their vulnerability to environmental change by building capacity and improving information for decision-making and climate risk management. Furthermore, the impacts of climate cross the entire energy supply chain. Existing energy infrastructure, new infrastructure and future planning need to consider emerging climate conditions and impacts on design, construction, operation and maintenance. Impacts on energy supply and demand are the most intuitive, but there are also direct effects on energy resource endowment, infrastructure and transportation, and indirect effects through other economic sectors (for example, water and agriculture) (Ebinger and Vergara, 2011).

Integrated risk-based planning processes are critical for addressing these impacts and harmonizing actions within and across sectors. They help to avoid locking in unsustainable practices through investments in long-lived infrastructure and associated consumption patterns. Lack of awareness, knowledge and capacity can impede mainstreaming of climate risk management into the energy sector. Information needs are complex and, to a certain extent, regional and sector specific, which make the tasks more complicated. Issues are exacerbated in developing countries, where there is often a dearth of historical hydrometeorological data and limited capacity to provide climate services (Ebinger and Vergara, 2011).

Specific vulnerabilities of the power sector to projected climatic changes are discussed in an Asian Development Bank publication (Johnston et al., 2012):

- Increases in air temperature will reduce generation efficiency and output as well as increase customer cooling demands, stressing the capacity of generation and grid networks;
• Changes in precipitation patterns and surface water discharges, as well as an increasing frequency and/or intensity of droughts, may adversely impact hydropower generation and reduce water availability for cooling purposes to thermal and nuclear power plants;

• Extreme weather events, such as stronger and/or more frequent storms, ice accretion loads, extreme winds and offshore hazards, can reduce the supply and potentially the quality of fuel (coal, oil or gas), reduce the input of energy (for example, water, wind, solar or biomass), damage generation and grid infrastructure, reduce output and affect security of supply;

• Sea-level rise can affect energy infrastructure in general and limit areas appropriate for the location of power plants and grids.

Detailed local assessments are necessary to provide confidence in understanding current climate variability and how the climate might change in the future, and therefore which measures are warranted at the level of specific projects. There is a need to enhance energy sector (and broader) decision-making by improving local weather and climate knowledge, regardless of whether large climatic changes are expected, by improving access to existing meteorological and hydrological data, and by developing better mechanisms so that local weather and climate data as well as specialized analyses are archived for the public good (Johnston et al., 2012).

To improve the energy sector’s resilience to climate change, there are some technological improvements that could be made to thermal power plants, which, if implemented, will bring efficiency gains that more than compensate for losses due to higher ambient temperatures. For instance, coal-mining companies can improve drainage and runoff for on-site coal storage, as well as implement changes in coal handling due to the increased moisture content of coal. Authorities can plan for evolving demand needs for heating and cooling by assessing the impact on the fuel mix: heating often involves direct burning of fossil fuels, whereas cooling is generally electrically powered. More demand for cooling and less for heating will create a downward pressure on direct fossil fuel use, but an upward pressure on demand for electricity (ECF/WEC/UoC, 2014).

Figure 3 illustrates some of the potential effects on energy supply due to climatic changes, and Table 1 shows the relationships among climate change projections and possible implications for the energy sector.

Figure 3. Potential effects on energy supply due to climatic changes. T&D – technology and development
Table 1. Relationships among climate change projections and implications for the energy sector. Additional details are provided in Annex 1 for selected subsectors

<table>
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<th>Energy subsector</th>
<th>Climate change projection</th>
<th>Potential implication</th>
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<td></td>
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<tr>
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<tr>
<td></td>
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<td>Energy demand</td>
<td>Increasing air temperatures</td>
<td>Increased electricity demand for cooling; decreased fuel oil and natural gas demand for heating</td>
</tr>
<tr>
<td></td>
<td>Increasing magnitude and frequency of extreme heat and cold events</td>
<td>Increased peak electricity demand</td>
</tr>
</tbody>
</table>

Source: DOE (2013)
1.5.1 Examples of impacts of extreme climate events experienced by the energy industry

While projected climatic changes are likely to considerably affect the energy industry, energy systems have been historically exposed to the vagaries of climate events. The following examples illustrate some of the practical consequences of severe climatic events.

The 1998 eastern Canada ice storm damaged 116 transmission lines and 3,110 support structures (including 1,000 steel pylons), as well as 350 low-voltage lines and 16,000 wooden posts. To restore service rapidly to its customers following the disaster, Hydro-Québec spent Can$ 725 million repairing the lines and support structures with the least damage and building temporary transmission and distribution equipment (Audinet et al., 2014).

Several strong hurricanes have brought widespread disruption to the oil industry, for example, Hurricanes Katrina (2005), Ike (2008) and Isaac (2012). The repair costs for Hurricane Isaac were estimated to have reached about US$ 400 million in four states in the United States of America (Arkansas, Louisiana, Mississippi and New Orleans) for Entergy alone (Audinet et al., 2014).

In 2008, south-central China faced an unprecedented ice storm, not common in this area, which caused direct economic losses of more than US$ 20 billion. The extreme event lasted several days and affected several infrastructures of the region (most populated and economically developed area of China), including the power grid, where 36,740 high-voltage transmission lines, 8,381 towers and 2,018 transformer stations were damaged (CEC, 2008).

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Coal mines in Queensland, Australia, experienced widespread disruptions in late 2010 to early 2011 because of heavy rains and floods caused by an unusually strong La Niña event. As a consequence of this event, and the projection of similar ones to come, one large mine built a new bridge and a levee designed for a 1-in-1,000-year flood event to prepare for the eventuality that these conditions become more typical (Johnston et al., 2012; Love et al., 2014).

Nuclear power stations rely on water flows for cooling. Warm and hot weather may cause cooling water to reach temperatures that are too high for the water to be effective. In addition, such higher-temperature water returned to rivers can result in damage to flora and fauna. In France in 2003, the very low river flows and increased water temperature led to reductions in power production and exceptional exemptions from legal limits on the temperature at which water may be returned to rivers (Dubus, 2010).

It is therefore evident that weather and climate is an important factor for planning and operation in traditional energy subsectors, typically coal, oil, gas, nuclear and hydro – additional examples can be found in the publications by Troccoli (2009), Schaeffer et al. (2012), DOE (2013) and Troccoli et al. (2014). This is a reflection of the current mix in energy supply. With increasing meteorological observations and monitoring (Obs/Mon), and the acquired knowledge about our ever-changing climate, the resilience of the energy system to climatic events can be enhanced (Troccoli et al., 2013).
Weather and climate information is also important for providing information for energy-efficiency measures. For example, insulating a home allows a building to use less heating and cooling energy to achieve and maintain a comfortable temperature. Also, although thermal power plants are designed to operate under diverse climatic conditions, they will be affected by the decreasing efficiency of thermal conversion as a result of rising ambient temperatures (ECF/WEC/UoC, 2014). Overall, energy efficiency – in buildings, industrial processes and transportation – is a large and low-cost energy resource that can save approximately 20% of the end-use energy consumption and which costs substantially less than new supply resources. It also helps to control global GHG emissions (Environmental Protection Agency, 2009).

The projected increase in renewable energy generation means that weather and climate information will become even more critical for the energy industry as a whole. Indeed, there is growing awareness that increased deployment of renewable energy is critical for addressing climate change, creating new economic opportunities and providing energy access to the billions of people still living without modern energy services. Renewable energy provided an estimated 19.1% of global final energy consumption in 2013, and growth in capacity and generation continued to expand in 2014. In parallel with growth in renewable energy markets, 2014 saw significant advances in the development and deployment of energy storage systems across all sectors. The year also saw the increasing electrification of transportation and heating applications, highlighting the potential for further overlap among these sectors in the future (REN21, 2016).

1.5.2 Towards a climate-resilient energy industry

Accurately assessing climate risks for the energy sector is difficult because of the uncertainty in predicting the level, impacts and timing of climate threats. Climate change uncertainties can originate from three sources (WBCSD, 2014):

- Economic and policy uncertainty. It is not clear how emissions of GHGs will be affected by demographic and socioeconomic trends, technologies and political commitments;

- Scientific uncertainty. The understanding of the functioning of the complex climate system is still developing. While the link between GHG emissions and global temperatures is clear, the impacts at regional levels and the reactions of affected systems (for example, lakes and glaciers) are more difficult to predict;

- Natural variability. Given the complexity and interlinked nature of the climate system, climate models can provide statistical information and causal relationships but not a deterministic prediction.

The International Energy Agency (IEA) has started to focus on the importance of making the energy sector resilient to climate change (IEA, 2015). The threat that climate change poses to energy systems is important to the IEA core mission of enhancing energy security. Overall, the energy sector will need to develop resilience to climate change impacts through technological solutions, proactive climate design considerations, flexible management practices, preventive emergency preparedness and response measures. To facilitate these processes and enhance their effectiveness, policy and institutional responses will be needed (IEA, 2015).

1.6 Climate service needs and priorities for the energy sector

Not only is there an increasing concern about climate impacts on the energy industry, world-leading energy organizations such as IEA are taking action to ensure energy systems become more resilient to changes in the
climate. It is evident, however, that tackling the energy sector requires: (a) climate resilience and adaptation, 
(b) energy-efficiency measures and (c) an increase in the share of renewable energy sources, which is a 
mammoth task that will require a concerted effort from a large number of organizations at various levels 
from global, to regional, to national. GFCS offers a unique opportunity to provide an overarching framework 
to help guide investments for the development of key enablers such as User Interface Platforms (UIPs), 
climate services, observations, research and capacity-building, which will ensure a robust implementation 
of resilience and adaptation measures for the energy sector. GFCS can provide a key contribution towards 
the preparedness of the energy industry to tackle possible impacts resulting from future severe climatic 
events as well as to ensure appropriate weather and climate services are developed in support of renewable 
energy generation and energy efficiency.

In order to assist with the development of climate services for the energy sector, a schematic framework 
that identifies key elements in the way the energy industry operates is provided below. While recognizing 
that the complexity of the industry does not allow for a unique and simple way to achieve this goal, a viable 
approach is to adopt a classification that reflects the various project stages of a generic energy industry 
project, namely from planning to construction, to operation and maintenance, including also the balancing 
of supply and demand. This classification is well aligned with the timescales of climate and weather 
information and its level of detail and accuracy. The energy sector stages, or areas of focus, that form the 
backbone of this Exemplar, along with their main requirements for climate information, are:

1. Identification and Resource Assessment – requires climate information (historical and projected) for 
an initial assessment of the energy resource and the required infrastructure, and for management of 
weather/climate hazards and risks;

2. Impact Assessment (including infrastructure and environment) – requires detailed and tailored weather 
and climate information (historical and projected) for codes, standards, site-specific designs and 
policies, to assist with the construction and maintenance of the energy system infrastructure (for 
example, power plants, solar collectors or coal mines), including connecting infrastructure for energy 
transmission, distribution and transfer. It also requires detailed site-specific and regional climate 
information (mainly historical) for assessment and mitigation of the impacts of energy systems on the 
surrounding environment (for example, air quality modifications), on human health (for example, air 
particles), on ecosystems (for example, solar plants or marine turbines) and wildlife, as well as potential 
contributions to GHG emission reduction;

3. Site Selection and Financing – requires highly detailed site-specific climate information (mainly historical) 
for rigorous resource assessment, risk management and financial closure;

4. Operation and Maintenance – requires highly detailed site-specific weather and climate information 
(predicted, historical and projected) for efficient running of the energy system as well as for site 
maintenance (for example, for on/offshore wind turbines or oil rigs);

5. Energy Integration – requires energy supplied by individual generators to be dispatched in a balanced/ 
integrated manner to suitably meet energy demand:

   a. Market trading (including supply and demand forecasts) and insurance – requires highly detailed weather 
   and climate information (predicted and historical) for efficient use of generated energy via optimal 
   balancing of supply and demand as well as for pricing of insurance structures used to hedge against 
   market volatility and/or risks to assets, such as wind farms, oil rigs and transmission infrastructure;
b. Energy efficiency – requires highly detailed climate information (predicted, historical and projected) for an efficient use of generated energy via measures such as optimal infrastructure siting or use of shading on hot days to offset air-conditioning energy use.

For each of these focus areas, the requirements for climate services are mapped against each of the five GFCS pillars:

1. UIPs – forums for forging the stakeholder relationships needed to define needs and respond to requirements for climate information and services in particular sectors and contexts;

2. Climate Services Information System (CSIS) – for producing and distributing climate data and information tailored for policy and decision support;

3. Obs/Mon – for generating the necessary data for the development of climate services;

4. Research, Modelling and Prediction (RMP) – for advancing the science needed for improved climate services and climate-related outcomes;

5. Capacity Development (CD) – for supporting the systematic development of the institutions, infrastructure and human resources needed for effective climate services, accounted for in each of the four above pillars.

For each focus area and each of the first four GFCS pillars, specific requirements for the energy sector have been identified as a whole (Table 2). Such requirements, summarized in a synthetic and schematic way in Table 2, form the building blocks of the climate services/products that will be developed by the Energy Exemplar. The information in the table is elaborated further by combining the general requirements with the specific services and/or activities identified in Annexes 2 and 3. A generic product/service framework, which will form the backbone of this Exemplar implementation, is presented in the next chapter.

Having presented the background and introduced the building blocks for the implementation of the Energy Exemplar, the following chapters focus on measures that could be performed, either as new initiatives or as a reinforcement of current activities, in order to provide valuable and effective climate services to the energy industry. After exploring some of the necessary conditions for successful implementation, chapter 2 describes some specific activities as well as a framework for generic projects based on the above building blocks. The way in which these suggested activities can be linked with existing activities – including those in the other GFCS priority areas – to leverage current efforts and therefore enhance the likelihood of success of this Exemplar, is discussed in chapter 3. Possible cooperation and funding mechanisms are presented in chapter 4. Chapter 5 provides a consolidation of priority activities for effective initial implementation of the Energy Exemplar. Finally, a series of annexes provides additional supporting material.
<table>
<thead>
<tr>
<th>UIP</th>
<th>CSIS</th>
<th>Obs/Mon</th>
<th>RMP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Identification and Resource Assessment</strong></td>
<td>Provide information about relevant repositories of data and products for climate services.</td>
<td>Historical datasets of relevant meteorological and climate-related data and modelled data (in situ, satellite derived and model based) and tailored datasets to specific energy subsectors (e.g. heating and cooling degree day, wind gusts, water height, rainfall, etc.).</td>
<td>Provide an appreciation of and guidance on climate variability and change. Discuss options for improvement of resource and risk estimation methods.</td>
</tr>
<tr>
<td><strong>Impact Assessment</strong></td>
<td>Identify relevant meteorological and climate phenomena for specific infrastructure and environmental impacts.</td>
<td>Identify relevant extreme events and their impacts on energy systems.</td>
<td>Update standards and guidelines for energy systems.</td>
</tr>
<tr>
<td><strong>Characterization of environment and climate impacts</strong></td>
<td>Support for national and international standards, codes, etc.</td>
<td>Climate protection estimates of resource and risk estimations.</td>
<td>Support for national and international standards, codes, etc.</td>
</tr>
<tr>
<td><strong>Historical datasets and analyses of extreme events</strong></td>
<td>Historical datasets and analyses of extreme events.</td>
<td>Historical datasets of relevant meteorological and climate-related data and modelled data (in situ, satellite derived and model based) and tailored datasets to specific energy subsectors (e.g. heating and cooling degree day, wind gusts, water height, rainfall, etc.).</td>
<td>Historical datasets and analyses of extreme events.</td>
</tr>
<tr>
<td><strong>High-grade in situ data</strong></td>
<td>High-grade in situ data.</td>
<td>High-grade in situ data.</td>
<td>High-grade in situ data.</td>
</tr>
<tr>
<td><strong>Model-based high-resolution data</strong></td>
<td>Model-based high-resolution data.</td>
<td>Model-based high-resolution data.</td>
<td>Model-based high-resolution data.</td>
</tr>
<tr>
<td><strong>Development of tailored climate change projections</strong></td>
<td>Development of tailored climate change projections.</td>
<td>Development of tailored climate change projections.</td>
<td>Development of tailored climate change projections.</td>
</tr>
<tr>
<td><strong>Integration of climate and weather information</strong></td>
<td>Integration of climate and weather information.</td>
<td>Integration of climate and weather information.</td>
<td>Integration of climate and weather information.</td>
</tr>
<tr>
<td><strong>Additional assessments of energy system impacts</strong></td>
<td>Additional assessments of energy system impacts.</td>
<td>Additional assessments of energy system impacts.</td>
<td>Additional assessments of energy system impacts.</td>
</tr>
</tbody>
</table>
| Site Selection and Financing | Provide understanding of dataset quality for resource and risk estimations  
| Provide an appreciation of, and guidance on, climate variability and change  
| Elicit suggestions for improvement of data collection and statistical assessments |
| High-quality historical datasets  
| Uncertainty estimation of the resource and system risks  
| Statistical properties, including extreme event probabilities, of resources and risks  
| Guidance on climate change trends and projections for future energy yield and risks |
| Very high-grade in situ data, both in terms of quality of instrumentation and temporal resolution  
| Detailed site-specific modelling (e.g. wind gust estimation, extreme low and high streamflows) |
| Enhanced ways to extend short-term in situ data to encompass interannual variability of resource and its system risks  
| Enhanced modelling of flow and orographic-dependent features  
| Enhanced quantification of weather and climate extremes  
| Enhanced statistical estimation of probability distribution functions of relevant variables  
| Approaches to bridge near-term forecasting to decadal projections |

| Operation and Maintenance | Interpretation and accuracy of site-specific forecasts  
| Issuance of relevant early warnings at various lead times, with appropriate commentary and personal briefings  
| Relative attributes of statistically and physically based forecasts and seasonal predictions  
| Elicit expert technical knowledge  
| Support targeted training |
| Site-specific short-range to seasonal forecasts  
| Early warning systems based on statistical and physical modelling and at various lead times  
| Analysis and forecasts of probabilities of extreme events from short-range to seasonal timescales  
| Providing climate data and information for planning operation and maintenance under future climate trends |
| Site-specific ground station data  
| Infrastructure-specific meteorological data  
| Database and analyses of historical meteorologically driven problem (forensic) events for operation and maintenance |
| Forecasting tools to improve site-specific and sector-specific information  
| Characterization of extreme events, return periods, probabilities of occurrence and exceedance thresholds  
| Linkages among short-term, seasonal and longer-term climate needs for operation and maintenance (e.g. planning for variability, ranges or trends)  
| Improved communication methodologies to effectively convey warnings at various lead times |

| Energy Integration (market trading and insurance; energy efficiency) | Interpretation of trends in demand and relevant meteorological/climate variables  
| Seek energy market operator opinions on role of meteorology and climate in demand modelling  
| Collect experiences in demand modelling and compile databases and analyses (e.g. forensic analyses)  
| Analysis of correlation between climatic indices and conventional power plant efficiency and safety  
| Increased interactions among energy traders/insurers and meteorologists/climatologists for the exchange of practices towards the development of improved tools (this is an area where meteorologists can learn a lot as industry uses advanced tools; at the same time, commercial sensitivities make the exchange less straightforward)  
| Predictions of energy demand with meteorology/climate as driver/predictor at various timescales from minutes to years to decades |
| Historical data of demand-related meteorological/climate variables  
| Analysis and forecasts of probabilities of extreme events from short range to sub-seasonal to decadal range (e.g. plan energy infrastructure to meet future trends in demand)  
| Short-term to seasonal-scale meteorological forecasts of sites and/or regions, including synoptic assessments  
| Assessment of historical performance of short-term to seasonal forecasts  
| Probabilistic post-processing of forecasts  
| Climate trends and projections for the future |
| Historical datasets of meteorological/climate variables relevant for demand, insurance and energy efficiency  
| Historical datasets of energy demand  
| Model-based data to extend observation records  
| Ancillary datasets such as shading, orientations of buildings and energy system responses to weather variables  
| Historical energy trade data  
| Site-specific ground station data for triggering of weather index insurance policies  
| Data policy for consistent use of observations for insurance payouts  
| Modelling of interaction among meteorological/climate variables and energy demand  
| Forecasting tools to improve meteorologically driven demand (including trends and projections longer into the future)  
| Investigation of relationships among meteorological variables and energy efficiency of buildings or other energy systems (includes longer-term seasonal and decadal trends)  
| Improvement of skill of short-term to, especially, seasonal forecasts targeted at regions where energy systems operate  
| Tools to improve use of probabilistic information  
| Approaches to bridge timescales for decisions from weather forecasts to seasonal predictions to climate change trends and projections  
| Guidance on interpretation of climate change projections and their limitations and uncertainties |

**Capacity Development**

CSIS – Climate Services Information System; Obs/Mon – Observation and Monitoring; RMP – Research Modelling and Prediction; UIP – User Interface Platform
2. Implementation

The Energy Exemplar is the primary mechanism for the energy sector to contribute to and benefit from GFCS. This Exemplar is the translation of GFCS to the energy sector, and guides how the energy community can implement the framework. The Exemplar workplan outlines specific activities that link energy sector priorities to the overall framework. Implementation of the Exemplar can identify and accelerate beneficial interactions among the climate and energy communities at global, regional and national levels.

The Exemplar is informed by the issues and requirements identified in the previous chapter. Their variety points to an overarching need to compile, assess and learn from past and current projects and path-finding collaborations, which can indicate good practices, gaps and opportunities for ongoing work under GFCS. This Exemplar serves as a structure to facilitate the stocktaking, help standardize and institutionalize good practices, and bring partners together to innovatively respond to energy user needs. It aims to facilitate and structure the process towards eventually mainstreaming climate services for the energy industry.

2.1 Conditions for successful implementation

For this Exemplar to be successful, there must be full engagement and buy-in of the energy industry, including energy companies, power suppliers, transmission and distribution operators, finance and insurance providers, and energy market operators. Depending on the situation, such entities can operate at local, national, regional or, sometimes, global levels. The following three conditions (or principles) are critical for encouraging this ownership and facilitating joint implementation of climate services for energy:

1. Take stock – GFCS will take stock of relevant current activities in the area of meteorology/climate and energy, in order to have a detailed overview of the state of the art. Energy companies have been using weather and climate information for decades, as in the case of the metocean information used by the oil and gas subsector or, more recently, with the wind and solar resource assessment. It is critical therefore that an initial effort be devoted to a thorough and systematic analysis of available products and services. Such an analysis needs to be carried out in close consultation with the energy industry, so as to ensure accuracy of information and, at the same time, to become acquainted with industry players and their standard terminology. Thus, a major role of the Energy Exemplar will be to facilitate stocktaking of relevant current climate-dependent energy sector activities;

2. Harmonize activities – GFCS will assist in the coordination of available activities whenever there is a perceived benefit for doing so by a range of stakeholders. GFCS is not meant to replace current activities, but to provide a harmonization platform, with the aim of allowing stakeholders to increase
their awareness of available data, tools and policies. Thus, it is critical that the stakeholders of the Exemplar be informed of activities of potential interest – harmonization of activities may therefore be achieved by providing platforms for knowledge-sharing, such as web portals or workshops;

3. Provide multiple benefits – GFCS will provide a platform for collaboration among energy sector stakeholders with a need for improved climate services. GFCS will facilitate the implementation of new complementary projects and may be able to assist with resource mobilization. Such complementary projects will be aimed at facilitating harmonization of activities (mentioned above) and at identifying gaps, with reference to the building blocks in Table 2 and Annex 2, and with guidance provided by the outlines of specific projects discussed in section 2.3 below.

It is important to emphasize that, for these principles to be effectively applied and, therefore, for the Energy Exemplar to be successfully implemented, strong leadership is required. Such leadership currently provided by the World Meteorological Organization (WMO) will have to be complemented by a counterpart organization representing the energy industry, in a similar way to that done, for instance, with the WMO/World Health Organization (WHO) partnership for the Health Exemplar. Possible organizations that would be appropriate for such collaborative leadership include: UN-Energy, the World Energy Council (WEC), IEA and the International Renewable Energy Agency (IRENA) (see Annex 4 for their descriptions).

2.2 Identification of projects

Categories of activities for implementing the Exemplar fall into four classes:

Priority Categories of Activities: the five focus areas are presented in section 2.3 as generic descriptions of objectives, outputs, specific activities, inputs and partnerships. These descriptions illustrate how GFCS can best add value to existing areas of work in the energy sector. These are not implementable projects, but rather are intended to define, for the wider GFCS community, some of the key products and services for the energy sector, and to explain how they are generated.

1. Individual Projects: partners can use the priority categories from class (1) above as templates or framing criteria when preparing actual projects for implementation in specific contexts. Funding mobilized for GFCS implementation could potentially be directed towards these projects, through a process yet to be determined. Alternatively, partners may find the generic descriptions below to be useful guidance for preparing projects that embody the GFCS pillars, for funding by third parties. Specific examples of individual projects are provided in Annex 3.

2. GFCS Energy CD and Support Activities: in the initial stages of the Energy Exemplar, in furtherance of the general areas of work described, it is recommended that a set of start-up CD and support activities that would facilitate coordination be identified and designed. Initial proposals for activities in this category are contained in the Priority Needs for the Operationalization of the Global Framework for Climate Services (2016–2018) (WMO, 2017). These proposals are intended to catalyse the contributions of the GFCS pillars to the categories of activities related to the energy industry that are identified in Table 2 and below.

3. Ongoing Activities: as indicated in Annex 2, there is a large body of ongoing activities at country, regional and global levels. These activities provide entry points for GFCS products and services, as well as, potentially, resources for advancing the GFCS agenda of climate-resilient societies.
All individual Exemplar projects should support national sustainable development goals. They should also build on other government or intergovernmental efforts such as SE4ALL.

The GFCS High-Level Taskforce report (WMO, 2011) identified the following time frames for project implementation: two year (2014/2015), six year (2014–2019) and 10 year (2014–2023) time frames. Most of the first three years has been used to set up the governance structure of GFCS and coordination mechanisms, but the Exemplar will benefit from this GFCS-wide initial work. A critical step for this Exemplar will be the establishment of a specific coordination mechanism. The coordination function could be one of the initial activities to be carried out. Projects in the six-year and 10-year time frames will take advantage of the implementation lessons learned in the first two years, but may or may not be continuations or scale-up of the first-term projects.

2.3 Suggested priority categories of activities

For each of the five focus areas (or categories) identified in Table 2, this section outlines generic activities or services that are suggested priorities for GFCS in the area of energy. Priority categories of activities are provided as project outlines. The rationale behind these project outlines is that GFCS provides a framework, rather than being prescriptive about specific products/services. Activities in these categories would catalyse provision of GFCS-related products and services, and promote widespread implementation of programmes and initiatives that incorporate climate information and services.

Central to the implementation of this Exemplar are also capacity-building and support activities such as:

- The provision of coordination, planning and technical advisory services at the country level;
- The organization of:
  - Regular workshops, repeated in different regions of the world;
  - Targeted summer schools on specific topics;
  - Regular webinars;
  - A regular international conference (for example, by linking with the International Conference Energy & Meteorology (ICEM) series);
- The setting up of a website and other social media tools (for example, Twitter or LinkedIn groups) where regular updates are posted.

Section 1.6 and Table 2 have already identified the five focus areas and some of the activities that this Exemplar can enhance, and contribute to, through its operations and the five constituent pillars, as:

1. Identification and Resource Assessment;
2. Impact Assessment (including infrastructure and environment);
3. Site Selection and Financing;
4. Operation and Maintenance;
5. Energy Integration:
   a. Market trading (including supply and demand forecasts) and insurance;
   b. Energy efficiency.

Through a process of generalization of specific product/services similar to those elaborated in Annex 3 and using the building blocks in Table 2, generic project outlines are derived here. The view is taken that while the specific product/services in Annex 3 are useful references for developing new projects, they
may be either too subsector and/or geography specific or have a limited shelf life. Thus, the generic and flexible project outlines presented below should allow for a higher degree of versatility. The aim is that such project outlines will facilitate the development of specific projects, while also increasing the outline shelf lives.

In the following, the activities or services are described following standard project planning descriptors such as objective, benefit and output. The descriptions illustrate how GFCS can add value to existing areas of work in the energy industry. These are not implementable projects, but rather are intended to define, for the wider GFCS community, some of the key products and services for energy, and to explain how they are generated. It is important to note that applicability of activities in each focus area should be relevant for any subsector across the energy industry, whether for renewable or traditional energy generation.

The generic templates for development of climate services to address various areas of potential need within the energy sector provided below and in Annex 3 are intended as a basis for co-production of the necessary services through collaboration among climate and energy stakeholders. Specific objectives (outputs, activities, inputs and partnerships) that would improve climate-related energy outcomes in specific contexts for specific stakeholders can be elaborated from the generic descriptions provided. These can be converted into project proposals or business plans for public–private partnerships as appropriate.

Specific projects in the categories described in Table 3, and which could be undertaken in conjunction with partners in GFCS during its implementation to demonstrate discrete climate service results, are presented in Annexes 2 and 3. An inclusive, comprehensive process that ensures that the projects are part of a system-wide international effort is recommended so as to identify GFCS activities for the six-year and 10-year time frames. Particular focus should be devoted to improving services for developing countries, for which the value added would be the greatest.

The product/services in Annex 3 were identified by a number of experts who participated in the Private Sector Partnership Forum Climate Services and Decision Support Tools for the Energy Sector. Although attempts were made to make them as generic as possible, they are framed around specific issues/contexts.
**Table 3.** Description of specific projects to be implemented with partners according to the focus areas of the energy sector

<table>
<thead>
<tr>
<th>Focus area 1</th>
<th>Identification and Resource Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td>Activities in this category aim to collect, share and assess information regarding possible siting of new energy sources. For this stage, information does not need to be highly resolved or accurate, but it has to be sufficiently detailed to encourage investments for the next phases of Impact Assessment and Site Selection and Financing. Information required covers not only climate, but also all the electrical, economic, social, geological and planning aspects necessary for proper site identification and initial resource assessment.</td>
</tr>
<tr>
<td><strong>Objective</strong></td>
<td>To provide energy site developers with data and tools to assist with initial estimates of potentially viable energy production sites</td>
</tr>
<tr>
<td><strong>Benefits</strong></td>
<td>Project cost reduction</td>
</tr>
<tr>
<td></td>
<td>Duration of project planning phase reduced</td>
</tr>
<tr>
<td></td>
<td>Potential wider competition for the development of energy projects with consequent possible reduction in final energy costs</td>
</tr>
<tr>
<td></td>
<td>Comprehensive knowledge of available sources of information</td>
</tr>
<tr>
<td></td>
<td>Potential efficiency in sharing data through agreed standard formats</td>
</tr>
<tr>
<td></td>
<td>Potential establishment of new collaborations/partnerships</td>
</tr>
<tr>
<td><strong>Outputs</strong></td>
<td>Historical datasets of relevant meteorological data (in situ, satellite derived and model based) and related metadata</td>
</tr>
<tr>
<td></td>
<td>Tailored datasets to specific energy subsectors (e.g. heating and cooling degree days, wind gusts, water temperature and river flows)</td>
</tr>
<tr>
<td></td>
<td>Climate projections of relevant data along with uncertainty estimates of resource and risk estimations</td>
</tr>
<tr>
<td></td>
<td>Development of tailored climate values for energy systems codes, standards, best practices and guidelines</td>
</tr>
<tr>
<td><strong>Activities</strong></td>
<td>Collect information about appropriate repository of data for resource and climate risk estimation</td>
</tr>
<tr>
<td></td>
<td>Provide understanding of quality of datasets for resource and climate risk estimation</td>
</tr>
<tr>
<td></td>
<td>Provide support for the proper installation, running and maintenance of meteorological instrumentation</td>
</tr>
<tr>
<td></td>
<td>Provide estimation of resource and climate uncertainty</td>
</tr>
<tr>
<td></td>
<td>Provide an appreciation of and guidance on climate variability and change</td>
</tr>
<tr>
<td></td>
<td>Discuss options for improvement of resource and climate risk assessment</td>
</tr>
<tr>
<td></td>
<td>Improve observation instrumentation</td>
</tr>
<tr>
<td></td>
<td>Improve satellite retrieval and conversion algorithms</td>
</tr>
<tr>
<td></td>
<td>Study sensitivity of resources to atmospheric constituents (e.g. aerosols)</td>
</tr>
<tr>
<td></td>
<td>Characterize uncertainty of different data sources</td>
</tr>
<tr>
<td></td>
<td>Develop methods to combine various data sources</td>
</tr>
<tr>
<td></td>
<td>Develop approaches:</td>
</tr>
<tr>
<td></td>
<td>• To bridge timescales and predictions from weather forecasts to seasonal predictions to climate change projections</td>
</tr>
<tr>
<td></td>
<td>• To localize or down-scale climate change projections for specific decisions</td>
</tr>
<tr>
<td></td>
<td>• To assess and combine uncertainty information in individual data sources</td>
</tr>
<tr>
<td><strong>Inputs</strong></td>
<td>In situ, and satellite-derived meteorological data for assessment of resources and risks</td>
</tr>
<tr>
<td></td>
<td>Model-based high-resolution historical meteorological data</td>
</tr>
<tr>
<td></td>
<td>Climate change projections</td>
</tr>
<tr>
<td></td>
<td>Data policy; guidance and possible formulation of updated guidelines</td>
</tr>
<tr>
<td></td>
<td>Ancillary datasets such as electric grid, distance to coast, elevations, populated centres, geomorphology, social acceptance surveys, etc.</td>
</tr>
<tr>
<td><strong>Partners</strong></td>
<td>Energy companies</td>
</tr>
<tr>
<td></td>
<td>Energy development and investment companies</td>
</tr>
<tr>
<td></td>
<td>Consultancy services companies</td>
</tr>
<tr>
<td></td>
<td>National and regional government institutions</td>
</tr>
<tr>
<td></td>
<td>National Meteorological and Hydrological Services</td>
</tr>
<tr>
<td></td>
<td>Climate and energy research communities</td>
</tr>
<tr>
<td></td>
<td>Energy commissions and regulators</td>
</tr>
<tr>
<td></td>
<td>Citizens</td>
</tr>
<tr>
<td>Focus area 2</td>
<td><strong>Impact Assessment (including infrastructure and environment)</strong></td>
</tr>
<tr>
<td>-------------</td>
<td>-------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Description</strong></td>
<td>Activities in this category aim to collect, share and assess detailed information regarding potential impacts on the infrastructure of possible sites of new energy sources as well as on the local environment. Resolution, temporal extent and accuracy of these data need to be sufficiently high to allow estimation of key statistics such as return periods, probabilities of occurrence and exceedance thresholds of relevant extreme events. Impact Assessment also includes effects of new energy infrastructure on the regional and global environment, and may involve evaluations such as changes in the atmospheric circulation or greenhouse gas emissions.</td>
</tr>
</tbody>
</table>
| **Objectives** | To provide energy site developers with data and tools to assist with accurate information to identify and estimate relevant meteorological impacts on infrastructure of new energy extraction and/or production sites  
To provide policymakers, planning officers, citizens and other stakeholders with accurate information about impacts of new energy site on the environment |
| **Benefits** | Project cost reduction  
Duration of project planning phase reduced  
Impacts on infrastructure and environment minimized  
Better use of raw materials, due to improved estimation of infrastructure impacts  
Potential wider competition for the development of energy projects with consequent possible reduction in final energy costs  
Robust decision-making by planning offices  
Potential efficiency in sharing data through agreed standard formats  
Better and more informed engagement with the public due to improved knowledge on environmental impacts |
| **Outputs** | Return periods, probabilities of occurrence and exceedance thresholds of relevant extreme events  
Support for national and international codes, standards, etc.  
Climate change guidance for long-term decisions and assets  
Relevant data for decision support based on established relationships among energy systems and air quality, gas emissions, wildlife and other environmental factors  
Prediction of air quality and gas dispersion in the neighbourhood of relevant energy systems  
Integration of climate and weather information for near net zero energy communities and energy systems, greenhouse gas emission reductions and support of sustainable energy use |
| **Activities** | Identify relevant meteorological and climate phenomena for specific infrastructure (e.g. effects of hail, snow and wind loads on photovoltaic panels or effects of extreme rainfall and drought on hydroelectric systems)  
Identify relevant climate-related environmental impacts (e.g. effects of air quality on human health or effects of wind turbines on wildlife)  
Provide statistics on the impacts of weather and climate on energy systems and discuss assumptions  
Provide statistics on the impacts of energy systems on the environment and discuss assumptions  
Discuss climate support for national and international standards, codes and guidelines  
Update standards, codes, etc., taking into account tailored, up-to-date climate information  
Enter engaged with civil societies by providing assessments of scientifically proven energy system impacts  
Elicit stakeholder input on suggested additional assessments of energy system impacts  
Characterize extreme events and probabilities, return periods, probabilities of occurrence and exceedance thresholds  
Investigate specific physical phenomena (e.g. ice accretion or ice plus wind loading on transmission lines)  
Down-scale climate change projections  
Investigate linkages among seasonal predictions and climate change projections  
Develop new parameterizations for high-resolution numerical models in order to integrate energy features (e.g. wind turbines or albedo of solar plants)  
Research climate-related environmental impacts associated with specific energy installations and technologies (e.g. particulate and gas emissions and their relationships to meteorological conditions)  
Enter investigate links among efficient energy systems, greenhouse gas mitigation strategies and climate change impacts  
Identify “win–win” energy systems supporting greenhouse gas mitigation, climate adaptation, development and poverty alleviation  
Develop new modelling experiments for geoengineering evaluations (e.g. biochar, albedo and solar plants) |
### Inputs

<table>
<thead>
<tr>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-grade in situ data</td>
<td>Detailed site-specific modelling</td>
</tr>
<tr>
<td>Detailed site-specific modelling</td>
<td>Historical dataset and analyses of extreme events</td>
</tr>
<tr>
<td>Historical dataset and analyses of extreme events</td>
<td>Projections of potential relevant meteorological/climate trends and changes</td>
</tr>
<tr>
<td>Observations and monitoring of relevant climate-related variables for identification and mitigation of environmental impacts (e.g. on human health, safety and wildlife)</td>
<td>Air quality and gas emission database (e.g. carbon-based gases from shale gas extractions)</td>
</tr>
<tr>
<td>Database on impacts of above effects on health and other externalities (e.g. water quality)</td>
<td>Database on weather/climate risks to hydroelectric facilities, solar panel risks to buildings, energy transport risks to communities, etc.</td>
</tr>
</tbody>
</table>

### Partners

<table>
<thead>
<tr>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy companies</td>
<td>Energy development and investment companies</td>
</tr>
<tr>
<td>Industry or specific energy-technology associations</td>
<td>Development banks</td>
</tr>
<tr>
<td>Consultancy services companies</td>
<td>National and regional government institutions</td>
</tr>
<tr>
<td>National Meteorological and Hydrological Services</td>
<td>Climate and energy research communities</td>
</tr>
<tr>
<td>Energy commissions and regulators</td>
<td>Citizens</td>
</tr>
</tbody>
</table>

### Focus area 3: Site Selection and Financing

<table>
<thead>
<tr>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activities in this category aim to collect and assess information regarding power yield, and related financing, for possible new energy extraction and/or production sites. For this stage, information needs to be as highly resolved and accurate as possible in order to reduce uncertainty in the long-term viability (e.g. financial investment) of new sites. Information required covers not only climate, but also all the electrical, economic, social, geological and planning aspects necessary for a proper site selection and an accurate resource assessment. Also required is site-specific climatic design information that meets the requirements of (inter)national codes and standards.</td>
<td>Activities in this category aim to collect and assess information regarding power yield, and related financing, for possible new energy extraction and/or production sites. For this stage, information needs to be as highly resolved and accurate as possible in order to reduce uncertainty in the long-term viability (e.g. financial investment) of new sites. Information required covers not only climate, but also all the electrical, economic, social, geological and planning aspects necessary for a proper site selection and an accurate resource assessment. Also required is site-specific climatic design information that meets the requirements of (inter)national codes and standards.</td>
</tr>
</tbody>
</table>

### Objective

**To provide energy site developers and investment institutions with data and tools to assist with highly accurate estimates of energy yield at production sites**

### Benefits

- Improved energy yield estimation
- Project cost reduction with consequent reduction in final energy costs
- Duration of project planning phase reduced
- Efficient use of energy resources
- Increase in investment in meteorological observations and subject experts, with potential strengthening of National Meteorological and Hydrological Services, particularly in developing countries
- Potential improvement in meteorological observations, modelling capabilities and scientific understanding of meteorological phenomena relevant for energy extraction and/or production

### Outputs

- High-quality historical datasets
- Uncertainty estimation of the resource and system risks
- Statistical properties, including extreme event probabilities, of resources and risks
- Guidance on climate change trends and projections for future energy yield and risks

### Activities

- Provide understanding of quality of datasets for resource and risk estimations
- Provide an appreciation of, and guidance on, climate variability and change
- Elicit suggestions for improvement of data collection and statistical assessments
- Improve:
  - Ways to extend short-term in situ data to encompass interannual variability of resources and system risks
  - Modelling of flow and orographic-dependent features
  - Quantification of weather and climate extremes
  - Statistical estimation of probability distribution functions of relevant variables
- Develop approaches to bridge near-term forecasting to decadal projections

### Inputs

<table>
<thead>
<tr>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high-grade in situ data, both in terms of quality of instrumentation and temporal resolution</td>
<td>Detailed site-specific modelling (e.g. wind gust estimation, extreme low and high streamflows)</td>
</tr>
<tr>
<td>Partners</td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Energy companies</td>
<td></td>
</tr>
<tr>
<td>Energy development and investment companies</td>
<td></td>
</tr>
<tr>
<td>Energy planning authorities</td>
<td></td>
</tr>
<tr>
<td>Energy commissions and regulators</td>
<td></td>
</tr>
<tr>
<td>Consultancy services companies</td>
<td></td>
</tr>
<tr>
<td>National Meteorological and Hydrological Services</td>
<td></td>
</tr>
<tr>
<td>Meteorological instrumentation manufacturers</td>
<td></td>
</tr>
<tr>
<td>Climate and energy research communities</td>
<td></td>
</tr>
<tr>
<td>Citizens</td>
<td></td>
</tr>
</tbody>
</table>

**Focus area 4: Operation and Maintenance**

| Description                                                                 |
|-----------------------------|-----------------------------------------------------------------|
| Activities in this category aim to improve energy production performance by monitoring and reducing stress on energy infrastructure, so as to extend asset lifetime, and to optimally schedule maintenance and downtime sessions. Meteorological information, including local observations and forecasts, needs to be as detailed and accurate as possible. Information required covers not only climate, but also quantities such as electrical load and price. |

| Objectives                                                                 |
|-----------------------------|--------------------------------------------------------------------------------|
| To provide energy site operators with accurate information in order to ensure infrastructures operate within the specified ranges, thus limiting undesirable and avoidable stresses on infrastructures, and therefore optimizing asset lifetime |
| To provide energy site operators with advance warning of severe events at different lead times in order for them to effectively plan maintenance sessions |

| Benefits                                                                 |
|-----------------------------|--------------------------------------------------------------------------------|
| Improved performance/yield of energy production                      |
| Better protection of infrastructures/assets                            |
| Improved asset protection with consequent optimization of asset lifetime |
| Improved scheduling of maintenance sessions with consequent more-efficient use of alternate energy sources and possible reduction in final energy costs |
| Lower insurance risk                                                  |
| Increase in investment in meteorological observations and subject experts, with potential strengthening of National Meteorological and Hydrological Services particularly in developing countries |
| Improve forecasting methodology                                       |
| Improve the production, identification and delivery of warnings of severe events |

| Outputs                                                                 |
|-----------------------------|--------------------------------------------------------------------------------|
| Site-specific short-range to seasonal forecasts                        |
| Early warning systems based on statistical and physical modelling and at various lead times |
| Analysis and forecasts of extreme events from short-range to seasonal timescales |
| Planning for operation and maintenance under future climate trends and projections |

| Activities                                                                 |
|-----------------------------|--------------------------------------------------------------------------------|
| Interpret and assess the accuracy of site-specific forecasts                |
| Issue relevant early warnings at various lead times, with appropriate commentary and personal briefings |
| Assess the relative attributes of statistically and physically based forecasts and seasonal predictions |
| Elicit expert technical knowledge                                           |
| Provide targeted training                                                   |
| Develop forecasting tools to improve site-specific and sector-specific information |
| Characterize extreme events, return periods, probabilities of occurrence and exceedance thresholds |
| Investigate linkages among short-term, seasonal and longer-term climate needs for operation and maintenance (e.g. planning for variability, ranges or trends) |
| Develop improved communication methodologies to effectively convey warnings at various lead times |

| Inputs                                                                    |
|-----------------------------|--------------------------------------------------------------------------------|
| Site-specific ground station data                                       |
| Infrastructure-specific meteorological data                             |
| Databases and analyses of historical meteorologically driven problem (forensic) events for operation and maintenance |
| Forecasts at various lead times                                         |
| Communication methodologies for warning systems                         |
### Focus area 5: Energy Integration

**Description**
Activities in this category aim to ensure energy demand is continually met by supply from a number of energy sources, via market or mandated mechanisms, in order to provide citizens with the most-efficient, sustainable and least-cost energy. Meteorological information, including local observations and forecasts, needs to be as detailed and accurate as possible and used to predict both energy production and demand, as well as energy efficiency and insurance pricing. Information required also covers energy demand data, itself climate dependent, which is clearly critical in optimizing energy integration as well as other aspects such as grid connectors, maintenance schedules and financial/insurance tools.

**Objectives**
- To provide energy market operators with accurate weather and climate information in order to ensure the most-efficient, sustainable and least-cost energy to meet demand is generated
- To provide (re-)insurance providers with accurate weather and climate information in order to competitively price insurance premiums and to provide appropriate target measurements for payouts
- To provide local energy companies, businesses and citizens with accurate weather and climate information in order to apply appropriate energy-efficiency measures

**Benefits**
- Improved energy demand forecast
- Improved energy supply provision
- Efficient, balanced and sustainable use of energy resources
- Reduced final energy costs
- Reduced insurance risk and related premiums
- Improved forecasting methodologies and forecast communication
- Improved production, identification and delivery of warnings of severe events
- Greater involvement in energy-efficiency decisions by businesses and citizens

**Outputs**
- Historical data of demand-related meteorological/climate variables
- Predictions of energy demand with meteorology/climate as a driver/predictor at various timescales from minutes to years to decades
- Analysis and forecasts of probabilities of extreme events from short range to sub-seasonal to decadal range (e.g. plan energy infrastructure to meet future trends in demand)
- Short-term to seasonal-scale meteorological forecasts of sites and/or regions, including synoptic assessments
- Assessment of historical performance of short-term to seasonal forecasts
- Probabilistic post-processing of forecasts
- Climate trends and projections for the future

**Activities**
- Interpret trends in demand and relevant meteorological/climate variables
- Seek energy market operator opinion on role of meteorology and climate in demand modelling
- Collect experiences in demand modelling and compile databases and analyses (e.g. forensic analyses)
- Analyse correlation among climatic indices and conventional power plant efficiency and safety
- Increase interactions among energy traders/insurers and meteorologists/climatologists for the exchange of practices towards the development of improved tools
- Model interactions among meteorological/climate variables and energy demand
- Develop forecasting tools to improve meteorologically driven demand (including trends and projections for the longer-term future)
- Investigate relationships among meteorological variables and energy efficiency of buildings or other energy systems (including longer-term seasonal and decadal trends)
- Improve the skill of short-term to, especially, seasonal forecasts targeted at regions where energy systems operate
- Develop tools to improve use of probabilistic information
- Investigate approaches to bridge timescales for decisions from weather forecasts to seasonal predictions to climate change trends and projections
- Provide guidance on interpretation of climate change projections and their limitations and uncertainties
2.4 Initial implementation activities and approach

To implement the GFCS Exemplar on energy, the first steps will be to identify relevant stakeholders and ways to integrate the described activities, organizationally and operationally, into existing programmes and initiatives. Activities will be demand driven, with demand assessed by proxy through the existing processes of partners and with the assistance of the GFCS office. Therefore, implementation of the activities described in this Exemplar will require discussion with potential partners to further define the scope of activities, identify roles and responsibilities, garner the support of energy companies and funding agencies, mobilize and allocate resources, agree on monitoring and evaluation methods, and undertake initial administrative procedures.

Throughout the development of this Exemplar, consultation with participants underlined the need to engage the final stakeholders of climate information – particularly energy companies but also private providers of climate information – to ensure that it is relevant and used. It is also important to engage with national, regional and global activities such as the Global Earth Observation System of Systems (GEOSS), the United States Department of Energy (DOE) Partnership for Energy Sector Climate Resilience, the climate services developed under the European Union (EU) Copernicus programme and the European Earth Observation Programme, which also has a specific focus on energy.6

Critical to success of the Energy Exemplar is the establishment of a coordinating entity tasked to provide strong leadership and coordination throughout the implementation of the Exemplar, by ensuring effective engagement with energy stakeholders and GFCS. Additional key ingredients for successful implementation are the development of formal partnerships and collaboration with agencies and organizations working on energy, such as UN-Energy, IRENA, IEA, WEC, as well as organizations working at the intersection between

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energy and climate such as the World Energy & Meteorology Council (WEMC). Overall, the underlying approach must be one that adopts weather and climate information with the sole purpose of genuinely addressing key and relevant energy industry challenges.

This Exemplar will be implemented following analogous phases to the initial four GFCS priority areas (agriculture and food security, water, health and disaster risk reduction) – phase I (2015–2017), phase II (2017–2019) and phase III (2019–2023). As the other four Exemplars started operating in 2013, initial activities in this current Exemplar will have to be accelerated; however, these activities will also benefit from the work done by the initial four priority areas. Table 4 describes the actions proposed for the three phases of the Energy Exemplar. Phase 1 may be largely centralized with the GFCS UIP and the representative bodies involved, whereas regional and national implementation activities will be concentrated on within phases II and III.

| Table 4. Key actions for each phase of the implementation of the Energy Exemplar |
|---------------------------------|---------------------------------|---------------------------------|
| Establish institutional mechanisms/secretariat in close cooperation with counterpart energy organization(s) | Maintain and improve engagement in institutional mechanisms | Maintain and sustain institutional mechanisms |
| Establish workplans | Develop refined technical guidance, tools and training curricula | Provide technical and operational support for continuation of existing projects |
| Establish a website and communication strategy | Identify new projects and processes | Establish widespread use of technical guidance and training curricula |
| Develop initial technical guidance | Expand and continue existing projects | Review performance and lessons learned |
| Harmonize existing projects involving climate and energy | | Ensure sustainability and mainstreaming of climate services for energy |
| Build awareness and partnerships within the energy sector | | |

2.5 Monitoring and evaluation of implementation activities

Monitoring and evaluation of GFCS activities will be required on at least two levels: to assess activity progress, and to measure achievement in meeting the larger goals of GFCS for improved climate knowledge and communication. For both levels, standard project management tools and reporting procedures can be used, through agreement among relevant partners. The mechanism for the final evaluation of activities will also be identified by agreement among the activity partners, to ensure that the reporting requirements of each partner organization are met.

The definition of criteria for monitoring and evaluation would be specific to each project. A method for quantifying the financial costs and benefits of implementing GFCS activities for energy should be developed and included in the monitoring and evaluation processes. This information would be an important contribution to global efforts to attach value to activities that the weather and climate communities develop in partnership with energy sector companies, and it could help make the case for further investment to strengthen the link between energy and climate.

Furthermore, given the importance of information, knowledge-sharing and training to the success of GFCS, a monitoring and evaluation process is also required to assess whether GFCS activities implemented under this Exemplar serve the purpose of improving outcomes for the energy sector. This could include,
for example, efficient and sustainable risk management practices through the adoption of improved weather and climate information. Part of the evaluation process should include the development of a set of indicators to determine whether the activities are achieving their objectives. Did the activities enable stakeholder needs to be understood to better deliver climate services? Did they promote dialogue among climate service providers and energy stakeholders? Did they contribute to monitoring and evaluating the effectiveness of GFCS?

In the framework of a public–private partnership, the indicators will take the form of economic benefits: return on investments, savings, risk mitigation, reduction of maintenance time, etc. Key performance indicators, for example, can be identified for assessing improvements of the energy sector’s resilience to climate and weather extreme events in several activities spanning the generation, distribution and trading of energy. Table 5 shows the possible climate/weather impacts and performance indicators.
Table 5. Climate/weather impacts on energy subsectors and performance indicators

<table>
<thead>
<tr>
<th>Activity</th>
<th>Climate/weather impacts</th>
<th>Indicators of improvements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydropower</td>
<td>Number of accidents related to extreme weather events</td>
<td>Power produced (MW)/water availability</td>
</tr>
<tr>
<td></td>
<td>Power produced versus installed capacity (MW)</td>
<td>Expected installed capacity expansion according to the expected water availability (MW)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of delay days in the maintenance schedule</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amount invested for risk-hedging activities (monetary unit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Economic losses in infrastructure (monetary unit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Economic losses in operations (monetary unit)</td>
</tr>
<tr>
<td>Transmission</td>
<td>Quality of electricity supply (frequency of blackouts/brownouts)</td>
<td>Number of delay days in the maintenance schedule</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amount invested for risk-hedging activities (monetary unit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Economic losses in infrastructure (monetary unit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Economic losses in operations (monetary unit)</td>
</tr>
<tr>
<td>Wind power</td>
<td>Power produced versus installed capacity (MW)</td>
<td>Number of delay days in the maintenance schedule</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amount invested for risk-hedging activities (monetary unit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Economic losses in infrastructure (monetary unit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Economic losses in operations (monetary unit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Expected installed capacity (MW)</td>
</tr>
<tr>
<td>Thermal power</td>
<td>Number of oil and gas installations affected by extreme weather events (onshore and offshore)</td>
<td>Water consumed for cooling procedures in thermal power plants (m³)</td>
</tr>
<tr>
<td></td>
<td>Number of accidents in maritime fuel transportation related to extreme weather events</td>
<td>Number of delay days in the maritime fuel transportation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of delay days in the maintenance schedule</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amount invested for risk-hedging activities (monetary unit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Economic losses in infrastructure (monetary unit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Economic losses in operations (monetary unit)</td>
</tr>
<tr>
<td>Market</td>
<td>Energy price maximum (monetary unit)</td>
<td>Energy consumer satisfaction</td>
</tr>
<tr>
<td></td>
<td>Energy price minimum (monetary unit)</td>
<td>Customer bills</td>
</tr>
<tr>
<td></td>
<td>Liquidity of the market (number of participants)</td>
<td></td>
</tr>
<tr>
<td>Policy/decision-makers</td>
<td>Diversity of electricity generation mix in a country</td>
<td>Energy security</td>
</tr>
<tr>
<td></td>
<td>(amount and share of each generation technology)</td>
<td>CO₂ emission mitigation</td>
</tr>
<tr>
<td></td>
<td>Share of energy produced from renewable energy (amount and share of each generation technology)</td>
<td>Population welfare</td>
</tr>
<tr>
<td></td>
<td>Total efficiency for the electricity generation (MW produced versus MW installed capacity)</td>
<td></td>
</tr>
</tbody>
</table>
2.6 Risk management of activity implementation

The principal challenge faced by GFCS in its initial stages will be to demonstrate its ability to add value. In this sense, the risks associated with implementing GFCS priority activities for energy include organizational complexity, leadership and management, resourcing, and support for coordination among the entirety of the energy industry (energy producers, transmission operators, etc.) and the weather and climate community in all its facets (research organizations, NMHSs, private service providers, etc.). In other words, there needs to be significant and genuine buy-in and ownership from the energy industry in order for partnerships and actions to occur in the domain of climate services for the energy sector.

In a broader sense, the challenge for GFCS is enabling effective communication between a science-led provider community and a business-driven sector. Decision-making will take place whether or not adequate climate information is available. Nevertheless, it is hoped that by making improved climate services available via implementation of GFCS as soon as possible, decision-making will be aided, and the desired outcome – that of reducing risks or reducing costs of the decision – will be promoted.

In addition, without mobilizing and sustaining financial resources at global, regional and national levels via engagement of the energy sector, implementation of the Exemplar will be hampered. The energy industry might still continue to develop its own climate services, but, without the overarching framework provided by GFCS, duplication of efforts would be more likely; similarly, execution time would be slower. Therefore, the GFCS Secretariat and the coordinating/implementing entity for the Energy Exemplar will need to make active efforts to identify, raise and sustain funding for the development of relevant and effective climate service activities. Rigorous monitoring and evaluation linked to energy outcomes will help to mainstream climate services as an essential contributor to the energy sector, including enhancing climate risk management, and thus leveraging resources for mainstreaming climate in all relevant aspects of energy projects across the five focus areas.

Exemplar implementation risks may include:

1. High expectations from energy users for robust and highly accurate weather and climate information and services;

2. Inadequate availability of, or access to, relevant weather and climate data, including limitations of the science, deficient translation of science into decision-relevant information and poor communication of the information and services (particularly acute in developing countries);

3. Ineffective processes for communication and dissemination of decision-relevant information to users;

4. Difficulties in establishing an effective engagement channel with the energy industry;

5. Dearth of qualified weather and climate experts (particularly acute in developing countries);

6. Lack of, or inadequate, guidelines in the collection and use of weather and climate information.
3. Enabling Mechanisms

Implementation of the Energy Exemplar entails building synergies with existing activities (both within the energy sector and across the other GFCS priority areas), strengthening partnerships, and promoting effective review, communication and resource mobilization. Investment in these mechanisms can ensure that the necessary conditions are met and sustained, and that energy sector priority needs for climate services are met.

3.1 Synergies with existing activities

Synergy with existing energy agendas and operations is not only an enabling mechanism, but also a necessary condition for Exemplar implementation. As indicated in section 2.1, the stocktake and harmonization principles are key to the enhancement of synergies within the energy sector. Thus, to ensure immediate progress and results, this Exemplar will benefit by learning from existing activities at global, regional and national scales (see Annex 2) while attempting to provide an overarching thread to these activities through GFCS. Proper application of these two principles would then allow efficient and effective development of new activities/services.

However, synergies should be also sought across the initial four GFCS priority areas (agriculture and food security, water, health and disaster risk reduction). Indeed, requirements on quality of meteorological observations and/or of forecasts are often of a similar nature across societal sectors. Thus, for instance, observations collected for water management may also be useful for hydropower generation. Similarly, solar radiation data used for agricultural purposes would also be of value to the solar power industry. Climate model information is another common factor with the other priority areas. In addition, there are other apparent potential cross-sector synergies, such as water and energy – as with competition of water resources for electricity generation, oil refining, irrigation of energy crops or human water consumption (SEI, 2014) – or agriculture and energy – as with land competition for food and biofuels production (Scheffer et al., 2012). If properly addressed, such cross-sector issues can be harnessed to ensure climate services become even more relevant. Therefore, and in order to avoid costly duplication of effort, synergies among energy and each of the four initial GFCS priority areas should be sought when developing new activities/services.

Annex 4 outlines existing partnerships, institutions, projects and mechanisms that serve as initial points of engagement for the Exemplar. Almost all partners, even those based in countries that are members of the Organisation for Economic Co-operation and Development, either operate internationally or may serve as a resource base for capacity-building, technical transfer and collaboration with developing country partners.

3.2 Building national, regional and global partnerships

The strength of future partnerships will depend upon multiple factors including the political support for the framework by government and energy partners, the flexibility to advertise successful experience to encourage engagement, the ability to secure adequate financing and the effective establishment of a functional and communicative coordinating body. This Exemplar must offer concrete incentives, opportunities and advantages for partners to engage.
One of the central principles of GFCS is that its structure and activities should build on existing partnerships and avoid duplication. This principle can be implemented through active engagement in the working mechanisms, programmes and activities of existing energy networks and key organizations at national, regional and international levels. Linking with partners in ongoing global and regional work will be perhaps the most important component of such engagement. Working at the global and regional levels will ensure that stocktaking and harmonization of current activities, with the assistance of relevant global industry associations, can be achieved in a systematic and effective way.

The stakeholders in the energy sector are many and varied. They include energy exploration companies, generators, site operators, transmission operators, distribution operators, market operators, energy traders, private service companies, NMHSSs, universities, national, state and local governments, non-profit organizations, national and international associations, the general public and many others – Annex 4 provides a list of stakeholders with which possible partnerships can be formed. Given the wide scope of the energy sector, mechanisms for involvement and interactions also vary significantly, from high-level ministerial councils to local meetings, and also involve media-based awareness-raising and information distribution mechanisms.

At the global level, effective partnerships could be strengthened among the Energy Exemplar and organizations such as the World Bank and the World Business Council for Sustainable Development (WBCSD). In the publication by Ebinger and Vergara (2011), the World Bank’s Energy Sector Management Assistance Program (ESMAP) highlighted a number of actions that could benefit from strong partnerships (for example, supporting awareness and knowledge exchange; see Annex 5 for a comprehensive list of suggested actions). Similarly, the WBCSD (2014) report provides a number of recommendations that could be effectively enacted by partnerships among energy experts and the meteorology community (for example, “organize effective pooling of technical expertise”; see Annex 6 for the full list of recommendations). Partnerships with other international and regional efforts such as the Group on Earth Observations (GEO)/GEOSS, IEA, IRENA, WEC, DOE and Copernicus are also important for successful implementation of the Exemplar.
While flexibility in approach is essential, a key role of GFCS, as an overarching global effort, will be to ensure multi-stakeholder partnerships are built throughout the value chain, that is, from initial energy exploration to final energy consumption. Such partnerships would have the potential to attract buy-in from additional industry players and hence lead to strong outcomes.

3.3 Review mechanisms

The mechanisms for review and evaluation of Energy Exemplar implementation activities will be agreed with GFCS partners, through coordinating/implementing entities, to ensure that the reporting requirements of each organization are met.

Long-term success of the overall Exemplar will be assessed in terms of improved climate-informed energy decision-making, which results in outcomes such as more-efficient energy supply, reduced impacts on energy infrastructure, lower overall energy costs and increased access to energy. In the shorter term, success will be shown through metrics that capture the adequate access to, and appropriate application of, weather and climate information to energy decisions.

In terms of accountability, the Exemplar should:

- Establish a results-based monitoring and evaluation framework to quantify how energy decision-making has improved with the availability and use of climate services, through metrics that capture outcomes such as improved relevance and quality of forecasts for energy demand and supply, effectiveness of warnings for energy infrastructure impacts and achievement of better awareness of climate and energy interactions;

- Develop and apply monitoring and evaluation standards for existing and new interventions, and develop indicators particularly related to economic costs and benefits;

- Integrate reporting on delivery of GFCS into the existing governance mechanisms for meteorological agencies and energy agencies, possibly including UN-Energy, and equivalent bodies at the regional and national levels;

- Adopt financial reporting and auditing processes that comply with the standard criteria of WMO and/or the United Nations.

3.4 Communication strategy

Communication is vital for strengthening partnerships among the energy sector and the meteorological community towards the development of useful and effective climate services. Key messages that GFCS should deliver are:

- The opportunity offered by GFCS: potential partners need to know that a framework is now available to develop climate information activities/services in an effective way;

- The benefits of collaboration: potential partners need to understand the final products that could result from collaboration, such as new tools for improved climate risk management decisions or information factsheets to inform the energy sectors about latest developments by the climate community;
• What is available and what is possible: climate service providers need to be able to describe, in non-technical terms, the existing technologies and climate products (such as their specifications and formats), as well as their limitations;

• Willingness to understand and improve: climate service producers must show willingness to take time to understand potential partners’ climate information requirements and the information used for energy;

• Willingness to jointly develop, test and upgrade climate products: climate service producers must convey willingness to work with other stakeholders, rather than alone, in, say, meteorological services, by establishing a community of practise and a network of partners and experts supporting and implementing climate and energy work;

• Willingness to be proactive: climate service providers need to be keen to engage the energy industry in information sessions, via mechanisms such as webinars, workshops and community events.

Several national, regional and international events are being established that could represent ideal forums for the communication of (some of) the above points towards a better engagement between the energy industry and the weather and climate community. Among those are the ICEM series, the American Meteorological Society sessions on Weather, Climate, and the New Energy Economy, and the European Meteorological Society sessions on Energy Meteorology (for further details, refer to Annex 2).
4. Resource Mobilization

The success of the Energy Exemplar will be a function of the effectiveness of communicating the benefits of this initiative, and leveraging existing and new resources and partnerships. At present, the arrangements for provision of climate services for energy, in many instances, fall short of meeting the identified needs. There is vast, and as yet largely untapped, potential to improve these arrangements and enhance the quality and utility of climate services for the benefit of many countries and all sectors of society.

This Exemplar is critical, given ongoing investments in energy systems and increasing amounts of investment needed in coming years. By 2035, annual investment needs are projected to steadily rise towards US$ 2 trillion, while annual spending on energy efficiency is expected to increase to US$ 550 billion. This means a cumulative global investment bill of more than US$ 48 trillion. It is important that these investments incorporate the best climate information, particularly as infrastructure investments will have a considerable influence long into the future (WEIO, 2014).

4.1 Global to national levels

While many services/activities can and will be implemented at national level, a proactive resource mobilization from a GFCS perspective would be best targeted at the global, or perhaps regional, levels. Working at these levels would allow GFCS to maintain focus on the overall framework, and help to harmonize activities at a high level in an effective way.
At these global and regional levels, there are a number of energy associations/organizations whose involvement in mobilizing resources would be critical. These are essentially the same organizations that have demonstrated a direct interest in issues at the intersection between energy, weather and climate through, inter alia, the publications referred to in the Introduction above, namely the World Bank/ESMAP, WBCSD, WEC, Asian Development Bank, IEA and IRENA. Not only have these organizations made important recommendations for strengthening the link between energy and weather and climate in their publications (for example, the WBCSD recommendation “organize effective pooling of technical expertise”, see Annex 6), ESMAP, for instance, has been mobilizing resources by investing in a multimillion-dollar project to map renewable energy resources in many developing countries.7 Partnering with these organizations would facilitate resource mobilization by assisting to navigate international funding procedures for development, environment and climate change adaptation in the context of energy resilience, access, efficiency and sustainability.

In general, effective resource mobilization can be achieved through development banks and climate funds (WMO, 2014). In the case of this Exemplar, direct involvement of the private sector, possibly via industry associations, may also be an effective way to mobilize resource.

### 4.2 Development banks and climate funds

Development banks include the World Bank and regional development banks such as the African Development Bank, Asian Development Bank, European Bank for Reconstruction and Development and the Inter-American Development Bank.

Table 6 shows the key funds related to climate change that countries might approach to support the framework.

<table>
<thead>
<tr>
<th>Name; web page</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Adaptation Fund; <a href="https://www.adaptation-fund.org/">https://www.adaptation-fund.org/</a></td>
<td>Finances projects and programmes that help vulnerable communities in developing countries to adapt to climate change. Initiatives are based on country needs, views and priorities. Established under the Kyoto Protocol of the United Nations Framework Convention on Climate Change, and has committed US$ 357.5 million in 63 countries since 2010 to climate adaptation and resilience activities.</td>
</tr>
<tr>
<td>Climate Investment Funds; <a href="http://www-cif.climateinvestmentfunds.org/">http://www-cif.climateinvestmentfunds.org/</a></td>
<td>Provides 72 developing and middle-income countries with US$ 8.3 billion of urgently needed resources to manage the challenges of climate change and reduce greenhouse gas emissions. Comprised four programmes: Clean Technology Fund, Pilot Program for Climate Resilience, Scaling up Renewable Energy in low Income Countries Program and Forest Investment Program.</td>
</tr>
<tr>
<td>Global Environment Facility; <a href="https://www.thegef.org/">https://www.thegef.org/</a></td>
<td>Established on the eve of the 1992 Rio Earth Summit, to help tackle our planet's most pressing environmental problems. Since then, it has provided US$ 14.5 billion in grants and mobilized US$ 75.4 billion in additional financing for almost 4 000 projects.</td>
</tr>
</tbody>
</table>

7 http://www.esmap.org/RE_Mapping
Advised by the European Investment Bank Group, it is an innovative fund-of-funds catalysing private sector capital into clean energy projects in developing countries and economies in transition. Total funds under management are € 222 million.

International Climate Initiative; https://www.international-climate-initiative.com/
Initiative of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, which has been financing climate and biodiversity projects since 2008 in developing and newly industrializing countries, as well as in countries in transition. Places clear emphasis on climate change mitigation, adaptation to the impacts of climate change and the protection of biological diversity.

Global Climate Change Alliance; http://www.gcca.eu/
Established by the European Union in 2007 to strengthen dialogue and cooperation with developing countries, in particular, in least developed countries and small island developing States. Presently has a budget of more than € 300 million and is one of the most significant climate initiatives in the world. Supports 51 programmes and is active in 38 countries and eight regions and subregions worldwide.

Green Climate Fund; http://www.greenclimate.fund/
Created by the United Nations Framework Convention on Climate Change in 2010, it aims to support a paradigm shift in the global response to climate change. The initial resource mobilization has raised approximately US$ 10 billion. The fund works through a wide range of entities to channel its resources into projects and programmes. Such entities may be international, regional, national or subnational, or public or private institutions that meet the standards of the fund. Countries may access the fund through multiple entities simultaneously.

4.3 Private sector

While much of the responsibility for driving climate change solutions that address the needs of the poor and vulnerable rests with governments, clearly, business will remain an essential partner in building resilient, efficient and sustainable energy systems. The private sector has much to contribute to developing and implementing climate change adaptation solutions, including providing sector-specific expertise, technology, significant levels of financing, efficiency and an entrepreneurial spirit. This is particularly valid in the case of the energy industry.

Thus, the Energy Exemplar could be used as a platform for new forms of public–private partnerships for building climate services to tackle the complex challenges to sustainable development and climate resilience for the energy sector. International corporate associations, such as WBCSD, Global Sustainable Electricity Partnership (GSEP),8 WEC and the Global Wind Energy Council (GWEC), could provide pertinent avenues for bringing this Exemplar to the private sector and for engaging in dialogue on how the private sector can provide support.

In order to reach the targeted private sector and to fully improve its security, operability and sustainability, a business plan has been developed (see Annex 7). This includes a description of the current energy sector situation (through a market analysis and strengths, weaknesses, opportunities and threats analysis of the proposed climate services) and the identification of possible implementation methodologies. The business plan highlights the roles of WMO and its Members in supporting implementation of the Energy Exemplar.

8 http://www.globalelectricity.org/en/
while recognizing that private sector engagement is important if customer-oriented climate services are to be embraced and adopted.

The present and future market for climate services is currently expanding. As energy systems evolve, new opportunities and niches may arise for providing accurate climate services to improve current systems. One of the core elements of the business plan is to demonstrate the added value of the climate services and to illustrate accurately the benefits to energy sector stakeholders. The Colombian hydroelectric system is presented as a proof-of-concept case study in Annex 7.

The energy sector in Colombia is well organized, and useful reports on the energy sector are available that facilitate study of the interactions among the principal agents. The analysis in Colombia includes conclusions as to which methodologies are most appropriate to use as a basis for business plan development.
Effective implementation of the Energy Exemplar will benefit from focused initial priorities. As discussed in the previous chapters, such priorities will need to include the following activities:

1. Energy organization partnership identification and formation:
   a. Involvement of one-to-one, as well as broader, meetings to consolidate relationships with key potential partners for the co-development of the Energy Exemplar; such organizations include the World Bank/ESMAP, WBCSD, WEC, IEA and IRENA;
   b. Preparation of a proposal for an Energy Exemplar implementation partnership with select organization(s), including clear commitment to a common development plan for this Exemplar and identification of appropriate funding sources (for example, Adaptation Fund or Green Climate Fund);

2. Pilot activities/projects:
   a. Identification of opportunities and countries for initial pilot activities/projects;
   b. Development of a stakeholder workshop to consult relevant collaborators on the design and implementation of the pilot activities/projects;
   c. Provision of capacity-building and support activities to train relevant personnel for implementation of the pilot activities/projects;

3. Knowledge-sharing:
   a. Development and implementation of a communication strategy, including via the establishment of an informative website and an active Twitter account;
   b. Development of a consultation workshop to define terms of reference for an initial stocktake activity;
   c. Systematic stocktaking analysis of relevant products and services (an initial assessment is provided in Annex 2).

All the above activities will have to be appropriately formulated through a standard project planning approach – with definitions of tasks, deliverables, milestones, people and funding allocations. In addition, for the Exemplar to demonstrate solid progress, and as an indicative time frame, these activities will need to have reached a very advanced stage by the end of the first year from the start of the implementation of this Exemplar. An organization such as WEMC may be tasked with actively assisting in the implementation of the Energy Exemplar.
Annex 1 – Climate-Sensitive Energy Subsectors: A Selection

This annex provides an overview of a selection of energy subsectors in the context of climate services. Each of the selected (power) subsectors – wind, solar, hydro and thermal – are presented following a similar structure: the importance of the subsector, its interaction with the surrounding environment and its needs in terms of climate services.

It is useful to refer to Table 2 in the main text above for additional details about energy industry requirements. As a general rule, the accuracy of weather and climate information generally needs to be progressively higher, going from focus area one (Identification and Resource Assessment) through to focus area five (Energy Integration).

1. Wind power

1.1. Importance of wind power for society

Wind energy offers significant potential for near-term (2020) and long-term (2050) GHG emission reductions. Several different wind energy technologies are available across a range of applications, but the primary use of wind energy is to generate electricity from large, grid-connected wind turbines, deployed either onshore or offshore. Wind power capacity installed by the end of 2013 was capable of meeting approximately 1% of the worldwide total energy consumption (REN21, 2016), and that contribution could grow many-fold by 2050, if ambitious efforts are made to reduce GHG emissions and to address the other impediments to increased wind energy deployment (IPCC, 2011; WER, 2016). Onshore wind energy is already being deployed at a rapid pace in many countries, and no insurmountable technical barriers exist that preclude increased levels of wind energy penetration into electricity supply systems. Moreover, though average wind speeds vary considerably by location, ample technical potential exists in most regions of the world to enable significant wind energy deployment.

In some areas with good wind resources, the cost of wind energy is already competitive with current energy market prices, even without considering the relative environmental impacts. Indeed, onshore wind energy is a tried and tested technology that is already cost competitive with conventional power in some parts of the world, for example, in Australia, Brazil and parts of the United States (IPCC, 2011; IEA, 2014). Nonetheless, in most regions of the world, policy measures are still required to ensure rapid deployment. However, subsidies for onshore wind are projected to reach a peak just before 2020 and then decline steadily as it becomes competitive with conventional power plants in many locations (WEO, 2014).

The total wind resource is vast and is estimated to be about 1 x 10^6 GW “for total land coverage” (excluding offshore installations). If only 1% of this land area was utilized, and allowance was made for the lower load factors of wind plants (15–40%, compared with 75–90% for thermal plants), that would still correspond, roughly, to the total worldwide capacity of all electricity generating plants in operation today (WER, 2016). However, electricity generation from wind turbines is constrained by the varying availability of wind. This can make it challenging to maintain the necessary balance of electricity supply and consumption at all times. Consequently, the cost-effective integration of variable renewable energy (VRE; including other
variable renewable energy sources, mainly solar technologies) has become a pressing challenge for the energy sector. Based on a thorough assessment of flexibility options currently available for VRE integration, large shares of VRE (up to 45% in annual generation) can be integrated without significantly increasing power system costs in the long term (IEA, 2014b). It is also clear that the role of high-quality weather and climate information is a crucial component towards the achievement of such a cost-effective integration.

1.2 Wind power and its interaction with the atmosphere

Wind power harnesses the kinetic energy of moving air. Wind is available virtually everywhere on Earth, although there are wide geographical variations in wind strength. Technological advancements have led to a dramatic increase in wind turbine size, and hence their power, over the last 30–40 years (Figure 1). For instance, in the early 1980s, wind turbines 15–20 m high with a power of 15–100 kW were available, but by the early 2000s, turbines exceeded 100 m in height (and a few megawatts in power). Today’s turbines have reached heights of about 200 m and are expected to further increase in size, particularly for offshore applications (Kaldellis, 2012; IEA, 2013a).

In terms of interaction with the atmosphere, this technological evolution has meant that it has become critical to understand exactly how wind turbines are affected by wind flow. In turn, it is crucial to identify the weather and climate variables of most relevance to the wind energy industry. Early onshore wind turbines had rotor diameters much smaller than the vertical extent of the atmospheric surface layer, which is roughly 80–100 m deep. With the increasing size of turbines, the hub heights of multimegawatt turbines are now often above the atmospheric surface layer, and rotor diameters larger than 100 m are becoming common. Offshore turbines with diameters larger than 160 m and a power of 7 MW have already been designed and will be deployed in the near future. This will lead to complicated interactions between the turbines and the lower atmosphere. Weather and climate features that had been considered as irrelevant for a long time are now becoming decisive for planning and running single, large turbines and increasingly larger wind parks (Emeis, 2014). In particular, vertical gradients in mean wind speed and wind direction, as well as in turbulence intensity above the surface layer, are critical to the construction, planning and operations of wind turbines. Similarly, the impact of wind turbines and wind parks on wind flow is another very important meteorological consideration.

In terms of measurements of the key weather and climate variables, onshore surface layer winds are relatively easy to assess, because in situ measurements from masts can be made with reasonable effort in order to calculate turbine loads and energy yields. Logarithmic and power laws that describe the vertical wind profiles in the surface layer allow for reliable vertical interpolations and extrapolations in flat and homogeneous terrain. However, with the new, much larger turbines, the relevant wind parameters can no longer be fully obtained using masts. New measurement techniques are required to collect the necessary wind information. This has led to a boom in surface-based remote-sensing techniques such as wind lidars (Emeis, 2014).
In addition, it is likely that offshore wind parks will deliver a considerable proportion of the wind energy in the future, because of the wider available space and the usually higher wind speeds compared to onshore sites. Therefore, marine boundary-layer weather and climate variables need to be assessed. Until a few years ago, experimental data for the marine atmospheric boundary layer were available, if at all, for only a shallow layer explored from buoys, ships and oil rigs. A few masts, such as the three German 100 m high Forschungsplattformen in Nord- und Ostsee masts, have been erected in the last 10 years. They are presently delivering long-term information on a deep layer of the marine boundary for the first time (Emeis, 2014).

While the largest wind turbines tend to attract most interest, as they produce the bulk of wind power, it is important to note that there is a wide range of turbine sizes available commercially, from small battery-charging machines with ratings of a few watts, up to, say 100 kW for farm use (WER, 2016). Although such turbines are relatively more expensive than their larger counterparts, they are generally not competing with electricity from large thermal power stations and may be the only convenient source of power, possibly in conjunction with batteries or diesel generators, in some locations. In developing countries, small wind turbines are used for a wide range of rural energy applications, and there are many “off-grid” applications in the developed world as well – such as providing power for navigation beacons and road signs (WER, 2016). The size and siting of such small turbines clearly have implications for the (different) types of weather and climate variables required for their operations, particularly if they are sited in complex terrains such as in urban environments.

Finally, it is also worth mentioning the higher-altitude wind power systems, which although still in a development phase, have recently received some attention as an approach for generating electricity from wind. A principal motivation for the development of this technology is the sizeable wind resource present at higher altitudes. Two main approaches to higher-altitude wind energy have been proposed: (a) tethered wind turbines that transmit electricity to Earth via cables; and (b) base stations that convert the kinetic energy from the wind collected via kites to electricity at ground level. A variety of concepts are under consideration, operating at altitudes of less than 500 m to more than 10 000 m. Though some research has
been conducted on these technologies and on the size of the potential resource, the technology remains in its infancy, and scientific, economic and institutional challenges must be overcome before pilot projects are widely deployed (Wiser et al., 2011).

Table 1 summarizes the main benefits and drawbacks of wind power.

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Drawbacks</th>
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<tbody>
<tr>
<td>Low operating costs</td>
<td>Best locations for wind sites are often far from demand</td>
</tr>
<tr>
<td>No waste or CO₂ emissions</td>
<td>Some pollution in the production of wind turbines</td>
</tr>
<tr>
<td>Only a small plot of land necessary</td>
<td>Inflexible and variable</td>
</tr>
<tr>
<td>Domestic source of energy</td>
<td>Noise and aesthetic pollution</td>
</tr>
<tr>
<td>Free and clean fuel source</td>
<td>Biodiversity impacts</td>
</tr>
<tr>
<td>Cost-competitiveness is being increased</td>
<td>Useful for remote areas</td>
</tr>
<tr>
<td>Enormous potential</td>
<td></td>
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1.3 Needs of the wind power subsector for climate services

In this section, the needs of the wind power industry in terms of climate services for each of the five focus areas are discussed. It is useful also to refer to a practical process adopted by wind power developers, such as the one shown in Figure 2.

Figure 2. Illustration of the wind energy installation development process in South Africa, from a developer’s perspective


Note: The following acronyms stand for: LO = landowner; SED = socio-economic development; ED = economic development; FC = financial close; PPA = power purchase agreement.
1.3.1 Identification and Resource Assessment

In this phase, historical (and possibly projected) wind climate information is critical for identifying the best sites for the development of a wind power plant. Such information is normally referred to as the wind resource, and it is used to assess not only how much power the plant could potentially produce over its expected lifetime, but also to learn about the statistical features of the resource (for example, interannual variability), as these are important considerations, for instance, for financial agreements. The process of quantifying the characteristics of the wind is referred to as resource assessment.

It is important to realize that, particularly from a UIP perspective, wind resource assessment is just a (relatively) small piece of a wind farm development process (Figure 2). Other key enabling factors and constraints that need to be considered include the reach of the transmission network, transmission flow patterns among different parts of an area, protected areas (including for landscape, environmental, military or civil transportation purposes) and potential cumulative effects on protected or endangered species. Using this information, governments can develop a policy framework that specifies where wind power deployment is encouraged and facilitated, where it is simply permitted and where it is restricted or excluded (ESMAP, 2012). Depending on the policy framework, there could be several barriers that delay the deployment of wind energy and the achievement of targets set in energy policy. Permit/authorization delays and high costs for administrative and grid connection procedures are issues in many countries. Other barriers relate to the lengthy approval of environmental impact assessments, compliance with spatial planning, the number of parties involved, an absence of information on the grid connection capacity, a lack of planning for grid extension and reinforcements, insufficient grid capacity and land ownership (IEA, 2013a).

Despite the potential complexity of the policy framework, it is undisputable that reliable wind resource data are crucial ingredients in providing the certainty sought by commercial wind power developers. The process of identifying the wind resource normally starts from pre-competitive large-scale regional maps, often produced via mesoscale modelling, and with the financial support of national governments. While providing useful broad appraisals of the wind resource, coarse-resolution data, as is often the case in such assessments, have very serious drawback because hills and ridges are normally not well resolved. Such orographic features tend to cause increased wind speeds. Consequently, coarse resolution leads to an erroneous negative bias in the wind resource (Gryning et al., 2014).

Work is also ongoing at the international level to develop a consolidated Global Atlas for Wind (and Solar), drawing on previous initiatives such as the Solar and Wind Energy Resource Assessment, and on the datasets that are already publicly available in most developed, and some developing, countries. Such large-scale maps offer a pre-competitive assessment of the wind resource and they are used to identify potentially high-yielding wind power sites. However, the lack of reliable ground-based data in many developing countries limits the accuracy of these resource assessments. An effort by IRENA to catalogue existing resource mapping studies concluded that the lack of a dense measurement network is the main reason for the limited number of maps and geographic information system portals in Africa and Oceania (IRENA, 2012). While country-level resource assessment does not replace the need for site-specific, microlevel assessment (for example, to determine the best location for a wind farm within a defined area and the optimal location of individual turbines within a wind farm), the data obtained from country-level measurement campaigns can be used for evaluation purposes, which can further shorten project development timelines and increase certainty. Therefore, country-level resource assessment, mapping and spatial planning should be viewed as a “public good” that has significant potential to increase investment, shorten deployment times and reduce development costs. For countries with limited or zero penetration of a particular renewable electricity option, resource mapping can be the first step in increasing awareness and encouraging investment (ESMAP, 2012).
Thus, CSIS products for wind resource assessment include maps and, more generally, datasets generated by using, and also combining, as many sources of wind data as possible (in situ, remote-sensing and modelled via mesoscale/regional models). Uncertainty estimates of wind data would also be very useful, even if efforts and computer resources are often directed to producing the highest resolution possible rather than different estimates of the same resource. Wind data from climate projections are an increasingly important complement to historical data for the estimation of power yield of a planned wind farm. However, these projections are currently not considered to be of high enough quality for them to play an important role in the resource assessment.

Obs/Mon of wind data for pre-competitive resource assessment should be carried out at as many sites as possible, so as to have an adequate geographical coverage but also a dense enough sampling of the wind at different heights. However, as it is highly dependent on orography and height, wind can never be sampled well enough. This is why numerical/physical modelling is critical in filling spatial gaps and also for extending wind time series to periods when data are not available – typically high-quality wind data, particularly mast data at heights of tens of metres, are only available for periods of up to 10 years. Therefore, the role of the RMP pillar is critical, as physical models require continuous improvements, both in terms of representation of processes and in terms of increased time/space resolution. Quality wind observations are key to guiding the development of physical models.

Climate services for the identification and resource assessment of wind power require a high level of sophistication, involving quality and long-term wind data, physical modelling at high resolution, and refined techniques of assessment and data combination. Each of these aspects needs a non-trivial level of technical preparation, capital investment funding and computer resources, which are often present in developed countries, but definitely lacking in developing countries. Capacity-building activities such as those implemented by ESMAP administered by the World Bank (ESMAP, 2012), should therefore be strengthened. Contributions from the wind power industry could also be harnessed, in order to ensure relevance of outcomes and possibly leverage investments.

1.3.2 Impact Assessment

Infrastructure impacts – wind turbines and their towers, like any other infrastructure, are engineered to sustain well-defined environmental-related loads. A wide variety of loads have to be considered in wind turbine design, from aerodynamic, to hydrodynamic, to gravitational, to inertial, to ice and soil interactions (Karimirad, 2012). For instance, wind turbines cannot operate above a certain wind threshold, the cut-out speed, typically between 20 and 30 m/s depending on the size of the turbine. Above the cut-out speed, power production is ramped down in order to protect the machine from heavy loading (Carta, 2012; Zafirakis et al., 2012). The frequency and intensity of wind gusts, that is, wind speeds exceeding a certain wind speed for time durations of a few seconds, are also of major concern for the evaluation of a site.

Damage could also be caused by turbulence induced from nearby turbines via wakes. The dynamic part of the wind speed, turbulence, includes all wind speed fluctuations with periods below the spectral gap. The spectral gap occurs at about 1 h, which separates the slowly changing and turbulent ranges. Turbulence has a major impact on aeroelastic structural response and electrical power quality. One useful parameter is the turbulence intensity, which is defined as the ratio of the standard deviation of the wind speed to the mean wind speed. The turbulence intensity decreases with height, and is higher when there are obstacles in the terrain. Hence, the turbulence intensity for an offshore site is less than that for a land site. Ice can cover both the non-rotating parts of the turbine and the rotating parts (mainly the blades). The blades of a
shutdown turbine can be covered by ice up to several centimetres thick, leading to extra surface roughness of the blades and stronger aerodynamic forces (Karimirad, 2012).

Environmental impacts – no energy source is free of environmental effects. As renewable energy sources make use of energy in forms that are increasingly diffuse, larger structures or greater land use tend to be required, and attention may be focused on the visual effects. In the case of wind energy, the effects of noise and possible disturbance to wildlife, especially birds, need to be taken into consideration (WER, 2016). Ensuring that the local community is fully briefed on the environmental implications of a planned wind farm, and particularly on the action taken by the wind farm developer to mitigate possible environmental impacts, is key to avoiding unnecessary delays in the construction, and subsequent operation, of wind farms. In fact, lengthy wind project approvals due to tortuous environmental impact assessments and/or lack of social acceptance are not uncommon (IEA, 2013a). In addition to the possible direct environmental impacts of wind farms, the public should also be informed about the indirect positive effects of wind farms, such as the reduction in GHG emissions and possibly improved air quality due to the offsetting of likely more-polluting traditional power plants.

Wind turbines emit noise from the rotation of the blades and from the machinery, principally the gearbox and generator. The noise level near the cut-in wind speed is important as the noise perceived by an observer depends on the level of local background noise in the vicinity, which has a masking effect. At very high wind speeds, on the other hand, background noise due to the wind itself may be higher than the noise generated by a wind turbine. The intensity of noise reduces with distance and it is also attenuated by air absorption. The exact distance at which noise from turbines becomes “acceptable” depends on a range of factors, especially local planning guidelines (WER, 2016). Climate services can therefore assist, for instance, in determining specific wind characteristics, such as occurrences of high wind events at different times of day, particularly during those times when local residents are likely to be most affected by noise disturbance.

The need to avoid areas where rare plants or animals are to be found is generally a matter of common sense, but the question of birds is more complicated and has been the subject of several studies. Problems arose at some early wind farms that were sited in locations where large numbers of birds congregate – especially on migration routes. However, such problems are now rare, and it must also be remembered that many other activities cause far more casualties to birds, such as collisions with vehicles (WER, 2016). Although a rather specialized use of weather and climate information, local flow data in the vicinity of wind farms could be used as input to evaluations of avian dynamics.

One of the obvious environmental effects of wind turbines is their visual aspect, especially that of a wind farm comprising a large number of wind turbines. There is no measurable way of assessing the effect, which is essentially subjective. As with noise, the background is important (WER, 2016).

There are also some indications about a potential beneficial impact on nearby agriculture activity due to the enhanced air mixing driven by the wind turbine rotation.

1.3.3 Site Selection and Financing

With pre-competitive planning data, observations and modelling of wind data do not necessarily need to focus on a specific site. However, with site selection and financing, wind data need to be as accurate as possible for the site where the planned wind power farm is intended. Thus, wind data have to be collected at the site of interest, using the best possible approach (ideally using mast data, but also lidar data), including
the wind at several heights and at a few locations around the site, noting that the extent of a large wind farm can be tens of kilometres and hence with potentially differing wind characteristics within the same wind farm. Detailed monitoring and modelling are also required to assist with the evaluation of spatially inhomogeneous wind fields in complex terrains or wakes behind turbines. Wakes can lead to reduced wind speeds and enhanced levels of turbulence, with consequent reduced yields and enhanced loads on downwind turbines (Emeis, 2014).

1.3.4 Operation and Maintenance

Proper management of operating wind farms is critical for maximizing returns on investment. In addition to day-to-day management, a wind farm operator will proactively seek to extract every possible hour of availability from the turbines. Thus, the primary aim of wind farm operation and maintenance is to minimize the production costs per unit of energy generated over the life of the asset. Broadly, this is achieved by:

1. Minimizing operational and maintenance costs;
2. Improving turbine performance/yield;
3. Lowering insurance risk;
4. Protecting assets.

To achieve these goals, wind farm operators require site-specific forecasts, which are normally developed using statistical techniques, often with predictors taken from the output of weather and/or climate prediction models. For instance, the National Center for Atmospheric Research (NCAR)/Xcel Energy Wind Power Forecasting System ingests external, publically available weather model data and observations. High-resolution numerical weather prediction (NWP) simulations assimilate specific local weather observations. The weather observations range from routine meteorological surface and upper-air data to data from wind farms, including wind speed data from Nacelle anemometers. An ensemble of somewhat coarser NWP runs provides an additional best estimate of wind speed and also includes uncertainty information. To optimize estimates of short-term changes in wind power requires nowcasting technologies such as the Variational Doppler Radar Analysis System and an Expert System (Haupt et al., 2014).

1.3.5 Energy Integration

The Australian Wind Energy Forecasting System (AWEFS) was established in response to the growth in variable generation in the National Electricity Market (NEM) and the increasing impact this growth was having on NEM forecasting processes. Operational since 2008, the aim of AWEFS was to provide better forecasts to drive improved efficiency of dispatch and pricing, and permit better network stability and security management. Its implementation project had two broad objectives:

- Facilitating the operation of the market through more-accurate wind-generation forecasts;
- Facilitating research to improve the quality and dimension of the forecast over time to accommodate other renewable energy types such as solar power.

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9 http://www.wwindea.org/technology/ch03/en/3_1_1.html
Specifically, AWEFS produces wind forecasts with lead times of up to two years ahead for planning purposes and to better allocate spinning reserves. The strength of AWEFS lies in blending various statistical models.

Resource assessment and forecasting can also increase wind farm efficiency through appropriate deployment of turbines within a farm in order to reduce wakes and to assist in assessing the optimal location of wind farms. This will take account of seasonal/interannual wind variability to balance other forms of generation to better meet variable/seasonal demand.

Moreover, wind power risk hedges, which allow investment protection, are being developed. The protection, as developed by Swiss Re, is based on a wind production index, which is a function of the measured wind speed and the turbine’s power curve expressed in produced megawatt-hours (implicit production). Wind protection pays for itself by permitting sponsors to:

- Get an investment financed (in case debt is the limiting factor);
- Optimize capital structure;
- Reduce volatility from cash flow;
- Hedge obligations under power purchase agreements.

2. Solar power

2.1 Importance of solar power for society

Solar energy is the most abundant energy resource. About 60% of the total energy emitted by the Sun reaches the Earth’s surface. Even if only 0.1% of this energy could be converted at an efficiency of 10%, it would be four times larger than the total world’s electricity generating capacity of about 5 000 GW (WER, 2016). Also, solar energy offers significant potential for near-term (2020) and long-term (2050) GHG emission reductions.

The use of solar energy is growing strongly around the world, in part due to the rapidly declining manufacturing costs of solar panels, also stimulated by national and regional subsidies. For instance, world photovoltaic (PV) capacity in 2008 was 16 GW (for comparison, around a tenth of the 121 GW for wind), but in 2014, this had jumped to 177 GW (with 39 GW installed just in 2014, and a little less than half of the 370 GW for wind). The other technology used to convert solar power into electricity, concentrating solar power (CSP), contributed a much smaller 4.3 GW in 2014. In addition, solar energy is used to heat water via collectors, generating 409 GWth in 2014 (REN21, 2016).

2.2 Solar power and its interaction with the atmosphere

PVs, solar heating and cooling, and CSP are primary forms of energy applications using sunlight. Solar energy technologies harness the energy of solar irradiance to produce electricity using PVs (via the photoelectric effect) and CSP (which produces electricity through an intermediary thermodynamic process). Such a distinction is critical as PVs and CSP respond in different ways to solar irradiance. PVs can produce electricity even under overcast conditions, as they are sensitive to the global component of irradiance, the

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11 [https://www.youtube.com/watch?v=hLi3IJ52tPA](https://www.youtube.com/watch?v=hLi3IJ52tPA)
sum of the direct and diffuse irradiance components (see Figure 3). However, CSP can only function under the direct irradiance component (namely clear sky), and broken cloud conditions are the most problematic for CSP operations. On the other hand, CSP has the capability to store the (thermal) energy produced, using materials such as molten salts, which allow a storage period of several hours. Although less common, concentration PVs is another available technology. This is a PV technology that generates electricity using concentrated sunlight, into a cell using an optic, as for CSP.

Accurate measurements of incoming irradiance are essential to solar power plant project design, implementation and operation. As irradiance data are relatively complex, and therefore expensive compared to other meteorological measurements, they are available for only a limited number of locations. This holds true especially for the direct irradiance component, as it requires a solar tracking device, which is usually several times more expensive than good-quality pyranometers, which are used to measure global irradiance (Sengupta et al., 2015). Also, spatial correlation of direct irradiance typically is a few times smaller than that of global irradiance, therefore requiring more measurement sites to yield resource mapping of similar quality to global irradiance (Davy and Troccoli, 2014).

Aside from the obvious crucial role of clouds in determining solar irradiance on the ground, atmospheric composition – water vapour, ozone and aerosols – is another very important factor. Aerosols are particularly relevant in certain areas such as near deserts, in coastal areas or in polluted cities (for the latter, rooftop PV production is affected). Indeed, there are several types of aerosols – sea salt, desert dust, organic and black carbon, and sulphate – and they can affect the amount of available irradiance on the ground, potentially reducing it by up to a few tens of per cent in areas with particularly high aerosol loading. For instance, a moderate smoke plume event, caused by bush fire burns, caused an overall reduction in PV output of 7% on average over a few hours and a peak reduction of 27% (Perry and Troccoli, 2015).

**Figure 3. Schematic of solar irradiance (or radiation) components.**

Global radiation = Direct beam + (Reflected diffuse + Backscattered diffuse + Transmitted diffuse) = Direct beam + Diffuse radiation
In the absence of surface radiation measurements, estimates of surface radiation can also be made using meteorological ground measurements such as cloud cover, temperature, visibility and water vapour in a radiative transfer model (Marion and Wilcox, 1994).

Table 2 summarizes the main benefits and drawbacks of solar power.

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low operating and maintenance costs</td>
<td>Low conversion efficiency</td>
</tr>
<tr>
<td>No waste or CO₂ emissions</td>
<td>Some pollution in the production of solar collectors</td>
</tr>
<tr>
<td>Enormous potential</td>
<td>Large areas of land required for solar farms</td>
</tr>
<tr>
<td>Domestic source of energy</td>
<td>Variable production, useful only during sunny daytime</td>
</tr>
<tr>
<td>Free and clean fuel source</td>
<td></td>
</tr>
<tr>
<td>Useful for remote areas</td>
<td></td>
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</tbody>
</table>

2.3 Needs of the solar power subsector for climate services

In a similar way to wind power, reliable solar information is required for every solar power conversion technology. This holds true for small installations on a rooftop as well as for large solar power plants. However, solar resource information is of particular interest for large installations, because they require a substantial investment, sometimes exceeding US$ 1 billion in construction costs. Before such a project is undertaken, the best possible information about the quality and reliability of the fuel source must be made available. That is, project developers need to have reliable solar data at specific locations, including historical trends with seasonal, daily, hourly and (preferably) subhourly variability to predict the daily and annual performance of a proposed power plant. Without these data, an accurate financial analysis is impossible (Sengupta et al., 2015).

Requirements for climate services by focus areas for solar power are very similar to those for wind power. The main differences are related to the accuracy of the meteorological variables needed for solar power devices – direct irradiance is particularly problematic given the very limited number of observation sites and the relatively small spatial representativeness of site data.

2.3.1 Identification and Resource Assessment

As for wind, pre-competitive solar resource mapping is produced by means of combinations of high-quality observations and numerical model data, with the model normally constrained by reanalysis data. Apart from the different accuracy of the meteorological variables involved, the main difference is that solar radiation resource assessment can benefit also from the use of satellite-derived solar data. These are computed by means of satellite information such as cloud images, top of atmosphere radiances and albedo, and are then processed using statistical or physical models to derive the irradiance at the ground (either or both of the global and direct components) (Sengupta et al., 2015).

Although PVs respond to global irradiance, this variable actually depends on the inclination and orientation of the plane used to measure it. Normally, global irradiance is measured on the horizontal plane, but PV panels are mounted at differing angles. Thus, pyranometers need to be oriented according to the PV panel orientations in order to provide the most appropriate resource assessment for the specific panel setting used. The cost of taking these measurements may be acceptable for a large solar farm, for which a large quantity of panels share the same geometry. In the case of residential rooftop PVs, however, the orientations generally vary from
case to case. Thus, a decomposition of the global irradiance, usually on the horizontal plane, is carried out
with a subsequent recomposition on the target PV plane. This process requires the knowledge of at least two
irradiance components, for example, global and direct irradiances, therefore increasing observation costs.
In practise, approximations exist, via statistical procedures, that convert global irradiance on the horizontal
plane onto any inclination and orientation angles. However, because they do not rely on local observations,
such statistical approximations have a lower accuracy.

In the absence of long-term ground data, the solar resource can be estimated via satellite imagery. In regional
terms, identifying prime solar resource areas is fairly simple. The south-western United States, for example,
has broad areas of excellent solar resource. However, narrowing down the data to a specific few square
kilometres of land requires considering local impacts. Although satellite data are very useful for mapping
large regions, individual sites should be vetted using ground-monitoring stations. Local measurements can
be compared to same-day satellite data to test for bias in the satellite model results (Sengupta et al., 2015).
Specifically, estimates of global horizontal irradiance (GHI) and direct normal irradiance (DNI) at the surface can
be obtained from geostationary satellites. As geostationary satellite coverage is available at regular intervals
on a fixed-grid surface, radiation can be available for the entire globe (at least between approximately −60°
and +60° latitudes) at temporal and spatial resolutions representative of a particular satellite.

In addition to solar irradiance, several other meteorological variables need to be considered for a proper
estimation of PV power yield. In fact, PV panel performance depends also on air temperature, wind speed
and, to a lesser extent, humidity. Specifically, air temperature (and irradiance) affects the solar panel
temperature, which has an inverse relationship with PV performance. As a general rule, an increase of 1 °C
in panel temperature reduces the power output by 0.5% (Skoplaki and Palyvos, 2009). PV panel temperatures
can reach values as high as 80 °C (Ye et al., 2013).

DNI is the most important meteorological input parameter for CSP plants; however, further parameters
must be provided for accurate yield analysis. High wind speed might force the plant operators to set
the collectors to their storage position. Thermal losses are influenced by wind (convection) and ambient
temperature. Humidity and pressure also have an effect on the thermodynamic performance of CSP plants
(Chhatbar and Meyer, 2011). Other parameters such as soiling and the extinction of radiation between the
mirror and the receivers have also attracted interest (Sengupta et al., 2015).

As with wind, there are a number of global, regional and national resource assessment initiatives, such as
those led by IRENA and ESMAP.

2.3.2 Impact Assessment

Infrastructure impacts – solar PV infrastructure can be affected by a number of factors such as:

- Humidity freeze
- Thermal cycle, especially with high-temperature operation
- Damp heat
- Strong winds, affecting the bracing or rotating parts of the solar power plant
- Hail

Environmental impacts – utility-scale solar energy environmental considerations include: land disturbance/
land-use impacts; potential impacts to specially designated areas; impacts to soil, water and air resources;
impacts to vegetation, wildlife, wildlife habitat and sensitive species; visual, cultural, palaeontological, socioeconomic and environmental justice impacts; and potential impacts from hazardous materials. Solar power facilities reduce the environmental impacts of combustion used in fossil fuel power generation, such as impacts from GHG emissions and other air pollution emissions. Unlike fossil fuel power generating facilities, solar facilities have very low air emissions of air pollutants such as sulphur dioxide, nitrogen oxides, carbon monoxide, volatile organic compounds and carbon dioxide during operation. However, there are also some adverse impacts associated with solar power facilities that must be considered. Potential adverse impacts to various resources associated with the construction, operation and decommissioning of solar power plants are briefly outlined below. These impacts and mitigation measures for solar facilities are addressed in detail in the Solar Energy Development Programmatic Environmental Impact Statement. Overall, and on the basis of 32 environmental impacts for solar power plants, Turney and Fthenakis (2011) found that 22 were beneficial relative to traditional power generation, 4 were neutral, none were detrimental and 6 needed further research. All high-priority impacts were favourable to solar power displacing traditional power generation, and all detrimental impacts from solar power were of low priority. Turney and Fthenakis (2011) found the land occupation metric to be the most appropriate for comparing land-use intensity of solar power to other power systems, and that a solar power plant occupied less land per kilowatt-hour than a coal-powered plant, for plant lifetimes beyond approximately 25 years.

Land disturbance/land-use impacts – all utility-scale solar energy facilities require relatively large areas for solar radiation collection when used to generate electricity at utility scale (defined for the Solar PEIS as facilities with a generation capacity of 20 MW or greater). Solar facilities may interfere with existing land uses, such as grazing, wild horse and burro management, military uses and mineral production. Solar facilities could impact the use of nearby specially designated areas such as wilderness areas, areas of critical environmental concern or special recreation management areas. Proper siting decisions can help to avoid land disturbance and land-use impacts.

Ecological impacts – the clearing and use of large areas of land for solar power facilities can adversely affect native vegetation and wildlife in many ways, including loss of habitat, interference with rainfall and drainage, or direct contact causing injury or death. The impacts are exacerbated when the species affected are classified as sensitive, rare, or threatened and endangered.

Other impacts – because they are generally large facilities with numerous highly geometric and sometimes highly reflective surfaces, solar energy facilities may create visual impacts; however, being visible is not necessarily the same as being intrusive. Aesthetic issues are, by their nature, highly subjective. Proper siting decisions can help to avoid aesthetic impacts to the landscape. Additionally, particularly CSP systems could potentially cause interference with aircraft operations if reflected light beams become misdirected into aircraft pathways. However, such effects are not too dissimilar from reflections from bodies of water or buildings.

2.3.3 Site Selection and Financing

Unlike the Identification and Resource Assessment stage, where the quality of the observations and also the exact location of the instrument are less critical, with Site Selection and Financing, the best possible instrumentation at the precise location of the proposed solar farm is required. This is because, and like with any other generation source, knowledge of the quality and future reliability of the fuel is essential for accurate analyses of system performance and financial viability of a project.

12  http://solareis.anl.gov/guide/environment/
Financial institutions evaluate the risk associated with uncertainty in solar resource data in terms of exceedance probabilities (for example, P50 or P90). P50 is the result of achieving an annual energy production based on the long-term median resource value. For this value, the probability of reaching a higher or lower energy value is 50:50. For example, typical meteorological years represent the P50 value. For an exceedance probability of P90, the risk that an annual energy value is not reached is 10% (90% of all values in a distribution exceed the P90 value) (Sengupta et al., 2015).

Studies have also been undertaken to determine how long surface measurements at a proposed site should be taken before the true long-term mean is captured. This is important when no concurrent datasets are available and yet project finance decisions must still be made. Another way to look at the problem is to ask how representative a short-term (perhaps one year) measurement is to the “true” climatological (nominally 30 year) mean. In the wind industry, a rule of thumb is that it takes 10 years of on-site wind measurements to obtain a mean annual wind speed that is within ±10% of the true long-term mean, which is generally required by financial institutions. But in a case with only one or two years of on-site measurements, these data may be all that are available to a financial institution conducting due diligence on a project (Sengupta et al., 2015).

Tomson et al. (2008) showed that the mean annual global irradiation in any year was virtually independent of the previous year, which means that 11 years of on-site measurements does not represent the long-term mean. Gueymard and Wilcox (2011) examined long-term data from four National Solar Radiation Database stations in the United States to address questions about how many years of measurements it takes to converge to the long-term mean and whether the variability in annual radiation changes significantly from one site to another. The results show that, first, there is much lower interannual variability in GHI than in DNI. GHI is almost always within ±5% of the true long-term mean after only one year of measurements, regardless of which year these measurements are taken. However, the situation is quite different for DNI. After only one year of measurements, the study shows that the estimate of the average DNI is no better than ±10% to ±20% of the true long-term mean. Another way of stating this finding is that the coefficient of variation for DNI is generally two to three times higher than the coefficient of variation for GHI (which is in line with the work of Davy and Troccoli (2014)).

2.3.4 Operation and Maintenance

Operation of solar farms relies heavily on forecasts at various timescales. Solar forecasting is an active area of research. Depending on the time-horizon, different techniques to produce a solar forecast can be used. At the shortest timescales, up to about 30-minute statistical models and/or sky imaging is used. For longer timescales and up to several hours, irradiance derived from satellite cloud images can be effective. Beyond several hours, however, the use of NWP models becomes necessary.

It is important to also consider potential losses due to shading, soiling and snow coverage, as well as temperature effects on PV panel efficiency, direct current cable losses and inverter losses.

Less than 3% of the total water consumption of solar thermal plants is used for the purpose of washing their mirrors. Development of an efficient and cost-effective programme for monitoring mirror reflectivity and washing mirrors is critical. Differing seasonal soiling rates require flexible procedures. For example, high soiling rates of 0.5%/day have been experienced during summer periods. After considerable experience, operation and maintenance procedures have settled on several methods, including deluge washing and direct and pulsating high-pressure sprays (Hoffschmidt et al., 2012).
As with wind energy, solar power forecasting is key to the effective integration of solar power into the grid. Much effort is being devoted to improving solar forecasting. For instance, NCAR leads a project that involves performing research, testing the forecasts in several geographically and climatologically diverse high-penetration solar utilities and independent system operators, and wide dissemination of the research results to raise the bar on solar power forecasting technology. The partners include three other national laboratories, six universities, industry partners, including four forecast providers, six utilities and four balancing authorities.\(^{13}\) Similarly, the Australian Solar Energy Forecasting System has provided the Australian Energy Market Operator (AEMO) with an operational system that uses basic forecasting techniques to cover all the AEMO-required forecasting time frames, which range from five minutes to two years. The system caters for large-scale PVs and solar thermal plants, as well as distributed small-scale PV systems.\(^{14}\)

3. Hydropower

Hydropower is a renewable energy source where power is derived from the potential energy of water moving from higher to lower elevations. It is a widespread, proven, mature, predictable and cost-competitive technology. It is one of the lower GHG-emitting technologies over its whole life cycle, and its contribution is therefore very interesting for reducing the power sector's carbon release to the atmosphere (IPCC, 2011). Hydropower is one of the most-efficient energy conversion systems, with 90% water to wire efficiency, and even up to 96% efficiency in the best operational conditions for recent turbines.

3.1 Importance of hydropower for society

Hydropower provides a significant amount of energy throughout the world, even if, so far, only 25% of the hydropower potential has been developed across the world. It is used in more than 100 countries, contributing approximately 17% of the global electricity production (Figure 4). The top countries for hydropower in terms of capacity and generation are (in increasing order) India, Russian Federation, Canada, the United States, Brazil and China. The total capacity of these six countries represented 60% of the global capacity at the end of 2014 (REN21, 2016). In several other countries, hydropower accounts for over 50% of all electricity generation, for example, Norway, Iceland and Mozambique. In 2014, an estimated 37 GW of new hydropower capacity was commissioned, bringing the global total to approximately 1 055 GW. An additional 2.4 GW of pumped storage capacity was commissioned: this reached an estimated total of 146 GW at the end of 2014 (REN21, 2016). In some countries, the growth in hydropower has been facilitated by the renewable energy support policies and carbon dioxide penalties. Over the past two decades, the total global installed hydropower capacity has increased by 55%, and the actual generation by 21%. However, in recent years, despite an increase in global installed hydropower capacity, the total electricity produced dropped significantly in many countries, partly due to water shortages, as well as an evolving energy mix and markets, which, in turn, encouraged hydropower industries to operate in peak mode rather than baseload, therefore reducing the overall generation figures (WER, 2016; REN21, 2016).

Hydropower is flexible and can be reactive, as power output can be increased or decreased very quickly to respond to variations in electricity demand. In addition, pumped storage is the largest-capacity and most

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\(^{13}\) [https://www.ral.ucar.edu/projects/doe-suncast-solar-forecasting](https://www.ral.ucar.edu/projects/doe-suncast-solar-forecasting)

commercially viable form of grid energy storage available today. Hydropower is therefore a vital component of electricity systems as it can deliver services to the whole power system of a country/area. Allowing for the management of river flow, reservoir hydropower can support fossil fuel and nuclear power generation, especially for regulating cooling water availability, and provides the required flexibility to allow a larger integration of VRE resources (wind and solar power, in particular). It can even be used to pump water back into reservoirs, absorbing excess system capacity and therefore avoiding VRE curtailment when such sources produce too much energy in periods of low demand.

**Figure 4. Estimated energy shares of global electricity production, end of 2015**

Though the primary role of hydropower in global energy supply today is in providing centralized electricity generation, hydropower plants can also operate in isolation and supply independent systems, often in rural and remote areas of the world (IPCC, 2011). Hydropower, when associated with reservoir storage capacity, can also provide services for water management for drinking water supply, irrigation, flood control, drought mitigation, navigation services and tourism.

Installed on rivers, hydropower plants can also take advantage of large tides, as is the case, for instance, in France for the La Rance tidal power production plant. However, this kind of application is only used marginally in a global context.

Table 3 summarizes the main benefits and drawbacks of hydropower.

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low operating costs; cost competitive with fossil fuels</td>
<td>High capital expenditure</td>
</tr>
<tr>
<td>No waste or CO₂ emissions</td>
<td>Significant land requirement for large plants with dams/lakes</td>
</tr>
<tr>
<td>Simple proven technology with high efficiency</td>
<td>Public resistance due to relocation or microclimate effects</td>
</tr>
<tr>
<td>Freshwater management for multiple purposes</td>
<td>Ecological impacts on the river system</td>
</tr>
<tr>
<td>Flexible and non-variable (as opposed to wind and solar power)</td>
<td></td>
</tr>
<tr>
<td>Lower levelized cost of energy than other renewable energy sources</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 summarizes the main benefits and drawbacks of hydropower.
3.2 Hydropower and its interaction with the climate system

Hydropower is obviously dependent on river flow, and more generally, the water cycle, and its variability. Generation depends on the season, with periods of high/low flows, but it is also affected by interannual variability. For instance, in France, in the last 25 years, the difference between the highest and lowest annual generation potential was 23 TWh, for a theoretical maximum generation of 44.4 TWh (Dubus, 2014).

River flow depends on:

• The geography, orography and geology of the watershed, and its land structure (the type of vegetation controlling, in part, the speed at which the water enters rivers or groundwater);
• Precipitation and snow amounts;
• Air temperature, which in particular controls the snow-melting process in spring in mountainous areas; the altitude of the 0 °C isotherm is of particular importance;
• Evaporation, which plays a strong role in controlling the water level in large areas of reservoirs, in particular in tropical and subtropical regions.

Of course, floods and droughts have a strong impact on hydropower generation. The former, generally a sudden, short-duration event, can imply the release of water with no electricity production, to ensure the security and safety of installations, and also of people living in the area. Consequent flooding can nevertheless also have detrimental impacts on people and assets downstream. Droughts, which are slower but longer lasting events, can substantially reduce power generation capacity, either because of the direct lack of water, or because the small available amount of water is needed to address other uses, such as drinking water supply or irrigation for agriculture.

As hydropower is dependent on weather and the water cycle, it can have the following environmental and social impacts (IPCC, 2011):

• Changes in hydrological/flow regimes;
• Erosion due to fluctuations in water levels, either in lakes or along rivers;
• Changes in biodiversity (including fish habitat and terrestrial habitat);
• Changes in water quality;
• Changes in sedimentation;
• Barriers for fish migration and navigation;
• Involuntary population displacement.

Hydropower generation management requires river flow forecasts at the different timescales at which power systems are operated: yearly, quarterly, monthly, weekly, daily and intra-daily. The current practice is to use weather forecasts that are either deterministic or probabilistic depending on the ability and means of each company, of up to one or two weeks. For longer timescales, some energy companies use intra-seasonal to seasonal forecasts, but the climatological approach, which uses historical time series of precipitation and/or river flow, is more widespread. On longer timescales, for planning purposes, the general rule is to use climatological information as well, even if an increasing number of companies have started to use climate change projections.

According to the Intergovernmental Panel on Climate Change (IPCC) Special Report on Renewable Energies (IPCC, 2011), climate change is expected to increase overall average precipitation and runoff, but regional patterns will vary. The impacts on hydropower generation are likely to be small on a global basis, but significant regional changes in river flow volumes and timing may pose challenges for planning and operation (Figure 5).
Figure 5. Annual mean changes in precipitation (P), evaporation (E), relative humidity, E – P, runoff and soil moisture for 2081–2100 relative to 1986–2005 under the representative concentration pathway RCP8.5. The number of Coupled Model Intercomparison Project phase 5 models to calculate the multimodel mean is indicated in the upper right corner of each panel. Hatching indicates regions where the multimodel mean change is less than one standard deviation of internal variability. Stippling indicates regions where the multimodel mean change is greater than two standard deviations of internal variability and where 90% of models agree on the sign of change.

The IPCC Fifth Assessment Report (IPCC, 2013) confirms that changes in the global water cycle in response to warming over the twenty-first century will not be uniform. The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions. In addition, the report indicates that regional- to global-scale projections of soil moisture and drought remain relatively uncertain compared to other aspects of the water cycle. Nonetheless, drying in the Mediterranean, south-western United States and southern African regions is consistent with projected changes in the atmospheric circulation. Therefore, drying in these regions as global temperatures increase is likely for several degrees of warming under the representative concentration pathway RCP8.5. Decreases in runoff are likely in southern Europe and the Middle East. Increased runoff is likely in high northern latitudes, consistent with the projected precipitation increases there.
A limited number of studies show that climate change may have a slightly positive impact on existing hydropower systems, but regional discrepancies exist, in line with the above described patterns of precipitation and river flow – for example, a negative impact is estimated in southern Europe and the Mediterranean basin.

Clearly, hydropower systems with a low storage capacity will be more vulnerable to climate change than those with a higher storage capacity, as they do not benefit from the operational flexibility provided by storage capacity. However, even installations with storage may be affected, especially with increased evaporation due to higher air temperatures, in particular in subtropical and tropical regions. Based on these likely changes, adaptation measures can be taken to improve the level of resilience of hydropower systems, with project design and location choices being key elements (WBCSD, 2014) (see Table 4).

The water storage component of hydropower (the reservoir) will become increasingly important in the future, as it will ensure hydropower assets are more resilient, but also because societies will need more water storage to help adapt to climate change. Reservoir hydropower can then provide climate adaptation services by allowing better management of water resources. Understanding future events, such as floods and droughts, will be a key component for deciding on the appropriate amount of reservoir storage capacity.

### Table 4. Climate change impacts and adaptation resources for hydropower systems

<table>
<thead>
<tr>
<th>Climate change effects</th>
<th>Likely impacts</th>
<th>Appropriate responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changes in precipitation and snowmelt</td>
<td>Changes in the location and patterns of precipitation will decrease hydropower production in some dams and increase it in others. Runoff from rivers in areas dominated by snowmelt may occur earlier in the year and with increased seasonal precipitation cycles. Even relatively minor variations may make hydropower output more difficult to forecast in the long term.</td>
<td>Changes to the management of the plant and redesigns for certain elements. Increase dam height and/or build small dams upstream if flow is expected to increase. Modify number and type of turbines more suited to expected water flow rates. Modify canals or tunnels to handle expected changes in water flows.</td>
</tr>
<tr>
<td>Drought</td>
<td>Inadequate water volumes and the risk of damage from silt, which has already happened to many turbines in India.</td>
<td>Build or augment water storage reservoirs. Modify spillway capacities to flush silted reservoirs. Upgrade or adapt turbine runners to increase silt resilience and ability to operate in lower capacity conditions.</td>
</tr>
<tr>
<td>Landslides and other land effects</td>
<td>Hydropower infrastructure may incur physical damage – the flood from the Dig Tsho glacial lake outburst in Nepal in 1985 destroyed 14 bridges and damaged a hydropower plant.</td>
<td>Design dams and infrastructure that are more robust to withstand heavy flooding and extreme events. Encourage forestation around reservoirs.</td>
</tr>
<tr>
<td>Higher air temperatures, wind speeds and humidities</td>
<td>Increased surface evaporation, reducing water storage and power output.</td>
<td>Build or augment reservoirs.</td>
</tr>
</tbody>
</table>

Source: WBCSD (2014)

### 3.3 Needs of the hydropower subsector for climate services

Given the technical, physical and societal considerations discussed above, the needs of the hydropower industry in terms of climate services for each of the five focus areas are identified here.
Generally speaking, the increasing share of renewable energy sources in energy mixes requires a homogeneous approach with regard to climate data. Historically, air temperature (which controls power demand) and river flow have been the key variables that needed to be considered in order to optimize the supply/demand balance for electricity. With the increased share of wind or/and solar power generation, the climate dependence of power systems is increased, and there is a strong need to provide energy companies with coherent and homogeneous datasets of the different climate variables they use: air and water temperature, wind speed, solar radiation, precipitation, river flow, etc.

Therefore, strengthening communication (UIP and CD) among the energy sector and the meteorological community will be essential for homogenizing datasets in terms of quality and availability (Obs/Mon and CSIS). Provision of climate predictions at all timescales, and most importantly at sub-seasonal to seasonal lead times, and climate projections will require the development of multivariate methodologies for downscaling and model bias adjustment.

As they share the same resource (water), another key aspect is that a close collaboration is required among the energy, water management and agriculture sectors in particular.

### 3.3.1 Identification and Resource Assessment

Some 75% of the world hydropower potential is still unexploited. Properly selecting the most relevant sites for building new plants is therefore a key issue. Apart from political, economic and social acceptance considerations, long-term information about the hydrological cycle is an essential piece of information, both in the past (Obs/Mon) and the future (CSIS). In particular, long time series of river runoff data are not available in many parts of the world. In addition to new observing systems, long and high-resolution reanalysis coupled to hydrological models can thus provide very useful information. As hydropower plants are built for several decades, the long-term evolution of the hydrological cycle, its seasonal variations in the future, and the changes in extreme events intensity and frequency also need to be assessed. Uncertainty about the hydrological cycle in current climate change projections is still high, despite constant improvement in climate models. Reduction in uncertainty, or at least a better understanding of the uncertainties, will help to reduce risks and better dimension future assets (RMP and CSIS), hence reducing the investments costs of hydropower projects. Improved communication, training and dialogue with users will allow the available information to be better taken into account in the decisions made (UIP and CD).

### 3.3.2 Impact Assessment

Infrastructure impacts – as for any other infrastructures, extreme events are of particular importance to the hydropower subsector. Information needs cover:

- **Short- to medium-term forecasts of flood risks**, where they do not exist, or improvements of existing systems, such as the European Flood Alert System;

- **Seasonal to annual forecasts of droughts**, to allow a better management of water stocks in reservoirs and to anticipate decrease in production due to runoff decrease;

- **Longer-term (decadal to centennial timescales) evaluation of extremes**, to adapt existing assets so that they can still operate under different conditions, without degrading the surrounding environment.
Environmental impacts – erosion, sediment transport and reservoir sedimentation have negative impacts on efficiency, and biological/chemical/biodiversity impacts. Obs/Mon and modelling of these processes is important in order to monitor and anticipate both power generation perturbations and environmental impacts. In addition to Obs/Mon, CSIS and RMP, this also requires increased communication among service providers and users in different sectors (energy, agriculture and water management), in particular, for sharing practices and exchanging information (UIP and CD).

3.3.3 Site Selection and Financing

Hydropower requires a high initial investment, but then has low operation and maintenance costs and long lifespan. The profitability of new production sites depends strongly on the initial assessment made in the power output potential and the availability of the resource over the whole duration of the plant. Again, long observed time series of river runoff and of its variability throughout the year, together with future projections, are essential. Climate data are also essential for selecting the most appropriate hydropower plant design to withstand climate impacts and to provide sufficient water storage for flood protection/drought mitigation.

3.3.4 Operation and Maintenance

Although hydropower is an advanced and efficient technology, improvement is still possible, in particular, if more-accurate weather and climate information is made available. Improvements in river runoff forecasts at all timescales would generally allow better management of water stocks in reservoirs, noting that the most interesting progress would come from sub-seasonal to seasonal forecasts instead of current climatological approaches. Research efforts are needed in this field to improve the understanding and modelling capacities of the hydrological cycle at these timescales (RMP).

On the shorter term, improved flood forecasts (intense rainfall events) can greatly help operation and save money by optimizing water releases (CSIS and RMP).

3.3.5 Energy Integration

As a flexible generation means, and with the help of storage and pumped storage, hydropower is an ideal candidate to support VRE integration. Pumped storage can be used to provide an active power reserve. In addition, for interconnected networks, hydropower can be used as a balancing reserve for neighbouring countries, as is the case for Norway, Germany and the United Kingdom. Hydropower can supplement wind and solar energy when their production is too low, or help avoid their curtailment when generation is too high, by using their energy to pump water back into reservoirs.

The integration component requires coherent information, both spatially and temporally, for the different production means (hydro, wind and solar power in particular) and electricity demand. The necessary weather and climate observations should then be available at the same space and time resolution, with the physical coherence of the datasets being key, in order to develop robust climate-based tools to advise energy planners and policymakers who must assess:

1. The ways in which energy supply and demand are affected by the spatial and temporal variations of their climate drivers;
2. How scenarios with different energy supply mixes can meet demand at the continental scale, particularly given the projected high level of highly climate-sensitive renewable energy.

Developing such datasets, both in the past (from observations or reanalyses) and in the future (climate predictions and projections), requires methodological developments, for instance, to calibrate reanalysis on in situ observations, or to adjust biases in a multivariate approach in climate simulations (RMP). This demands that available observations are shared widely, which, for instance, is far from being the case for river runoff data (Obs/Mon, UIP and CD).

4. Thermal power

Thermal power is the most common and currently used method for producing electricity. Steam that is generated drives a turbine, which is connected to an electrical generator. The steam is then condensed into water and reused. This cycle is known as the Rankine cycle. The different types of thermal power are defined by the procedure used to heat the water and produce steam. The fuel used can be coal, gas, nuclear, waste, biomass and even solar (CSP). A key element in a thermal power plant is its cooling system. The two main types are: (a) a heat exchanger, which uses cold water from the sea or a river; and (b) a cooling tower that provides cold fluid to the condenser, with the cold fluid becoming heated and the heat being released to the atmosphere via natural convection in the cooling tower. In many cases, both systems are used simultaneously.

4.1 Importance of thermal power for society

If renewable energy sources have increased significantly their share in the world energy production in the last decades, fossil fuels are still dominating the world total primary energy supply (Figure 6). Oil, coal and natural gas accounted for 81.1% of the total production in 2014.

![World total primary energy supply (TPES) from 1971 to 2014 by fuel (Mtoe)](https://example.com/figure6)

Figure 6. World total primary energy supply. Left: evolution from 1971 to 2014; right: shares in 2014

1. World includes international aviation and international marine bunkers.
2. In these graphs, peat and oil shale are aggregated with coal.
3. Includes geothermal, solar, wind, heat, etc.

IEA (2018)
World electricity generation is dominated by the use of fossil fuels, with 66.7% of the total supply in 2014 coming from coal, oil and gas. Nuclear power also plays an important role, especially in countries that are members of the Organisation for Economic Co-operation and Development, with 10.6% of the total supply in 2014 (Figure 7).

In many countries, thermal power is the main source of electricity generation. Where other production sources exist (nuclear and renewable energy sources, in particular), thermal power plants also have an important role. They provide the flexibility to manage peaks in demands, for instance, during cold snaps in winter or heatwaves in summer. They can also be used to deal with the intermittency of renewable energy sources such as wind and solar energy. In such countries, thermal power is generally the main backup for renewable energy sources.

Coal plays an important role in delivering energy access because it is widely available, safe, reliable and relatively low cost. Coal resources are large, particularly in developing countries in Asia and Africa, and coal will still play an important role in the developing world in the coming decades.

The oil industry is a mature industry with good returns on investments. Even if its share in global electricity production is modest (about 4% in 2014), it offers a low-cost resource in countries with reserves.

Natural gas has increased its share in global electricity supply, and the trend will continue in the coming decades, especially due to the replacement of old coal and fuel production units by modern and efficient gas-fired power generation plants, such as combined cycle gas turbines with conversion efficiencies of about 60%.

Notwithstanding considerations with respect to the problems of security of nuclear energy, nuclear waste and social acceptance, nuclear energy represents an advantage in climate change mitigation, as it is a power generation technique producing low emissions of carbon dioxide. In addition, once commissioned,
nuclear power plants have very low production costs, and allow countries to secure their power supply, in particular with respect to fossil fuel imports and prices. For example, France, which obtains a high percentage of its power from nuclear energy sources, has electricity prices among the lowest in Europe.

According to IEA and WEC, the share of nuclear energy should slightly increase by 2020 and beyond, and the share of fossil fuelled power production should decrease, due to decommissioning of old production units. However, the global share of fossil fuels and nuclear energy will remain dominant in the world energy production, in particular in the power sector (WER, 2016; IEA, 2016). Moving away from fossil fuels will take decades, as coal, oil and gas will remain the main energy resources in many countries. In the IEA New Policies Scenario, demand for oil will continue rising, despite measures and policies aimed at promoting energy efficiency and fuel switching (WEO, 2016). Global gas use will also continue to grow, and will become the second-highest fuel in the global energy mix, after oil.

Fossil fuels will continue to dominate the power sector, although their share of generation will decline from 67% in 2014 to 55% in 2040 according to the New Policies Scenario. Gas-fired power generation, in particular, will increase in most regions of the world. Nuclear power generation should slightly increase from about 11% today to 12% in 2040.

4.2 Thermal power and its interaction with the atmosphere

As thermal production is based on combustion of fossil fuels, it has impacts on the atmosphere, by releasing post-combustion chemical species into the air. These species can then either be deposited in the neighbourhood of the plant, or be transported in the atmosphere, where eventually they can interact chemically with other atmospheric constituents to form other species. The emitted species can be nitrous oxides, sulphurs, aerosols and, of course, carbon dioxide. All of these elements have impacts on the chemical composition of the atmosphere, and its radiation budget.

The power industry devotes considerable effort to reducing its GHG emissions, in particular, by developing technologies to reduce the impacts of thermal power plants on the atmosphere. These include, for instance, using circulating fluidized beds, which reduce nitrous oxides and sulphur emissions, using supercritical clean coal or using a combined cycle, which allows a higher efficiency rate. Knowledge of coal and fuel characteristics allows selection of the best-quality resource, and reduction of emissions. In addition, carbon capture and storage (CCS) allows significant reduction of the release of gases into the atmosphere, but at the price of a decrease in generation efficiency. CCS was identified by WER (2016) as one of the key elements for reducing carbon dioxide emissions in the power sector in the next few decades.

Conversely, the environment has impacts on thermal generation. First, exploration, extraction and transport of fossil fuels is dependent on climatic conditions, both onshore (mines can be flooded, as was the case, for instance, in eastern Australia in 2011) and offshore (oil drilling platforms, in particular, are exposed to storms and hurricanes, such as Katrina in 2005 in the Gulf of Mexico; operation and maintenance, and oil and coal shipping, depend on the sea state and wind force).

Like any other infrastructure, thermal power generation plants can be affected by severe and extreme weather events, causing unavailability of the production means or even damage to the plants.

Thermal conversion efficiency depends on the ambient air temperature. The efficiency of cooling systems depends on several parameters: water temperature (ocean and rivers), river flow (with special emphasis
on drought periods, but also in the case of floods) and air temperature and humidity, which control the efficiency of cooling towers. Rising air and water temperatures and lack of water may lead to reduced power generation or temporary shutdowns. Nuclear power plants are subject to similar risks, with possible disruption of the functioning of critical equipment.

Thermal plants include a variety of sources, and their shared advantages and disadvantages are listed in Table 5.

Table 5. Benefits and drawbacks of thermal energy

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexible</td>
<td>High CO₂ emissions</td>
</tr>
<tr>
<td>Adaptable anywhere</td>
<td>Possible non-domestic sources of energy</td>
</tr>
<tr>
<td>Reliable</td>
<td>Non-renewable resources</td>
</tr>
</tbody>
</table>

4.3 Needs of the thermal power subsector for climate services

Many needs have already been addressed in the previous sections on wind, solar and hydropower, which also apply to thermal power generation. In particular, the close links among thermal power production and water temperature and availability (river flow) reflect the fact that needs identified for the hydropower case are equally relevant for thermal power. In the following, we will only introduce incremental or specific needs to avoid repetition.

4.3.1 Identification and Resource Assessment

As thermal power strongly relies on fossil fuels, changes in conditions of access to resources is a key issue, especially in the offshore oil and gas industry; climate change is likely to increase sea level, exacerbate high-impact weather events (storm frequency and sea state) and affect deep currents for deep ocean drilling, or pipeline resilience. Oil and coal shipping cost and security are particularly sensitive to ocean waves. Therefore, long time series of observations and reanalysis (Obs/Mon) and statistical methods to anticipate future extremes in a non-stationary climate (RMP) are needed, to allow for evaluation of extremes. Short-term to seasonal forecasts of sea states and surface winds are also needed to optimize operation and maintenance, as well to optimize shipping routes and to choose the best locations for fuel supply (CSIS).

Cooling systems require information on air and water temperatures and river flow, at short to seasonal timescales for operation, and long-term projections for plant adaptation or site selection and dimensioning. CSIS would then consist of maps and, more generally, datasets generated by using, and also combining, as many sources of air temperature, water (ocean and river) temperature, river flow, and ocean waves and surface winds. The relevant spatial scales range from global to local, with a strong need for downscaling methods and uncertainty analysis (RMP and CSIS).

4.3.2 Impact Assessment

Thermal power plants have an impact on their surrounding environment through their releases both into the atmosphere and into the water. Regulations exist and are under constant revision to minimize such
impacts, for example, regulations aimed at preserving wildlife in rivers and at temperature limits to protect indigenous species. Thermal power plants consume up to several thousand litres of water per megawatt-hour produced, changing the natural environmental conditions of surrounding water, and the carbon dioxide emissions affect the climate of the planet through global warming.

Climate change will have impacts on the design and operation of thermal power plants too. As for hydropower, flood and drought risks may have to be revisited and adaptation measures taken. Sea level, wave heights, storm surges, and high air and water temperature extremes may have to be reassessed, through existing or to-be-developed methods in order to provide inputs for adaptation. In addition to adaptation, resilience may be enhanced by short- to medium-term forecasts of flood, storm surge or heatwave risks (air and water temperature forecasts).

4.3.3 Site Selection and Financing

Identification/selection of sites for mining and drilling by taking into account changes in access conditions needs to be improved, as does exploitation. Changes in coal handling will need to be implemented due to the increased/decreased moisture content of coal.

4.3.4 Operation and Maintenance

Real-time monitoring of atmospheric composition and associated alert systems can help to optimize the power generation unit mix, by reducing the power generation from fossil fuel units in the case of a pollution event, for instance, during an atmospheric blocking event. Development and availability of atmospheric composition observing and forecasting systems, such as those developed in the Global Atmospheric Watch programme and the Copernicus Monitoring Atmospheric Composition & Climate project in Europe would be required worldwide, with user-friendly, easy and real-time access to the information being a key issue for decision-making in operation. Strong interaction among providers and users is essential and emphasizes the role of UIPs and the need for CD.

In addition to the needs identified for the hydropower subsector (temperature of water in rivers, river flow and their evolution under future climate), the same type of information is required for water temperature (rivers and oceans), air temperature and humidity in the thermal power subsector, in order to assess changes in cooling capacity at different timescales, from seasonal to multidecadal.

Offshore operation and sea shipping require Obs/Mon and forecasts up to several weeks in advance for sea states (wave heights and surface winds), extreme winds and storms.

4.3.5 Energy Integration

In order to meet ever-fluctuating load demands, utilities must be able to predict, to a high degree of accuracy, when, and to what extent, loads will change, so that they can take action to increase or decrease the supply of electricity to meet these changes. The bulk of the power supplied to a grid typically comes from baseload power plants, traditionally plants that provide large quantities of electricity through steam generation systems or large hydropower plants. As the load increases, utilities must bring in additional power sources from facilities that can be started up quickly, such as mid-merit or peak plants (Renné, 2014).
In this context, it is critical to consider the reaction time of thermal power plants and the cost-effectiveness of their use, including possible carbon costs (the latter determined by either taxation or market mechanisms). Thus, gas turbine power plants are the most flexible in terms of adjusting power level, but are also among the most expensive to operate. Therefore, they are generally used as “peaking” units at times of maximum power demand. Diesel and gas engine power plants can be used for baseload to standby power production due to their high overall flexibility. Such power plants can be started rapidly to meet grid demands. Large coal-fired thermal power plants can also be used as load-following\textsuperscript{15}/variable-load power stations. Older nuclear (and coal) power plants may take many hours, if not days, to achieve a steady-state power output. In general, it is not economical for large thermal installations such as nuclear power plants to practise load following.

By adding predictions of energy demand – which, in turn, are markedly affected by meteorological conditions – to these cost considerations, scheduling of specific power plants can be planned. Consequently, the cost of electricity is determined by exactly which power plant(s) is (are) used to meet the expected demand.

\textsuperscript{15} A load-following power plant is a power plant that adjusts its power output as demand for electricity fluctuates throughout the day.
Annex 2 – Relevant Existing Activities in the Climate and Energy Domain

The climate and energy initiatives discussed in this annex highlight the breadth of products and services that are already being developed by a wide number of organizations around the world. By listing a number of relevant initiatives, the complexity of the needs of the energy sector for climate products and services will become apparent. Rather than trying to structure the annex according to well-defined clusters, the aim here is to provide an illustrative overview of currently developed climate services and products, to assist in identifying the needs and priorities of the energy sector. Naturally, the list of products and services presented here is by no means exhaustive.

1. International Energy Agency

To help address the threat that climate change poses to energy systems, IEA launched the Nexus Forum16 in 2012 as a platform for enhancing awareness of the impacts of a changing climate on the energy sector and to share emerging experience on building energy sector resilience. IEA is currently working to enhance the climate change resilience aspect in several of its core activities:

1. Dialogue facilitation: promote dialogue on climate change impacts and resilience topics of relevance to business and policymaking communities through the Nexus Forum workshops on the climate change–energy security nexus;

2. Policy information collection and dissemination: identify energy resilience and preparedness policies that are being used by governments and appropriate platforms for disseminating this information to stakeholders. The IEA Policies and Measures Database17 is being expanded to include relevant resilience policies;

3. Data and modelling: investigate how data and modelling of climate impacts on the energy system can be improved. IEA has already begun to deepen its analysis of resilience issues, notably reflected in the IEA publication on climate (IEA, 2013b). Further consideration is being given to integrating climate change impacts and their uncertainties (and potentially adaptation/resilience policies) into IEA modelling and analytic capabilities;

4. Research stocktaking on impacts, vulnerability and resilience policy: keep abreast of and help to disseminate emerging studies in the literature;

5. Policy development: facilitate the development of resilience and preparedness policies. Building on the experience of the Nexus Forum, IEA is exploring how it could play a proactive role in actual policy development on both the government and business sides. Existing processes within IEA, as well as outreach to member States, could potentially enable future actions in this workstream.

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17  http://www.iea.org/policiesandmeasures/
2. United States Department of Energy

DOE, in the United States, recently launched the Partnership for Energy Sector Climate Resilience\(^\text{18}\), an initiative to enhance energy security by improving the resilience of energy infrastructure to extreme weather and climate change impacts. The goal is to accelerate investment in technologies, practices and policies that will enable a resilient twenty-first century energy system. Under this partnership, owners and operators of energy assets will develop and pursue strategies to reduce climate and weather-related vulnerabilities. Collectively, these partners and DOE will develop resources to facilitate risk-based decision-making and pursue cost-effective strategies for development of an energy infrastructure that is more climate resilient.

3. Group on Earth Observations

GEO, through its GEO Energy-related programmes, namely GEO Energy and Geo-resources and GEO Impacts tasks, coordinates the development of tools and products that provide support to energy decision-makers. It also facilitates the provision of freely accessible data, both remotely sensed and in situ, via the GEOSS Portal\(^\text{19}\), the main entry point to Earth Observation data from all over the world. In terms of tools and products, these are organized in terms of energy resources, energy access and energy efficiency\(^\text{20}\).

**Energy resources.** The GEO Energy Team develops energy resources planning and monitoring tools and products, clustered into three main categories: renewable energy, fossil fuels and minerals, and energy mix scenarios. Examples of such products are given in the following (further details are available from the GEO website).

Renewable energy – renewable energy activities of the GEO Energy Team include a wide range of renewable energy technologies from wind and solar to hydropower and bioenergy, both offshore and onshore. The products and tools developed facilitate evidence-based decisions of both private and public sectors. For instance, the GEO Energy Team contributes to the development of the *Global Atlas for Renewable Energy* for IRENA and, more specifically, the development, compilation and provision of data through web portal and mapping tools (Figure 1).\(^\text{21}\) The World Bank’s ESMAP is also contributing to the provision of renewable energy observation and mapping services.\(^\text{22}\) These activities have benefited from the support of the Clean Energy Ministerial.


\(^{19}\) [http://www.geoportal.org](http://www.geoportal.org)

\(^{20}\) [https://www.earthobservations.org/geoss_en_ph.shtml](https://www.earthobservations.org/geoss_en_ph.shtml)


Other products include: prediction maps for wind and solar resources over a number of timescales (for example, monthly, seasonal, annual, multiannual or decadal) and at global and country levels\textsuperscript{23} and a portfolio of environmental performance maps enabling “geo-localized life cycle assessment” of offshore wind farms for different configurations.\textsuperscript{24}

Fossil fuels and minerals – fossil fuel activities of the GEO Energy Team are dominated by the impacts of coal mining. This is mainly due to: (a) the potential environmental impacts of coal production and energy utilization and (b) the fact that coal is currently the main energy resource of most developing countries. Tools and products that support the planning and monitoring of coal mining and utilization are of great value for national decision-makers, especially in developing countries, to ensure subnational and national sustainable development, and for regional or international decision-makers, who need to address regional and global environment issues and energy–water–food–air security.

Energy mix scenarios – the GEO Energy Team also provides decision-makers with tools that allow comparison of different technologies based on specific criteria. These tools can take into consideration national priorities, such as job creation, while respecting the related (international) sustainability standards, and can, therefore, be used both for planning in a specific area (for example, biofuels, forest conservation or wood production) and for promoting a specific technology (for example, optimum location for the promotion of a wind energy installation). An example of such a product is a modelling platform that will enable planners and governments to forecast and monitor the environmental and health impacts of changes in the energy mix for alternative energy scenarios. This platform, developed under the EU project EnerGEO,\textsuperscript{25} includes

\textsuperscript{23} http://www.ic3.cat/
\textsuperscript{24} http://viewer.webservice-energy.org/energeo_wind_pilot/index.htm
\textsuperscript{25} http://www.energeo-project.eu
(Figure 2): (a) integrated assessment models for designing and evaluating mitigation strategies for fossil fuel installation by correlating particulate matter, ozone and mercury emissions from fossil fuels with atmospheric levels of air pollutants through the use of chemistry transport models; and (b) a modelling framework that incorporates energy potential maps into energy models and subsequently integrated impact assessment models. Another example is the assessment of the percentage of heat demand coverage among different energy technologies in the Sauwald region of Austria.26

**Energy access.** The GEO Energy Team is currently working on optimization of the technical and economic integration of renewable energies into electricity grids and markets. The team is also working on the risk management of energy installations such as energy grids and pipelines, for instance, by developing an early warning system for hotspot areas. This will be achieved through collaboration with the GEO Disaster Team, which is active in risk management projects, and the development of early warning systems. Furthermore, the team is developing planning tools for new infrastructures including smart grids, and additional pilot projects in specific regions taking into consideration the energy resources of the region/country (for example, Africa or Latin America).

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Figure 2. Modelling platform to forecast and monitor the environmental and health impacts of various energy mix scenarios

Energy efficiency. The improvement of energy efficiency is case specific and should be targeted mainly downstream at energy users. The GEO Energy Team has developed a tool for computing the residential annual lighting energy savings resulting from the control of blinds and artificial lights by daylight, for building design and retrofit energy regulation policy planning and private investment (EU project ENDORSE27). Another tool being developed concerns the optimization of the coupling between geothermal resources and solar energy, in such a way as to save on the heating, cooling and power needed for the operation of greenhouses (pilot in northern Greece, EU project ENERGEIA28). Although the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) standards have been used for decades for building energy-efficient design and operations worldwide, some of the climate analyses in past ASHRAE climate information likely require improved country customization, at least for site-specific values (IECC, 2013). The International Energy Conservation Code is used for locations worldwide. It contains different climate analyses, even for regions of the United States, and likely also requires improved customization by country, at least for site-specific values.29

A number of different products have been developed by other EU projects such as Climate Local Information in the Mediterranean region Responding to User Needs (CLIM-RUN), European Provision of Regional Impacts Assessments on Seasonal and Decadal Timescales (EUPORIAS) and Seasonal-to-decadal climate Prediction for the improvement of European Climate Services (SPECS), which, although not solely focusing on energy applications, have developed important examples of climate services for the energy industry.

4. Metocean

The metocean community is another very active area, probably for longer than any other energy-related area. Over many years, oil and gas companies have together acquired a large volume of metocean datasets worldwide. Often, these datasets are acquired at substantial cost and for remote areas. However, there is not a common awareness of available datasets and no systematic indexing and archiving of these datasets within the industry. Knowledge of metocean conditions is essential for the safe and efficient design and operation of offshore installations. Wind, wave current and tidal conditions at the location of the installation are the most important conditions. However, other parameters, such as air and sea temperatures, visibility and ice conditions may also be important, depending on the location and type of operation. This information is also used for supporting the planning, for example, diving operations and the installation of pipelines, and the forecasting of storms and heavy weather conditions, which might require timely evacuation or other safety measures to be taken during the operation of offshore installations. In addition, “once in a hundred years” extreme metocean conditions need to be accounted for in the design stage; estimating extreme values associated with return periods of 100 years and beyond is an area of active research.

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27 http://www.endorse-fp7.eu/
28 http://www.energeia-med.eu/
29 http://reca-codes.org/about-iecc.php
30 http://www.climrun.eu/
31 http://www.euporias.eu/
32 http://www.specs-fp7.eu/
Members of the International Association of Oil & Gas Producers (IOGP) promote the development of these vital metocean data, and the tools to leverage it, through the Metocean Committee. Twice a year, the metocean community of the oil and gas industry arranges meetings to discuss the progress of various joint industry projects in which it is involved. These have included:

1. Generating hindcast databases of regions such as the South China Sea, West Africa and the North Sea;
2. Developing new methods for analysing data;
3. Comparing instruments such as wave sensors;
4. Conducting basic research such as the definition of distributions for wave crest elevations.

Since June 2005, the EU project System of Industry Metocean data for the Offshore and Research Communities (SIMORC) has been developing an Internet service with the following aims: (a) to manage and operate a central index and database of metocean datasets, collected by the oil and gas industry at various sites on the globe, both in the past and continuing at present; and (b) to facilitate harmonization in quality and formats, storage and retrieval of these industry metocean datasets for use by industry partners and scientific users. Under the coordination of the Mariene Informatie Service “MARIS” BV (MARIS), IOGP engages participation by major oil and gas companies, bringing in their considerable datasets. This is done via a Limited Interest Project, which has been signed by major oil and gas companies such as Shell, Total, BP, Hydro, Statoil and Chevron.

There have also been a number of knowledge-sharing and capacity-building efforts. Some of these are presented below, roughly following a chronological order.

5. Capacity-building projects

The Utility Variable-Generation Integration Group (UVIG), previously known as the Utility Wind Integration Group (UWIG), was established in 1989 to provide a forum for the critical analysis of wind and solar technology for utility applications and to serve as a source of credible information on the status of wind and solar technology and deployment. The group’s mission was to accelerate the development and application of good engineering and operational practices supporting the appropriate integration and reliable operation of variable generation on the electric power system. Some UVIG activities include regular topical and technical workshops and user groups, operating through live meetings, teleconferences and listserv forums.

The North Atlantic Treaty Organization’s Advanced Research Workshop on Weather/Climate Risk Management for the Energy Sector held in Italy in 2008 gathered about 30 participants including weather and climate scientists, engineers, economists and other specialists in the use of energy, and formulated recommendations aimed at improving the collaborative use of information by climate scientists and the energy industry (Troccoli et al., 2010). The ensuing ICEM sessions, with the inaugural one held in Australia in 2011, the second one in France in 2013, the third one in the United States in 2015 and the fourth one in Italy in 2017, have been continuing and strengthening the dialogue among energy industry experts and the meteorological (weather and climate) community (Troccoli et al., 2013). The need for an increasingly stronger interaction
among ICEM participants has resulted in the formation of WEMC,\(^{37}\) a non-profit organization devoted to promoting and enhancing interaction among the energy industry and the weather, climate and broader environmental science community. The primary goal of WEMC is to enable improved sustainability, resilience and efficiency of energy systems under ever-changing weather and climate for the greatest benefit of all people. Working together with a large number of stakeholders, WEMC organizes and implements recommendations from ICEMs.

The European Cooperation in Science and Technology network Weather Intelligence for Renewable Energies,\(^{38}\) which ran from 2011 to 2014, had two main lines of activity: the first was to develop dedicated post-processing algorithms coupled with weather prediction models and measurement data especially remote-sensing observations; the second was to investigate the difficult relationship between the variable weather dependent power production and the energy distribution towards end users. Also, although not sector specific, the Climate Services Partnership,\(^{39}\) a platform for knowledge-sharing and collaboration aimed at promoting resilience and advancing climate service capabilities worldwide, has a (minor) chapter on energy.

A number of specialized sessions are also being held during conferences organized either by meteorological organizations – the American Meteorological Society with a Weather, Climate, and the New Energy Economy\(^ {40}\) session and the European Meteorological Society\(^ {41}\) with an Energy Meteorology session – or by energy industry bodies (for example, American Wind Energy Association or SolarPaces).

In 2009, Meter Online (MOL)\(^ {42}\) was launched by CLP Power, Hong Kong, China, a power utility that provides electricity to 80% of the Hong Kong population. With a “saving energy through weather watch”, clients are assisted in their choice of energy consumption by information on electricity utilization patterns.

The MOL service enables customers to have a timely access to their latest half-hourly energy consumption and demand profiles online, generating a consumption profile that, together with the climate data, generates an electricity demand pattern of each consumer, through a tailor-made regression model and with reference to Hong Kong Observatory’s latest weather forecasts. It gives the possibility of having energy-saving measures in relation to high temperatures and high consumption days early alerts. As a result, after reviewing the MOL performance nine months later, 5% of electricity accounts were able to achieve energy savings.

\(^{37}\) [http://www.wemcouncil.org](http://www.wemcouncil.org)
\(^{38}\) [http://www.wire1002.ch/](http://www.wire1002.ch/)
\(^{39}\) [http://www.climate-services.org](http://www.climate-services.org)
\(^{41}\) [http://www.emetsoc.org/meetings-events/ems-annual-meetings](http://www.emetsoc.org/meetings-events/ems-annual-meetings)
On 23 and 24 March 2015, WMO organized a private sector partnership forum on Climate Services and Decision Support Tools for the Energy Sector, which was held at the WMO Secretariat, Geneva. This forum, which followed the approval by the GFCS governing board of the development of a component of the GFCS implementation plan (Exemplar) focused on climate services for the energy sector. Participants included a number of representatives from the energy sector and the meteorological community, who identified specific high-priority weather, water and climate-related products and services for decision support in the energy sector. The forum also highlighted specific contexts where such products and services could be initiated or strengthened, including what would be required in order to develop them. Seven climate product/services were developed during this forum:

- Scenarios for energy mixes;
- Decision-support climatic scenario data for use in the energy sector;
- Multi-year prospective climatologies for the energy sector;
- Training in the use of extended-range weather forecasts;
- Seasonal forecasting for hydropower production;
- Seasonal forecasting for energy demand;
- Observation and reanalysis data for energy.

Together with the activities mentioned in Annex 2 and the generic activities presented in section 2.3, this set of activities (expanded in the table below) provides an appreciation of the scope and breadth of the products and services that the energy sector would benefit from, either in the form of improved available products/services or as new products/services to be developed. Note that no costing is provided for these activities – this is done deliberately as the cost will vary depending on the scope, size and complexity of the specific project.
Examples of climate products and services for the energy sector

<table>
<thead>
<tr>
<th>1</th>
<th>Scenarios for energy mixes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product/service</strong></td>
<td>Design energy mix and percentage for each component that will meet the country’s electricity demand, both in the near term and in the long term</td>
</tr>
<tr>
<td><strong>Description</strong></td>
<td></td>
</tr>
<tr>
<td>(1)</td>
<td>Demand must equal supply</td>
</tr>
<tr>
<td>(2)</td>
<td>Supply can be generated from a known mix of options</td>
</tr>
<tr>
<td>(3)</td>
<td>Problem is to compartmentalize each energy component and define its expected potential contribution to the energy mix:</td>
</tr>
<tr>
<td></td>
<td>(a) Using the current climate, it is possible to build an expected (mean) supply profile over a typical year (including diurnal and seasonal variability);</td>
</tr>
<tr>
<td></td>
<td>(b) Based on the climate record, the variability can be quantified around this mean supply profile to build a range of supply</td>
</tr>
<tr>
<td></td>
<td>(c) Need to explicitly identify thresholds at which extreme conditions impact supply (e.g. when wind is over a threshold and turbine must be turned off, when cooling water for a thermal plant or nuclear reactor is too warm and power generation should be wound back)</td>
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<tr>
<td></td>
<td>(d) Around these energy profiles build a further uncertainty range that is driven by those considerations that are not known with certainty (e.g. climate change in which there may be some confidence, but also issues that are completely unknown)</td>
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<td></td>
<td>(e) Other future considerations that can impact this supply profile should be considered such as whether storage solutions can modulate the effectiveness of a component such as photovoltaics (PVs), which have a strong diurnal cycle</td>
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<tr>
<td></td>
<td>(f) Externalities must be acknowledged, for instance, a dam may serve multiple purposes such as water supply and flood mitigation, so that it may not be possible to operate it purely on the basis of energy production</td>
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<td>(4) A unit cost of energy (possibly variable based on scale) can be derived (uncertainties in this must also be acknowledged, as it is impossible to accurately predict commodity prices, etc., which some components will depend on)</td>
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<td></td>
<td>(5) Demand forecast should also be compartmentalized and its expected profile defined. Clearly seasonality affects extremes in demand:</td>
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<td></td>
<td>(a) Need to identify future unknowns (e.g. climate change may have future impacts on water availability in Mediterranean climates); some countries are being forced to consider desalination, which will become a large part of the electricity market demand side</td>
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</tr>
<tr>
<td>Objective</td>
<td>To match the energy supply mix from each component including its variability to meet the expected demand in the most cost-effective manner, acknowledging that demand must always be met; the tolerance for blackouts is effectively zero</td>
</tr>
</tbody>
</table>
| Benefits | Energy demand will be met through a well-thought-out range of expected scenarios (including climate change scenarios):  
- Low tolerance for blackouts will be avoided by pre-planning  
Energy mix will be provided in the most cost-effective manner |
| Outputs | Energy production profile for each energy mix (with ranges, uncertainties and unknowns built in)  
Energy demand profile scenarios (with ranges and uncertainties or projections)  
Optimization tool to take into account component mix profiles as well as externalities |
| Activities | Build profiles for each supply component  
Build profile for demand |
| Inputs | Last 20 years of energy usage to build a model around energy demand  
Last 20 (~100) years of climate information (solar, wind, rainfall, streamflow, dam levels, etc.); using 20 years gives typical sampling, whereas using 100 years gives better sampling for extremes to inform on design (e.g. a 1-in-50-year extreme event) |
| Partners | Energy suppliers  
Climate data holders  
Infrastructure designers |

### Delivering decision-support climatic scenario data for use in the energy sector

| Product/service | Climatic projections for renewable energy generation, transmission and distribution |
| Description | Climatic scenarios for sector-specific impact studies, including generation, transmission and distribution of energy |
| Objective | To provide energy sector stakeholders with relevant climate scenarios for medium-term (20–30 years) and long-term (50–100 years) planning, according to the lifetime of the energy infrastructure (grid infrastructure, lines, stations, dams, equipment, management, power plants, etc.) |
| Benefits | Inform and support political decision-makers  
Assist energy sector managers in their pursuit of efficient energy planning  
Address and support other concurrent sectors of the economy (e.g. farming or water management, including drought or flood control)  
Inform and support the end users, including the citizens  
Improve operational activities such as regulation of dams and rivers  
Ensure the sustainability of socioeconomic activities  
Provide efficient environmental security planning |
| Outputs | As different social, economic and technical segments are targeted, the output should be custom made to fill in the needs of the user (so, gridded data should be provided to the engineering and science communities; however, charts, tables and diagrams would be more appropriate for easier understanding and interpretation by policymakers)  
Guidelines to conduct impact studies  
Description of the methodology adopted so that it can, in principle, be applied to any region  
Software for downscaling and extracting the needed information for the preparation of impact studies  
Tools to interface climatic scenario data with impact models  
Uncertainty assessment studies |
| Activities | Selection of appropriate model or combination of models; analysis of model performance/sensitivity  
If existing climatic scenarios for selected variables are not sufficient, then adapt or post-process them for more-refined information  
Search for existing climatic scenarios for selected variables (e.g. temperature and rainfall) and their spatial resolution; these can be used directly or post-processed for refined information, if needed  
Formulate the output according to user needs (gridded data, graphics, etc.)  
Uncertainty estimation and capacity-building; ensure that the users are informed of the uncertainties and are able to incorporate this information into their own simulation and decision processes |
| Inputs | Necessary hardware, software and other resources (look for partnerships, if needed)  
Time frame for projections so that the objective is specified (i.e. decadal versus climatic projections)  
Existing data/observations to be used in model validation and hindcasts  
Existing climatic scenarios for selected variables (e.g. temperature and rainfall) and their spatial resolution; these can be used directly if they fulfil the needs |
| Partners | Politicians  
Decision-makers  
Researchers  
Energy regulators  
Energy commissions  
Meteorological services  
Industry representatives  
Regulators  
Financiers  
Citizens  
Regional climatic centres |
### Multi-year prospective climatologies for the energy sector

<table>
<thead>
<tr>
<th>Product/service</th>
<th>Provision of guidance on how to project climatologies for the future (10–30 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>There is a need for guidance on best practices for generating coarse spatial resolution, but high temporal resolution, climatologies that can be used as projections for the next 10–30 years; the climatologies should include at least temperature and precipitation, and should retain realistic covariability in space and time; the information is to be used to help the energy sector anticipate significant changes in the demand and production pattern at regional scale.</td>
</tr>
<tr>
<td>Objective</td>
<td>To provide high-quality climatologies for anticipating changes in future demand and possible disruptions to supply.</td>
</tr>
<tr>
<td>Benefits</td>
<td>Technical: improved representation of possible climate outcomes to better operate existing energy systems by anticipating possible risks. Management: scientifically validated methodologies for defining climatologies; harmonization of definitions.</td>
</tr>
<tr>
<td>Outputs</td>
<td>Guidance document on methodologies for generating climatologies (short term, Global Framework for Climate Services (GFCS) year-4, i.e. first 2 years). The climatologies themselves, designed and organized by region (defined by interconnection of power networks – typically subcontinental) (longer term, GFCS year-6 and year-10).</td>
</tr>
<tr>
<td>Activities</td>
<td><strong>First 2 years</strong>&lt;br&gt;Research, Modelling and Prediction (RMP): research on different methodologies (including dynamical, statistical and hybrid) for projecting climatologies that retain realistic, temporal and spatial covariability. User Interface Platform (UIP): thorough regionally and nationally based needs assessments for climate information for planning requirements for the next few years; in particular, the need for projections that represent multiannual variability may differ from region to region, as may the climate parameters of interest, definitions of extremes and acceptable validation criteria. <strong>Subsequent 4 years</strong>&lt;br&gt;Climate Services Information System (CSIS): Regional Climate Centres and some National Meteorological and Hydrological Services (NMHSs) generate climatologies using recommended methodologies. CSIS: Regional Climate Centres and some NMHSs validate climatologies with a focus on extreme events.</td>
</tr>
<tr>
<td>Inputs</td>
<td>Historical high temporal resolution climatologies. Decadal climate projections and relevant models (e.g., weather generators). Reanalyses (including ensembles to represent uncertainties). Validation criteria. Ancillary data for defining relevant spatial scales.</td>
</tr>
</tbody>
</table>

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### Training in the use of extended-range weather forecasts

<table>
<thead>
<tr>
<th>Product/service</th>
<th>Two-way training on the need for and use of extended-range weather and intra-seasonal forecasts.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>There is a need for training of energy system managers and team members in the use of probabilistic forecasts, including ensemble predictions and multimodel ensembles. There is a need for training of climate scientists to understand the decision-making process and potential climate inputs of the energy sector.</td>
</tr>
<tr>
<td>Objective</td>
<td>To raise the awareness and mutual understanding between climate and the energy sector.</td>
</tr>
<tr>
<td>Benefits</td>
<td>Better use of existing weather and climate information products. Improved service provision.</td>
</tr>
<tr>
<td>Outputs</td>
<td>Training programme addressing different needs of possible target audiences. Workshop reports and recommendations where appropriate. Trained personnel in the energy and climate sectors. Online training materials focused on specific issues.</td>
</tr>
<tr>
<td>Activities</td>
<td>Capacity Development (CD) and UIP: formulation of a training programme addressing different needs of possible target audiences. CD: a series of two-way one- to five-day training workshops. CD: development of online training materials focused on specific issues.</td>
</tr>
<tr>
<td>Inputs</td>
<td>Existing training materials, including online tools. List of training needs.</td>
</tr>
<tr>
<td>Partners</td>
<td>Climate and energy research community. Energy community. Experts in training in cross-sectoral settings. Information technology experts for online materials.</td>
</tr>
</tbody>
</table>
### Seasonal forecasting for hydropower production

<table>
<thead>
<tr>
<th>Product/service</th>
<th>Provision of seasonal forecasts of dam inflow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>There is a need to improve inflow 1- to 12-month forecasts at the watershed scale</td>
</tr>
<tr>
<td>Objective</td>
<td>To optimize management of water resources for generating power in the context of multiple uses</td>
</tr>
</tbody>
</table>
| Benefits        | Better reservoir management, including less-frequent water shortages for power generation and other uses  
                        Decreased cost of power generation  
                        More-reliable and cheaper supply of energy  
                        Provision of information at appropriate resolutions |
| Outputs         | Ensemble (rather than probabilistic) forecasts of monthly or seasonal accumulated dam inflow for the next 1–12 months  
                        Monthly or seasonal ensemble forecasts of daily rainfall and temperature for the next 1 to 12 months |
| Activities      | RMP: research to improve forecasts  
                        RMP: downscaling of climate information to relevant spatial and temporal timescales  
                        UIP: working groups to assist in the design of the forecast system, and to address possible constraints in using the information (e.g. legal constraints on standard operating procedures)  
                        RMP and UIP: pilot studies to demonstrate the value of using seasonal climate information |
| Inputs          | Basin-level hydrological models  
                        Monitoring and recent historical climate information for operational forecasting  
                        Historical climate and river flow information for verification and for training of statistical models |
| Partners        | Research community  
                        NMHSs  
                        Dam managers |

### Seasonal forecasting for energy demand

<table>
<thead>
<tr>
<th>Product/service</th>
<th>Seasonal forecasting temperature with a focus on high-impact events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>There is a need to improve the widespread use of climatology for anticipating anomalous periods of demand for energy</td>
</tr>
<tr>
<td>Objective</td>
<td>To improve anticipation of large fluctuations in demand for energy, and thus reduce the risk of power disruption</td>
</tr>
</tbody>
</table>
| Benefits        | Better anticipation of high-impact weather events resulting in improved management of demand–supply balance; better scheduling of use of production units  
                        Lower production costs |
| Outputs         | Prototype forecast products for high-impact temperature events (defined in terms of area, duration and intensity) |
| Activities      | RMP: improve forecast skill generally, and investigate predictability; verification  
                        UIP: interaction to define criteria  
                        CD: training  
                        CSIS: seasonal forecasts |
| Inputs          | Historical temperature data  
                        Historical demand data  
                        Seasonal forecasts  
                        Downscaling tools  
                        Criteria for definitions of relevant temperature events |
| Partners        | Research community  
                        NMHSs  
                        TSOs  
                        Energy companies |
<table>
<thead>
<tr>
<th><strong>Product/service</strong></th>
<th>Observations and reanalysis data needed for specific uses for power generation, demand estimation and assessment of risks associated with extreme events</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td>Meteorological variables needed for conversion to energy demand and supply and for estimation of risks</td>
</tr>
<tr>
<td><strong>Objective</strong></td>
<td>To increased efficiency and cost-effectiveness at various stages of planning, design and operation through the use of data in support of decision-making</td>
</tr>
</tbody>
</table>
| **Benefits**        | Data inputs for improved:  
  • Long-term plans  
  • Resource assessments  
  • Financing  
  • Forecast development  
  • Climate change scenarios  
  • Risk assessment for design and management and insurance resulting in improved outcomes for associated stakeholders |
| **Outputs**         | **Solar data**  
  Global horizontal irradiance  
  Direct normal irradiance  
  Cloud images  
  Temperature (efficiency of PVs)  
  Wind gusts for risk assessment  
  Hail for risk assessment  
  **Wind data**  
  Continuous wind speed and direction at different heights (80–100 m)  
  Temperature (monthly, or more frequent, summaries)  
  Pressure  
  Roughness/land use  
  **Hydro data**  
  Precipitation  
  Soil moisture  
  River flow  
  Wind  
  Temperature  
  Humidity  
  Soil type  
  Land use  
  Floods  
  **Ocean data**  
  Wave height  
  Wave direction  
  Wave spectrum  
  Bathymetry  
  Salinity  
  Current  
  Tides  
  Sea level  |
|                     | [Data needs of conventional energy, to be decided]  
| **Activities**      | Extremes can be characterized from the above by specifying location, duration, magnitude and timing  
  Define the requirements  
  Inventory available information  
  Evaluate usability/suitability of available data  
  Define quality control and assurance criteria  
  Perform appropriate downscaling of reanalyses  
  Construct data product meeting requirements from available data if necessary (e.g. reanalysis or blended product) |
| **Inputs**          | To be decided |
| **Partners**        | NMHSs  
  Group on Earth Observations  
  International Renewable Energy Agency  
  World Bank Energy Sector Management Assistance Program  
  Private sector (including as sources of observations, as well as consumers)  
  Insurance companies  
  Independent power producers  
  Research centres and academia  
  Comprehensive Nuclear Test Ban Treaty Organization (observation network and international data centre) |
Presented here is a list of organizations, private energy companies, international associations and regional projects that have produced important climate services and/or could be key partners in mobilizing resources. The list is by no means exhaustive.

1. International organizations

ESMAP (http://www.esmap.org/)

ESMAP (Energy Sector Management Assistance Program) is a global, multi-donor knowledge and technical assistance programme administered by the World Bank, established in 1983. It provides analytical and advisory services to low- and middle-income countries to increase their know-how and institutional capacity to achieve environmentally sustainable energy solutions for poverty reduction and economic growth. Supporting over 100 activities in countries around the world at any given time, ESMAP is an integral part of the Energy and Extractives Global Practice of the World Bank.

ESMAP services for its client countries can be grouped into two categories:

1. Technical assistance and policy advice. This includes country-level activities to address specific national energy challenges, which are designed to inform country policy development and reforms, as well as follow-on investments by the World Bank Group, its development partners and national governments. Other country-level engagements are grouped under strategic initiatives that leverage ESMAP experience and global resources. Examples include the Global Geothermal Development Plan, Renewable Energy Resource Mapping and the City Energy Efficiency Transformation Initiative.

2. Knowledge products and knowledge exchange. This includes supporting the development of global “public goods”: reports, decision-support tools and online knowledge resources that are designed to inform policymakers, technical specialists and teams from the World Bank Group and partner agencies. Examples include the Tool for Rapid Assessment for City Energy, the Geothermal Handbook, the Renewable Energy Project Resource Center and the Gender Online Resources. ESMAP also brings together countries to share experiences and disseminate global best practices on issues of mutual interest.

GSEP (http://www.globalelectricity.org/en)

GSEP (Global Sustainable Electricity Partnership) is a not-for-profit organization whose members are the world’s leading electricity companies. GSEP promotes sustainable energy development through electricity sector projects and human capacity-building activities in developing and emerging nations worldwide. The mission of GSEP is to play an active role in addressing global electricity issues and to promote sustainable development worldwide, by:
• Developing joint policy frameworks and implementing related initiatives in both domestic and international markets
• Engaging in global debates on electricity-related issues, taking joint positions
• Providing information and expertise on the efficient generation and use of electricity to assist developing countries in strengthening their human capabilities

GWEC (http://www.gwec.net/)

GWEC (Global Wind Energy Council) is the international trade association for the wind power industry. It is a member-based organization that represents the entire wind energy subsector. The members of GWEC represent over 1,500 companies, organizations and institutions in more than 80 countries, including manufacturers, developers, component suppliers, research institutes, national wind and renewables associations, electricity providers, and finance and insurance companies.

The GWEC mission is to ensure that wind power establishes itself as the answer to today’s energy challenges, providing substantial environmental and economic benefits:

• The GWEC mandate from members is to communicate the benefits of wind power – to national governments, policymakers and international institutions;
• GWEC provides authoritative research and analysis on the wind power industry in many countries around the world;
• GWEC works with governments to give them transparent information about the benefits and potential of wind power, enabling them to make informed decisions about national energy policies;
• GWEC supports collaboration among policymakers in different countries to help them share best practices and experiences in adding clean power to their energy mix.

IAEA (https://www.iaea.org/)

IAEA (International Atomic Energy Agency) is the world’s centre for cooperation in nuclear technology. It was set up as the world’s “Atoms for Peace” organization in 1957 within the United Nations family. IAEA works with its member States and multiple partners worldwide to promote the safe, secure and peaceful use of nuclear technologies. As an independent international organization related to the United Nations system, the IAEA relationship with the United Nations is regulated by a special agreement.

IEA (http://www.iea.org)

Founded in 1974, IEA (International Energy Agency) was initially designed to help countries coordinate a collective response to major disruptions in the supply of oil such as the crisis of 1973/1974. While this remains a key aspect of its work, IEA has evolved and expanded. It is at the heart of global dialogue on energy, providing authoritative statistics and analysis.

As an autonomous organization, IEA examines the full spectrum of energy issues and advocates policies that will enhance the reliability, affordability and sustainability of energy in its 29 member countries and beyond. The four main areas of IEA focus are:

• Energy security: promoting diversity, efficiency and flexibility within all energy subsectors;
• Economic development: ensuring the stable supply of energy to IEA member countries and promoting free markets to foster economic growth and eliminate energy poverty;
• Environmental awareness: enhancing international knowledge of options for tackling climate change;
• Engagement worldwide: working closely with non-member countries, especially major producers and consumers, to find solutions to shared energy and environmental concerns.

IMarEST (http://www.imarest.org)

IMarEST (Institute of Marine Engineering, Science and Technology) is an international professional body and learned society for all marine professionals. It is the first Institute to bring together marine engineers, scientists and technologists into one international multidisciplinary professional body. IMarEST is the largest marine organization of its kind with a worldwide membership based in over 100 countries, it is a registered charity and provides grades of membership for everyone, from those seeking to become chartered or gain other professional recognition, to those just starting out in their careers or studying in education.

IOGP (http://www.iogp.org/Metocean)

IOGP (International Association of Oil & Gas Producers) is the voice of the global oil and gas upstream industry. Oil and gas continue to provide a significant proportion of the world’s energy to meet growing demands for heat, light and transport. IOGP members produce more than half of the world’s oil and over a third of its gas. IOGP serves industry regulators as a global partner for improving safety, environmental and social performance. IOGP also acts as a uniquely upstream forum in which IOGP members identify and share knowledge and good practices to achieve improvements in health, safety, the environment, security and social responsibility.

IRENA (http://www.irena.org )

IRENA (International Renewable Energy Agency) is an intergovernmental organization that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international cooperation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. Currently, IRENA has 150 members, and 28 States have started the formal process of becoming members. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal energy, hydropower, ocean energy, solar energy and wind energy, in the pursuit of sustainable development, energy access, energy security, and low-carbon economic growth and prosperity.

With a mandate from countries around the world, IRENA encourages governments to adopt enabling policies for renewable energy investments, provides practical tools and policy advice to accelerate renewable energy deployment, and facilitates knowledge-sharing and technology transfer to provide clean, sustainable energy for the world’s growing population.

In line with these aims, IRENA provides a range of products and services, including:

• Renewable readiness assessments, conducted in partnership with governments and regional organizations, to provide policy guidance and facilitate the sharing of case studies and best practices;
• The Global Atlas for Renewable Energy, hosted on the IRENA website, which maps solar and wind sources country by country;
• The IRENA Renewable Energy Learning Partnership, an online learning network;
• Handbooks for renewable energy policy development;
• Technology briefs and cost studies to strengthen evidence-based policymaking and investment;
• Facilitation of renewable energy planning at regional levels;
• Renewable energy country profiles.

Specifically, the *Global Atlas for Renewable Energy* (http://irena.org/globalatlas) is an initiative coordinated by IRENA, aimed at closing the gap among nations having access to the necessary datasets, expertise and financial support to evaluate their national renewable energy potential, and those countries lacking such elements. About 70 countries and more than 50 institutes and partners contributed to the initiative. The Global Atlas facilitates a first screening for areas of opportunity where further assessments can be of particular relevance. It enables the user to overlay information listed in a catalogue of more than 1,100 datasets, and to identify areas of interest for further prospection. Currently, the initiative includes maps on solar, wind, geothermal and bioenergy resources along with one marine energy map. The initiative will eventually encompass all renewable energy resources, at the global scale.

**UN-Energy** (http://www.un-energy.org/)

UN-Energy, the United Nations mechanism for inter-agency collaboration in the field of energy, was established in 2004 to help ensure coherence in the United Nations system’s multidisciplinary response to the 2002 World Summit on Sustainable Development, and to support countries in their transition to sustainable energy. The core fields of access to energy, renewable energy and energy efficiency – UN-Energy’s clusters – have garnered major attention and experienced rapid growth in investments and policy-related focus with an ever-growing number and variety of players involved.

UN-Energy aims to promote system-wide collaboration in the area of energy with a coherent and consistent approach, as there is no single entity in the United Nations system that has primary responsibility for energy. Its role is to increase the sharing of information, encourage and facilitate joint programming and develop action-oriented approaches to coordination. It was also initiated to develop increased collective engagement among the United Nations and other key external stakeholders. UN-Energy brings together members on the basis of their shared responsibility, deep commitment and stake in achieving sustainable development.

UN-Energy’s work is organized around three thematic clusters, each led by two United Nations organizations:

• Energy access: led by the United Nations Department of Economic and Social Affairs and the United Nations Development Programme (UNDP), in partnership with the World Bank;
• Renewable energy: led by the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Environment Programme, with the support of the United Nations Educational, Scientific and Cultural Organization (UNESCO);
• Energy efficiency: led by the United Nations Industrial Development Organization (UNIDO) and IAEA.

In addition, UN-Energy Africa (UNEA) was established as a subprogramme of UN-Energy, focusing specifically on the African context. UNEA is currently chaired by UN-HABITAT and co-chaired by UNIDO. Secretariat services for UNEA are provided by United Nations Economic Commission for Africa and supported by UNIDO.

**UVIG** (http://uvig.org)

UVIG (Utility Variable-Generation Integration Group), previously known as UWIG (Utility Wind Integration Group), was established in 1989 to provide a forum for the critical analysis of wind and solar technology for utility applications and to serve as a source of credible information on the status of wind and solar
technology and deployment. The group’s mission is to accelerate the development and application of good engineering and operational practices, supporting the appropriate integration and reliable operation of variable generation on the electric power system.

**WBCSD** ([http://www.wbcsd.org/](http://www.wbcsd.org/))

WBCSD (World Business Council for Sustainable Development) is an organization of forward-thinking companies that galvanizes the global business community to create a sustainable future for business, society and the environment. From its starting point in 1992 to the present day, WBCSD has created respected thought leadership on business and sustainability. It also plays a leading advocacy role for business. Leveraging strong relationships with stakeholders, it helps to drive debate and policy change in favour of sustainable development solutions.

WBCSD provides a forum for its 200 member companies – who represent all business sectors, all continents and a combined revenue of over US$ 8.5 trillion – to share best practices on sustainable development issues and to develop innovative tools that change the status quo. WBCSD also benefits from a network of 70 national and regional business councils and partner organizations, the majority of which are based in developing countries.

By thinking ahead, advocating for progress and delivering results, WBCSD both increases the impact of its members’ individual actions and catalyses collective action that can change the future of our society for the better.

**WEC** ([http://www.worldenergy.org](http://www.worldenergy.org))

WEC (World Energy Council) is the principal impartial network of leaders and practitioners promoting an affordable, stable and environmentally sensitive energy system for the greatest benefit of all. Formed in 1923, WEC is the United Nations accredited global energy body, representing the entire energy spectrum, with more than 3 000 member organizations located in over 90 countries and drawn from governments, private and state corporations, academia, non-governmental organizations and energy-related stakeholders.

WEC informs global, regional and national energy strategies by hosting high-level events, publishing authoritative studies and working through its extensive member network to facilitate the world’s energy policy dialogue.

**WEMC** ([http://wemcouncil.org/](http://wemcouncil.org/))

WEMC (World Energy & Meteorology Council) is a fledgling non-profit organization devoted to promoting and enhancing the interaction among the energy industry and the weather, climate and broader environmental sciences community. Its primary goal is to enable improved sustainability, resilience and efficiency of energy systems under ever-changing weather and climate for the greatest benefit of all people. Working together with a large number of stakeholders, WEMC organizes and implements recommendations from ICEMs.
The United States DOE (Department of Energy) has as its mission to ensure the security and prosperity of the United States by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions. DOE catalyses the timely, material and efficient transformation of the nation’s energy system and secure United States leadership in clean energy technologies. It also enhances nuclear security through defence, non-proliferation and environmental efforts. Moreover, it maintains a vibrant effort in science and engineering as a cornerstone of economic prosperity with clear leadership in strategic areas.

To reach this aim, CLIM-RUN pursued the following:

1. Increasing the quality, reliability and detail of climate information for societal use in the Mediterranean area by activating an effective exchange of information among the science and stakeholder communities, in the key economic sectors of energy and tourism. These two sectors were complemented by a cross-cutting issue, forest fires, whose occurrence in the Mediterranean concerns several business activities, and by integrated case studies in which multiple sectors are involved;
2. Developing a communication protocol by which climate information is transferred from the researchers to the stakeholders in order to develop suitable adaptation measures. The most innovative aspect in the development of this protocol was its bottom-up approach, by which stakeholders were involved in the design of the protocol from its early stages in conjunction with and by strong communication with the science community and the climate information providers (for example, national and international meteorological centres). The protocol was illustrated through its application to a series of case studies throughout the Mediterranean basin;
3. Developing and providing training for new research expertise lying at the interface between the science results and the stakeholder application;
4. Developing a web portal for:
   • Integrating the different levels of climate and sector-relevant information and tailoring the dissemination for different stakeholders (policymakers, business stakeholders, etc.);
   • Disseminating online surveys to increase the number of stakeholders outside of the case study level
   • Optimizing communication within and outside the project (web communication tools, blogs, social networks, etc.);
   • Supporting e-learning tools (online training, interactive material, etc.).
EUMETSAT CM SAF (Satellite Application Facility on Climate Monitoring) generates, archives and distributes satellite-based climate data records. Among other parameters, CM SAF provides high-quality long-term data records of surface solar radiation based on geostationary and polar-orbiting satellite observations. The SARAH data record (Surface Solar Radiation Data Set – Heliosat, doi: 10.5676/EUM_SAF_CM/SARAH/V001) provides temporally (hourly, daily, monthly) and spatially (0.05° × 0.05°) highly resolved information on the global horizontal, the direct horizontal and the direct normalized surface solar radiation starting from 1983. The SARAH data record covers Europe, Africa and parts of South America. A comparable data record starting in 1999 is available covering central Asia and the western part of Australia. The CLARA data record (CM SAF Clouds, Albedo and Radiation dataset from Advanced Very High Resolution Radiometer data, doi: 10.5676/EUM_SAF_CM/CLARA_AVHRR/V001) includes daily and monthly global information on the surface horizontal irradiance starting in 1982, with a spatial resolution of 0.25° × 0.25°. These long-term climate data records are consistently and timely updated.

Copernicus (http://www.copernicus.eu/)

Copernicus is a European system for monitoring the Earth. It consists of a complex set of systems that collect data from multiple sources: Earth observation satellites and in situ sensors such as ground stations, airborne sensors and sea-borne sensors. It processes these data and provides users with reliable and up-to-date information through a set of services related to environmental and security issues. The services address six thematic areas: land, marine, atmosphere, climate change, emergency management and security. They support a wide range of applications, including environment protection, management of urban areas, regional and local planning, agriculture, forestry, fisheries, health, transport, climate change, sustainable development, civil protection and tourism.

The main users of Copernicus services are policymakers and public authorities who need the information to develop environmental legislation and policies or to take critical decisions in the event of an emergency, such as a natural disaster or a humanitarian crisis. Based on the Copernicus services and on the data collected through the sentinels and the contributing missions, many value added services can be tailored to specific public or commercial needs, resulting in new business opportunities. In fact, several economic studies have already demonstrated a huge potential for job creation, innovation and growth.

The Copernicus programme is coordinated and managed by the European Commission. The development of the observation infrastructure is performed under the aegis of the European Space Agency for the space component and of the European Environment Agency and the member States for the in situ component.

EUPORIAS (http://www.euporias.eu/)

EUPORIAS (European Provision of Regional Impacts Assessments on Seasonal and Decadal Timescales) was a four-year collaborative project funded by the European Commission under the Seventh Framework Programme. EUPORIAS commenced on 1 November 2012. The EUPORIAS consortium was made up of 24 partners from across Europe and brought together a wide set of expertise from academia, the private sector and the national met services.

EUPORIAS aimed at improving the ability to maximize the societal benefit of predictions of future environmental conditions. Working in close relation with a number of European stakeholders, this project developed a few fully working prototypes of climate services addressing the need of specific users. The time-horizon was
set between a month and a year ahead, with the aim of extending it towards the more-challenging decadal scale. Representing a diverse community ranging from United Nations organizations to small enterprises, EUPORIAS increased the resilience of the European Society to climate change by demonstrating how climate information could become directly usable by decision-makers in different sectors.


GEO (Group on Earth Observations), established in 2005, is coordinating efforts to build a GEOSS (Global Earth Observation System of Systems) with a vision of a world where decisions and actions are informed by coordinated, comprehensive and sustained Earth observations. For this purpose, GEO fosters the coordinated and sustained access to Earth observations and their use for the global environment and human well-being. GEO members include 90 countries and the European Commission plus 67 intergovernmental, international and regional organizations. GEO is organized around nine areas (energy, agriculture, biodiversity, climate, disaster, ecosystems, health, water and weather) and also five cross-cutting areas (sustainability impacts, forests, land cover, ocean and urban). Interactions among these areas help citizens, scientists and policymakers to address complex environmental issues in a cost-efficient and effective way.

The GEO Energy and Geo-resources Team consists of top energy experts from four continents who have joined forces under the umbrella of GEO to develop tools and products that cover the specific needs of decision-makers at multiple levels. This team develops tools and products that:

- Facilitate user choice of the most appropriate products or tools given user capacities and needs;
- Contribute to the monitoring and assessment of regional and global issues by allowing interoperability among the tools;
- Provide a state of knowledge on existing related materials;
- Identify potential gaps and fills them.

**SIMORC** ([http://www.simorc.org/](http://www.simorc.org/))

SIMORC (System of Industry Metocean data for the Offshore and Research Communities) was established to stimulate and support a wider application of industry metocean datasets. The SIMORC service aims at improving a common awareness of available datasets and a systematic indexing and archival of these datasets within the industry. It also aims at improving considerably the reporting and access to these datasets and results of field studies for other parties, in particular the scientific community.

The SIMORC service is the result of a unique and challenging development, undertaken by major ocean data management specialists: MARIS (Netherlands), British Oceanographic Data Centre (BODC; United Kingdom), Intergovernmental Oceanographic Commission/International Oceanographic Data and Information Exchange (UNESCO) and IOGP, involving participation of major oil and gas companies who bring in their considerable datasets. The initial development of SIMORC took place within the SIMORC project from 1 June 2005 to 1 December 2007 and was co-funded by the European Commission. Since 1 December 2007, the SIMORC service has been operated by MARIS and BODC in an arrangement with IOGP.

The SIMORC service had its public launch in March 2007. At present, it covers more than 6 900 datasets from Shell, Total and BP, covering more than 2 500 years of observations of winds, waves, currents and sea levels. The SIMORC system is operational to serve users in identifying and getting access to datasets and extends its coverage regularly with additional datasets from oil and gas companies.
SPECS (Seasonal-to-decadal climate Prediction for the improvement of European Climate Services) is an EU Seventh Framework Programme project and is motivated by the need to develop: (a) a new generation of European climate forecast systems that makes use of the latest scientific progress in climate modelling and in operational forecasting; (b) efficient local and regional forecast methods that produce skilful and reliable predictions over land areas for both the local and large scales; (c) clear examples of how actionable this climate information is for a range of stakeholders; and (d) a strategy to disseminate and illustrate the usefulness of improved, high-quality climate prediction information and to integrate it with other climate services initiatives, focusing mainly on the long-term climate change problem.

The recommendations given in the table below were made by ESMAP, World Bank, in the report *Climate Impacts on Energy Systems: Key Issues for Energy Sector Adaptation* (Ebinger and Vergara, 2011). The recommendations have a clear focus on adaptation of the energy sector to climate change, but they are appropriate for the GFCS Energy Exemplar too.

**General recommendations**

<table>
<thead>
<tr>
<th>Proposed near-term actions to foster dialogue among energy sector practitioners and to improve the knowledge base</th>
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<tr>
<td><strong>Support awareness and knowledge exchange</strong></td>
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<tr>
<td>There is a need to disseminate and learn from the increasing data and knowledge of climate impacts on the energy sector, and their management. To be able to take informed actions, it will be important to: (a) support better awareness of these issues with public and private decision-makers; and (b) support access to state-of-the-art data on the consequences of climate destabilization.</td>
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<tr>
<td><strong>Undertake climate impacts needs assessment</strong></td>
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<tr>
<td>Location-specific adaptation requirements are dependent on an analysis of impacts. Climate impact analysis is the first step towards the development of adaptation strategies. Such an assessment should quantify the impacts (and hence risks) and data and information needs through the energy life cycle to guide adaptation practise in any country. It should incorporate and critique existing practices and potentially include an assessment of the associated costs of impacts, and of consequences if climate risk management is not applied.</td>
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<tr>
<td><strong>Develop project screening tools</strong></td>
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<tr>
<td>Develop templates to screen individual energy projects for climate vulnerability and risks, either retrospectively or during project planning and implementation. This should particularly target strategic and large-scale projects. Develop supporting guidance, information and simple decision rules for climate risk integration into decision-making (e.g. how to choose locations for new power plants, taking into account climate change impacts, or power plant robustness to extreme events). Simulation modelling could support the development of pertinent “what-if” scenarios.</td>
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<tr>
<td><strong>Develop adaptation standards for the energy sector</strong></td>
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<tr>
<td>Such standards should cover engineering matters and information requirements. Though the development of standards is beyond the remit of the United Nations Framework Convention on Climate Change, it could be handled through the energy sector itself, through international organizations such as the United Nations, International Energy Agency, International Renewable Energy Association and universities or research institutions. The International Civil Aviation Authority could provide a model framework for an organization tasked with developing adaptation standards relevant to the energy sector. Agreement on, and enactment of, standards would require coordination with other pertinent organizations. Some examples include: standards for robust coastal infrastructure, which take into account the anticipated strength of extreme weather events, revised zoning standards, to minimize climate risks for future assets, and construction standards in traditional permafrost areas, to accommodate changes in soil structural characteristics.</td>
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<tr>
<td>Revisit planning time frames and the use of historical data for future investments</td>
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<tr>
<td>Address potential climate impacts when retrofitting existing infrastructure</td>
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<tr>
<td>Implement specific adaptation measures</td>
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<tr>
<td>• Explore the interaction among water demand and use, and cross-sector and regional energy and water balances;</td>
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<tr>
<td>• Better understand the impacts of climate change on renewable resource potential (e.g. wind, solar or biomass);</td>
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<tr>
<td>• Explore synergies and trade-offs among climate mitigation and adaptation strategies for the energy sector;</td>
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<tr>
<td>• Identify options (technological and behavioural) to save cooling energy and reduce electrical peak load demand.</td>
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<tr>
<td>Identify policy instruments</td>
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<tr>
<td>Support capacity-building</td>
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**Recommendations for climate information networks**

| Observation networks | In developing countries, a key priority is to return deteriorating observation networks to minimum WMO standards. This will provide broader weather and climate benefits (including calibrating satellite measurements) for the energy sector rather than immediate gains given the location-specific information needs for infrastructure-based decisions. However, energy information could be improved if basic weather and climate networks are provided with platforms (ideally automated) or supported with ongoing maintenance in areas with immediate benefit to the energy sector. Priority could be given to creating subsidiary hydrometeorological networks (again ideally automated, perhaps including upper-air and offshore measurements) that would benefit current and planned energy sector activities. Assistance might also be provided to improve communications and capacity, not only for a country to collect its own data but also to provide data to the international community and to receive and process data, including those from reanalyses and satellites. |
| Support data rescue and archiving | There are various programmes supporting data rescue, including the WMO Climate Data and Monitoring Programme, but the need is extensive. Paper records need to be digitized, and documented climate information needs to be recovered, such as from missionary diaries. Support is needed to build secure digitized data archives, ideally to a common standard, and to ensure archives are accessible and protected from possible destruction. If appropriate, extended climate series might be created using proxy data. |
In many countries, resources for the delivery of forecasts, and the development and use of forecast models for the energy sector, could be upgraded substantially. Support needs include:

- Facilities for receipt and processing of forecast information
- Capacity-building for forecasters to interpret and verify advanced forecasts, including from ensembles

Access to the projections of the Intergovernmental Panel on Climate Change is straightforward, but developing countries require substantial capacity-building support to process, interpret and produce national-level impact projections. The United Nations Framework Convention on Climate Change promotes adaptation through national adaptation programmes of action and the Nairobi Work Programme, which provides a framework for capacity-building. It includes national downscaling using regional climate models, which can be an invaluable tool provided that recognition is made of the inherent uncertainties.

Facilitate engagement among weather and climate information providers and energy users (possibly at a regional level), with the aim of providing early warning and advisory climate services.

Source: Ebinger and Vergara (2011)

The recommendations for increasing the resilience of the power sector and the communities it serves, given in the table below, were made by WBCSD in the report *Building a Resilient Power Sector* (WBCSD, 2014). Climate change is leading the emergence of new business models in the power sector that incorporate ways of approaching risks and uncertainty.

**Lessons learned from power companies around the world**

<table>
<thead>
<tr>
<th>Recommendations for the industry</th>
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<tr>
<td>Build expertise in analysing climate information to better understand risks, especially downscaling global climate models to a local level</td>
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<tr>
<td>Use risk management and risk–cost–benefit analysis when developing adaptation strategies to determine which solutions are efficient and cost-effective</td>
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<tr>
<td>Continue investing in research and development to develop effective upgrades to major infrastructure elements, broadening the range of options and reducing costs over time</td>
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<tr>
<td>Pool learning, exchange best practice and share resources to respond effectively to extreme events</td>
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<tr>
<th>Recommendations for policymakers</th>
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<tr>
<td>Consider market signals and regional regulatory structures appropriate to local circumstances that can mitigate some of the risks</td>
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<tr>
<td>Support a business model that is viable in the context of climate change, including incentives for utilities to invest in adaptation</td>
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<tr>
<td>Adjust regulations to recognize the high-impact risks faced today and the likelihood of increasing frequency in future</td>
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<tr>
<td>Reflect climate risks in system specification and equipment standards</td>
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<tr>
<th>Recommendations for public–private collaboration</th>
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<tr>
<td>Organize cross-sector collaboration for long-term infrastructure planning and organize mutual aid for crisis response</td>
</tr>
<tr>
<td>Organize effective pooling of technical expertise, risk assessment and understanding of socioeconomic costs and develop new business models to price and manage risk</td>
</tr>
<tr>
<td>Develop useful, local forecasts over time periods short enough to be relevant to business decision-making by giving utilities access to climate data and hydrological information</td>
</tr>
<tr>
<td>Improve public–private collaboration to share information, especially on a local scale, to improve community resilience</td>
</tr>
</tbody>
</table>

*Source: WBCSD (2014)*
Annex 7 – Business Models for Implementation of the Global Framework for Climate Services for the Energy Sector

Public–private partnership is essential for providing valuable information to energy enterprises that can use this information to generate profits and thereby support climate-resilient local economies. NMHSs have unique opportunities to build new revenue streams by developing business cases for providing weather and climate information to the energy industry. The following analyses have been developed in support of NMHSs to create a virtuous cycle that balances business-driven development with public interests for facilitating immediate and direct returns to both sides.

1. Strengths, weaknesses, opportunities and threats analysis

There are a number of strengths, weakness, opportunities and threats that affect the prospects for mutually beneficial interactions among WMO and its network of NMHSs, within the energy private sector (see the figure below).
1.1 Strengths

- WMO is the United Nations authoritative organization for weather, water and climate information.

- WMO operates through a network of 191 Member States and territories, covering all the world’s areas. NMHSs act as national/regional entities for weather, hydrological and climate information.

- The climate information generated relies on observations and analysis supported by rigorous research and technology practices.

- For more than 65 years, WMO has acted as the United Nations specialized agency underpinning international cooperation in the field of meteorology, hydrology and geophysical sciences.

- In addition to WMO Members, other intergovernmental and non-governmental, regional, national and local stakeholders have worked in partnership to develop targeted climate services.

- As the global mechanism to bring together efforts to improve the quality, availability and application of climate information, GFCS provides the framework for climate services for energy as well as for agriculture and food security, water, health and disaster risk reduction. Other United Nations and international agencies (e.g. WHO, World Bank, UNDP, International Federation of Red Cross and Red Crescent Societies, United Nations International Strategy for Disaster Reduction (UNISDR), World Food Programme, UNESCO and FAO) have activities and programmes to implement GFCS jointly with WMO.

1.2 Weaknesses

- WMO and the majority of its network still have not defined the regulatory environment for an effective partnering with the private sector.

- WMO products are generally not easily monetizable, limiting engagement with the private sector.

- Lack of in-depth knowledge of the energy sector, its industries and regulations – even if mitigation of such weakness could be achieved through collaboration and partnerships with specialized agencies (councils, academia, organizations, private and public sectors).

1.3 Opportunities

- Awareness of the importance of a sustainable energy system (more efficient, more resilient and cleaner). Global efforts have been employed to develop clean energy technologies (most of which are highly dependent on climate information for their optimal operation). For example, the SE4ALL (http://www.se4all.org/) initiative was launched at the end of 2011 to secure universal access to clean energy, double the global rate of improvement in energy efficiency and double the share of renewable energy in the global energy mix.

- Many global actors are involved in promoting energy sustainability. In addition to SE4ALL, there are several other organizations (public, private and non-governmental) working on emission mitigation and
clean energy, thus providing opportunities for cooperation with development agencies (governmental and non-governmental), civil society, private sector and other agents for best achieving shared objectives.

- Increasing energy demand and the need to satisfy it with cleaner technologies. The market for providing climate services for the energy sector will probably continue to expand.

1.4 Threats

- NMHSs may find it challenging to interface with the energy private industry for the provision of climate services.

- WMO, as technical, scientific and non-governmental agency on weather, water and climate, does not have sufficient expertise in some key areas of the energy sector to successfully implement the GFCS Energy Exemplar.

- The potential of climate services may not be fully recognized by the energy sector.

- The quality standards of climate services may not be achieved homogenously in all countries.

- Climate information has to meet a variety of needs, which are different from country to country; therefore, a uniform process for service provision is not feasible.

- Differentiation among large and small utilities could represent another crucial constraint for implementation.

- Similarly, other differences among the energy stakeholders, in terms of economic and technical capacity, may give rise to market and supply-price bias, leading to advantages for companies who have more resources.

2. Market analysis

Good knowledge of the energy industry landscape is an advantage when it comes to finding the best implementation methodology for business model development. This is generally achieved through market segmentation based on particular activities of the chain value of the energy process (or energy subsectors):

- Generation: thermal, solar, wind, nuclear or chemical energy is transformed into mechanical energy, and then into electrical energy. Each type of energy represents a very different opportunity to provide tailor-made climate services, as the particular requirements may differ considerably.

- Transmission and distribution: after generating the electricity, it is normally transported via very high-voltage lines (220–500 kV) to the distribution network, where it will be subsequently transformed to a lower voltage, to be supplied to final users. Even if the climate services for transmission and distribution are different, some of the infrastructure used in both situations is normally shared and may face similar threats in terms of exposure to weather and climate variability.

- Retail markets, emission market-trading and risk-hedging activities: these three subsectors can be grouped as upstream activities with common needs for specific climate services.
• Integration models and other public policies: these include long-term decisions on interregional market integration, national generation mixes and other relevant policies.

Depending on the national context, NMHSs may act as the primary enablers for gathering adequate information about the particular needs of energy system stakeholders. Strong communication among NMHSs or other intermediaries and energy sector actors in the above areas is key, not only for the identification of needs, but also for implementation of the GFCS Energy Exemplar (as part of the fully interactive process that has been defined and for the customer orientation that characterizes the project). With the aim of identifying the real needs of industry, some valuable interaction can also happen among partner organizations such as emergency management agencies, national/regional energy organizations, business councils or any other lead entity that interacts with the energy sector. The possibility to orient the climate services to a specific customer’s needs opens a wide field of beneficiaries within the energy provision chain.

An increasing number of private companies provide climate services with the aim to add value to weather and climate information, to serve the needs of the private sector of different industries. These entities are continuously developing tools that help their clients to manage climate-related risks and opportunities in the most effective ways. These companies may not generate weather and climate information, but rather act as information synthesizers and providers; they also sell climate services to users (with or without added value in terms of enhancements to the data and products provided).

3. Implementation methodologies

Four different implementation approaches to business model development are presented below. The reason for not selecting one model as the ideal one to be applied in all cases is due to the differences in the energy sector configurations across countries and regions. Some countries have a very mature industry, and have been operating under a liberalized scheme for decades, while other countries continue under a monopolistic structure. Other important differences include the energy generation mix and the amount of renewable energy share in the total energy generation. Even if the spectrum of energy systems is considerable, further categorization of countries may be feasible by clustering them according to their most notable characteristics. Application of the four proposed methodologies in different countries can lead to selection of the best practice and to an optimal unique approach. For the initial stage of the GFCS Energy Exemplar, and after resource identification and detailed study of the energy system is conducted (through market research), the selection of the most accurate implementation process can be performed.

3.1 Retailing/commercial model

In the retailing model, the products/services price is settled after adding a markup from the total cost. Given the nature of the services, and the fact that these are not provided to a mass market, the definition of the price strategy can be complicated, particularly as WMO is an intergovernmental agency whose objectives and practices are not defined by a profit-stream model. Nevertheless, the level of specialized expertise of Members of the WMO community creates possibilities for orienting service provision towards specific categories of products and services, targeting selected markets, and then adding value according to the preferences of the targeted agents, in such a way that the clients value these products and services sufficiently enough to pay for them.

Customer orientation can be stimulated through the creation of a WMO catalogue of climate services for the energy sector, as a valuable element of the retail model (not always used), and a supportive tool for offering
scientific specialized services for the energy industry. The primary purpose of having a catalogue is to provide a single document to easily allocate and update the network capabilities and to be able to present it to all the possible customers and participants. Another important benefit of having a catalogue of services is to reach a wide variety of energy-related actors. Some services can be strictly related to satisfying a specific area of the energy sector, but they may also be useful in some way in another area of the sector. Offering a robust collection of information on the service possibilities improves the interactions among the WMO community and its networks of users, leading to identification of the most appropriate resources and capability options.

The advantages of selecting a retail model are:

- Easy implementation;
- Familiarity with a wide spectrum of energy private and public sector entities;
- Generation of resources that can be used for the sustainability of service;
- Facilitate competitiveness;
- Initiate the valuation of hydrological/meteorological services;
- Associate the prestige of the service with the price definition;
- Strengthen customer relationships.

The disadvantages of the retail model are:

- If there is no differentiation from similar services in the market, the project’s objectives may be at risk;
- WMO, as an intergovernmental organization, and NMHSs, as public sector entities, may be subject to conflicts of interest stemming, in part, from lack of experience in the use of retail and commercial models;
- Creation of profits can generate monetary-related threats;
- Defining prices is a multidisciplinary and complex task;
- Success in the retail/commercial market is demanding of time and other resources.

3.2 Membership model

The main objective of the membership methodology is direct participation and engagement of users. This can be done by charging a fee or engaging energy private sector actors as project participants, to help to consolidate particular climate services in the countries where they operate and to facilitate interaction and communication processes. The membership implementation model may be applicable in some countries, while it might be impossible in some others, given the variety of the energy systems in the world.

In the membership model, the services provided can stimulate participation from the energy agents. Joint engagement on project-funded initiatives can also lead to improved NMHS capabilities to provide relevant tailor-made climate services.

The main advantages of the membership model are:

- Risk mitigation;
- Facilitation of new market development;
- Enhancement of energy stakeholder engagement and capacities;
- Facilitation of communication among the targeted audience;
- Contribution to establishing relationships with stakeholders;
- Improvement of relationships with the private sector.
The main disadvantages of the (fee-based) membership model are:

- Pre-definition of a value from the members
- Membership fee definition can be complex
- Benefits can differ according to the fee paid (and may not meet expectations)

The benefits that the climate services generate are not exclusive to member companies that are directly participating. Building an energy sector that is more resilient contributes to the development of the society and therefore benefits external agents. From big corporations to mid-size/small companies, there are corporate social responsibility programmes related to GHG emission reduction, for example, or to some other sustainability goals. Such programmes can be used to create a context for interaction among specific stakeholders, which leads to outcomes beneficial to society on a wider scale.

3.3 Licensing

This methodology is based on compensation payment for using a licensed platform of climate services. The key element of this business model is that the licensing agreement to be signed is a legal vehicle for defining each participant’s role and responsibilities. A major advantage is that developing a climate services user interface can facilitate the spreading of the services among the stakeholders and standardize, in some way, the implementation of the services among the users of an energy system. Nevertheless, as customer orientation is a key factor for the achievement of the Energy Exemplar’s goals, standardization can only take place across a subset of the climate services. In order to adapt the proposed interface to the provision of climate services, two different approaches to the platform design are proposed:

1. A platform serving a wide audience, with general weather and climate data. As the number of users increases, economies of scale can be created, given that the production costs remain the same. This interface is adequate for providing climate services for each energy subsector, as the required information tends to be the same among the energy-segmented users (by type of activity);

2. A personalized platform, providing tailored services through a user-driven interface particularly designed to facilitate interactions with the final user, taking into account their particular needs and requests.

Another key factor for optimal execution of the licensing methodology is the development of an interface platform with the best technological capabilities and standards, ensuring a smooth, user-friendly, operation.

The advantages of the licensing methodology are:

- Enhanced outreach of climate services
- Recognized WMO leadership
- Efficient way of disseminating products and best practices

The disadvantages of the licensing methodology are:

- Legal problems if the licensing agreement is not carefully drafted
- Complexities in the set-up of the interface: exclusive or non-exclusive licences and general or tailor-made options
- Success relies on mature projects
- Relatively high requirement for adequate technology development
3.4 Partnership

Another option for a GFCS Energy Exemplar implementation model is partnership among international and national entities. This methodology focuses on building relationships among climate services and energy stakeholders in order to facilitate (in different ways) the generation and delivery of climate services.

The global awareness of sustainability and climate change issues, as well as recognition of the need for climate mitigation and adaptation action, is a crucial driver for partner engagement. The partnership model aims to increase the list of current GFCS partners, and to focus efforts needed to implement the GFCS Energy Exemplar. Core partners engaged in this manner can facilitate the development of relationships with a wide network of energy sector practitioners.

One example of partnership among private sector and international organizations is provided by UNIDO, which is continuously pursuing efforts to develop new synergies with the private industrial sector. UNIDO created the Business Partnership Programme for harnessing new and shared expertise and resources of partners to advance inclusive and sustainable industrial development while simultaneously driving business value.

Another example is UNISDR, which has launched a campaign to work closely with private stakeholders. In 2015, ARISE (Private Sector Alliance for Disaster Resilient Societies) was established with the overall goal of creating risk-resilient societies by energizing the private sector in collaboration with the public sector and other stakeholders. More than 140 private sector members are affiliated with this global initiative.

The advantages of the partnership model are:

- Risk mitigation;
- Opportunities for new market development;
- Leveraging of members for outreach to energy system actors;
- Facilitate communication;
- Enhance engagement by the private sector and other stakeholders;
- Knowledge and resource enhancement.

The disadvantages of the partnership model:

- Disagreements and friction among partners if mandates are not well defined
- Intimidation by some partners
- Flexibility is required

4. Example: the Colombian hydropower subsector

According to the market analysis provided by the operators and administrators of the Colombian electric market (http://www.xm.com.co/), the power generation sector in Colombia is dominated by a system of hydroelectric plants operated by several local and multinational agents.

The Colombian hydropower subsector is vulnerable to weather and climate events. The long drought as a consequence of the strong El Niño event in 2015/2016, for example, led the Colombian Government to adopt measures of energy-use restrictions because the energy supply dropped by 21% compared to previous years. El Niño affected the energy demand and generation, river inflows, water level in the reservoirs and energy prices (XM, 2015).
The current electrical system in Colombia suggests that the retailing and the stakeholder partnership models are both suitable for GFCS implementation in the context of a public–private engagement. Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM), as the country’s NMHS, is the active player in providing the hydrometeorological and climate information for helping the hydropower operating companies to reduce weather and climate vulnerabilities.

The Colombian energy sector is organized through different public and private entities (associations and councils), which facilitate outreach to a wide range of beneficiaries. Meeting the needs of a targeted group such as the hydropower operators through a combination of retail and partnership approaches may lead to strengthened coordination among these key organizations and consequently expand the benefits of climate services beyond the initially targeted customers.

In Colombia, key institutions that group energy sector stakeholders are:

CNO (Consejo Nacional de Operaciones, http://www.cno.org.co/) is a non-governmental entity, whose operating budget comes from annual contributions of electricity sector members. CNO is organized through different committees (Operation, Distribution, Legal, Transmission and Technological), subcommittees and working groups.

BCSD Colombia (CECODES, www.cecodes.org.co) is the Colombian Business Council for Sustainable Development. Operating for more than 20 years as a promoter of sustainable development, BCSD helps private companies to align their business strategies to environmental and sustainable operations and planning. Several energy utilities in Colombia are members of CECODES.

AGOLGEN (Asociacion Colombiana de Generadores electricos) is a non-profit and non-governmental trade organization aimed at promoting fair competition among energy utilities and market development with better policy and sector regulation. Currently, 18 generation companies are members of AGOLGEN, representing 86% of the net effective generation capacity in Colombia.

Different kinds of partnership could be established with the vision of sharing common interests and contributing to mutual benefits:

- Expertise partnerships: knowledge-sharing from partners in their operating fields, to provide essential insights for continuous improvement of climate services and to strengthen interaction among energy stakeholders;

- Capacity partnerships: sharing of infrastructure, equipment, experienced staff and any other resources (research and development collaborations are also included in this category);

- Communication partnerships: organizing joint events or activities such as conferences, training courses, workshops, etc., to contribute to the outreach strategy;

- Financial partnerships: co-designing proposals and/or tenders for resource mobilization;

- Learning partnerships: developing contents for projects to ensure scaling up.

Co-production of a climate services catalogue should be guided by several consultations involving IDEAM and the partners mentioned above. As a first step, IDEAM could list the climate services already available
and initiate pilot projects with the aim to identify and meet the specific needs of the hydropower subsector. In this way, further adjustments and improvements could be implemented through the engagement and support of the energy stakeholders. Initial pilot projects could entail the reconstruction of precipitation in a catchment area and skilful seasonal forecast of key meteorological variables. The co-production of a climate services catalogue should also include the process of climate services valuation and pricing. In this area, some seminal work has been done by WMO, the World Bank Group, USAID and the Global Facility for Disaster Reduction and Recovery, the results of which are documented in *Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services* (WMO, 2015).
References


### Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>AEMO</td>
<td>Australian Energy Market Operator</td>
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<tr>
<td>AGOLGEN</td>
<td>Asociacion Colombiana de Generadores electricos</td>
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<tr>
<td>ASHRAE</td>
<td>American Society of Heating, Refrigerating and Air-Conditioning Engineers</td>
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<td>AWEFS</td>
<td>Australian Wind Energy Forecasting System</td>
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<td>BCSD</td>
<td>Colombian Business Council for Sustainable Development</td>
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<tr>
<td>BODC</td>
<td>British Oceanographic Data Centre</td>
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<td>CCS</td>
<td>carbon capture and storage</td>
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<td>CD</td>
<td>Capacity Development</td>
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<tr>
<td>CLIM-RUN</td>
<td>Climate Local Information in the Mediterranean region Responding to User Needs</td>
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<td>CM SAF</td>
<td>Satellite Application Facility on Climate Monitoring</td>
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<tr>
<td>CNO</td>
<td>Consejo Nacional de Operaciones</td>
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<td>CSIS</td>
<td>Climate Services Information System</td>
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<td>CSP</td>
<td>concentrating solar power</td>
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<td>DNI</td>
<td>direct normal irradiance</td>
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<td>DOE</td>
<td>Department of Energy (United States)</td>
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<td>ESMAP</td>
<td>Energy Sector Management Assistance Program</td>
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<td>EU</td>
<td>European Union</td>
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<tr>
<td>EUPORIAS</td>
<td>European Provision of Regional Impacts Assessments on Seasonal and Decadal Timescales</td>
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<td>FAO</td>
<td>Food and Agricultural Organization of the United Nations</td>
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<td>GEO</td>
<td>Group on Earth Observations</td>
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<td>GEOSS</td>
<td>Global Earth Observation System of Systems</td>
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<td>GFCS</td>
<td>Global Framework for Climate Services</td>
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<td>GHG</td>
<td>greenhouse gas</td>
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<td>GHI</td>
<td>global horizontal irradiance</td>
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<td>GSEP</td>
<td>Global Sustainable Electricity Partnership</td>
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<td>GWEC</td>
<td>Global Wind Energy Council</td>
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<td>IAEA</td>
<td>International Atomic Energy Agency</td>
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<tr>
<td>ICEM</td>
<td>International Conference Energy &amp; Meteorology</td>
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<tr>
<td>IDEAM</td>
<td>Instituto de Hidrología, Meteorología y Estudios</td>
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<tr>
<td>IEA</td>
<td>International Energy Agency</td>
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<tr>
<td>IMarEST</td>
<td>Institute of Marine Engineering, Science and Technology</td>
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<td>IOGP</td>
<td>International Association of Oil &amp; Gas Producers</td>
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<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<td>IRENA</td>
<td>International Renewable Energy Agency</td>
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<td>MARIS</td>
<td>Mariene Informatie Service “MARIS” BV</td>
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<td>MOL</td>
<td>Meter Online</td>
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<td>NCAR</td>
<td>National Center for Atmospheric Research</td>
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<td>NEM</td>
<td>National Electricity Market</td>
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<td>NMHS</td>
<td>National Meteorological and Hydrological Service</td>
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<tr>
<td>NWP</td>
<td>numerical weather prediction</td>
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<tr>
<td>Obs/Mon</td>
<td>Observations and Monitoring</td>
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<td>PV</td>
<td>photovoltaic</td>
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<tr>
<td>RMP</td>
<td>Research, Modelling and Prediction</td>
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<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>SCADA</td>
<td>supervisory control and data acquisition</td>
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<tr>
<td>SE4ALL</td>
<td>Sustainable Energy for All</td>
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<tr>
<td>SIMORC</td>
<td>System of Industry Metocean data for the Offshore and Research Communities</td>
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<tr>
<td>SPECS</td>
<td>Seasonal-to-decadal climate Prediction for the improvement of European Climate Services</td>
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<tr>
<td>TSO</td>
<td>transmission system operator</td>
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<td>UIP</td>
<td>User Interface Platform</td>
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<tr>
<td>UNDP</td>
<td>United Nations Development Programme</td>
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<tr>
<td>UNEA</td>
<td>UN-Energy Africa</td>
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<tr>
<td>UNESCO</td>
<td>United Nations Educational, Scientific and Cultural Organization</td>
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<tr>
<td>UNIDO</td>
<td>United Nations Industrial Development Organization</td>
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<tr>
<td>UNISDR</td>
<td>United Nations International Strategy for Disaster Reduction</td>
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<tr>
<td>UVIIG</td>
<td>Utility Variable-Generation Integration Group</td>
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<tr>
<td>UWIG</td>
<td>Utility Wind Integration Group</td>
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<tr>
<td>VRE</td>
<td>variable renewable energy</td>
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<tr>
<td>WBCSD</td>
<td>World Business Council for Sustainable Development</td>
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<td>WEC</td>
<td>World Energy Council</td>
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<td>WEMC</td>
<td>World Energy &amp; Meteorology Council</td>
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<td>WHO</td>
<td>World Health Organization</td>
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<td>WMO</td>
<td>World Meteorological Organization</td>
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