Alberto Troccoli · Laurent Dubus
Sue Ellen Haupt *Editors*

Weather Matters for Energy

Springer

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Foreword 1

In France, the energy sector has been for a long time among the main users of meteorological, hydrological, and other climate information. Météo-France enjoys the benefit of a long-term strategic cooperation with this sector. This is why I am happy to congratulate the team of Editors of this International Conference Energy & Meteorology (ICEM) 2011 book and to contribute to it with this short introduction.

The public and the industry expect more secure and cleaner energy, which means that the vulnerability of energy systems has to be minimized in accordance with the possible hazards impacting them, in compliance with sustainable development. Meteorological, hydrological, and other climate data are indeed essential both in day-to-day energy management and for the definition of production and distribution infrastructures. For instance, provision of electricity to users can be endangered by extreme meteorological and hydrological events such as thunderstorms with unusually strong winds, flash floods, severe icing, severe colds, heat waves, sea-level elevation associated to storm surges, floods, or other hazards.

To be protected against such events, it is not sufficient to act after their impacts have happened. It is also necessary to identify precisely the potential impacts in advance and to assess their probabilities and manage the risk through regularly updated and seamless Weather-Water and Climate Services such as the ones identified within the World Meteorological Organization (WMO)-led World Climate Conference 3 (WCC-3, 2009) and now being implemented through the Global Framework for Climate Services (GFCS-2012).

The recent advances in atmospheric sciences and in the field of energy production and management offer a huge range of new possibilities. Considering that further developments will benefit essentially from the dialog between experts from both fields, Météo-France as a member of the world meteorological community is willing to take the lead and foster this dialog within the European energy and climate agenda and even more widely. The present book will be most useful both for meteorologists and for energy practitioners to get acquainted with the recent progresses in that direction and to learn for instance from the successful cooperation between EDF and Météo-France, and many others around the globe.

The weather, water and climate community coordinated under WMO is strongly committed to improve continuously its services to the energy sector. More generally, building on the WCC-3 recommendations, WMO and many partners have agreed to establish a GFCS and are since October 2012 working on its implementation. The GFCS has the objective to ensure that climate information and predictions are made available to decision-makers enduring the increasing impacts of climate variability and change. A historic extraordinary session of the World Meteorological Congress took place on 29–31 October 2012, which approved the governance structure and implementation plan for the GFCS. This is a sweeping initiative to capitalize on scientific advances and roll out user-driven services starting from improved weather, water short-term forecasts to longer term climate predictions such as seasonal climate outlooks and El Niño watches, flood prediction and drought monitoring tools, and extreme events occurrence probabilities.

The GFCS is a necessary step in view to define and implement scientifically sound measures of adaptation to climate variability and climate change. It will contribute to improve the field observations in the world, to make them easily accessible under a readily utilizable form. It will also help to develop numerical modeling of the atmosphere and the Earth in general, and to produce information tailored to the users needs.

I take this opportunity to commend the work done by all the experts involved, then all the partners who contributed with resources and NATO for being the initiator and supporting the first workshop in 2008 and the first publication in 2010 which in 2011 provided the framework for the first international conference on Energy and Meteorology, conference which has assembled the material for the present publication. In view of the determination, commitment, and professionalism of the organizers of this Energy and Meteorology partnership process, I have no doubt that this endeavor, which started very simply in 2008 as an advanced research workshop will continue on a long term as a capacity building program. Météo-France was happy to host the ICEM 2013 conference, which took place in the Conference Centre of the "Meteopole" in South–West France (Toulouse, 25–28 June 2013, < https://www.icem2013.org >).

François Jacq

François Jacq studied at the École Polytechnique (Paris) and at the École Nationale Supérieure des Mines de Paris. He holds a Ph.D. in History and Sociology of Science. Before joining Météo-France in April 2009 as CEO, he was adviser to the Prime Minister on Sustainable Development, Research and Industry. He was previously a researcher at École des Mines de Paris, Director of the Department on Energy, Transportation, Environment and Natural resources in the Ministry of Research, Chief executive of the National Agency for the Management of Radioactive Waste, and Director for Energy demand and markets in the Ministry of Industry of France. Dr. Jacq is also a member of the Executive Council of the World Meteorological Organization.

Foreword 2

When Laurent Dubus asked me to write a foreword for the book he is editing, and contributing to, with Alberto Troccoli and Sue Ellen Haupt, I accepted at once. Indeed, this is a topic which is key in my mind! I do believe that the relationships between weather, weather forecast, climate, and our job, which is to deliver safe, reliable, and affordable electricity, will increase in the future.

The interactions make sense on all aspects of our business: production, transport and distribution, and consumption. My sense is that the effect that meteorology has on energy systems can be represented by four important categories, roughly related to different meteorological time scales. I believe these four categories are as follows.

Crisis management—By improving our knowledge of severe meteorological events such as floods, strong winds, heavy snowfalls, heat and cold waves, we can better manage both demand side (with DSM—Demand Side Management) and supply side and thus we can manage crises more effectively. This means being able to access short-term forecasts but with very high resolution especially around areas of critical interest like power plants, rivers, towns, and so on. It is particularly important to try to anticipate these severe events and provide appropriate alerts, when the risk of extreme events is above a tolerable threshold, even if this means accepting some false alarms.

Day-to-day operations—My understanding about the strong relationship between electricity production, electricity use, and weather initially came through my on the ground experience. I have gained a good appreciation about the limits of forecasts so as to be able to use them properly; I worked toward improving the forecast quality and reliability to reduce the gaps between predictions and observed weather, particularly for air temperature as linked to consumption, wind speed or rainfall as linked to production. In the future, the development of electricity from renewable sources will further increase the dependence of power systems on weather variability, and hence the importance of climate uncertainty.

Planning of production facilities—Power production requires having an idea of the weather in the middle term (warm or cold weather, drought or excess in river discharge). This means not only the use of forecasts of mean weather conditions but also their probabilities. More research is required to be able to produce reliable midterm forecasts. Exactly like farmers who would like to know what cereals they can grow under certain rain patterns, we need to know if the coming summer will be sunny or rainy as this knowledge will shape the consumption (more or less cooling) and the balance between the different ways to produce electricity (e.g., do we need to “save” water in the reservoirs or can we release some?), also taking into account the necessary maintenance of power plants.

Facility construction and maintenance—We rely on climate knowledge to build our facilities: floods, temperature of rivers, winds etc…These data are critical in the dimensioning of plants. We use data from the past to assess the events and to define the characteristics of our plants. This point is certainly the most important for me as it requires a complete change in our relationship with stakeholders including people working on climate. The changing world, in which we currently live, including climate variations and changes, will require a serious rethinking of our “business as usual approach”. We will need to expand our knowledge and practice with an eye not only on the past but also critically, on the future. We built our infrastructures to resist to the extreme events we knew through past climate data; today we need to redefine the limits between resistance and resilience of our facilities and this will require understanding of interactions with meteorological variables under climate change.

The cooperation EDF develops with the scientific community, including meteorologists, to fulfill its needs on weather and climate forecasts is more alive than ever. We need meteorologist and climatologists to increase the knowledge, provide new and more accurate data, and develop new models, forecasts, and projection at all time scales, from the real time to the end of the century.

Fulfilling our needs is only possible with a close collaboration between the weather and climate sector on the one side, and the energy sector on the other side. I do believe that this volume, and the International Conference Energy and Meteorology (ICEM) conference cycle, is an important component of such an efficient partnership.

Claude Nahon

Claude Nahon was named Group’s Executive Vice President for Sustainable Development at Electricité de France (EDF) in January 2003. Prior to her appointment, she was Head of Hydro and Renewable Energies. A graduate of France’s prestigious École Polytechnique, Claude Nahon has been with EDF since 1978, holding managerial positions in both generation and distribution. In addition to her responsibilities at EDF, Claude Nahon represents EDF Group in different occasions and institutions. She is Liaison Delegate of Henri Proglio in the World Business Council for Sustainable Development (WBCSD). She sits on Institut du Développement Durable et des Relations Internationales (IDDRI) and Entreprises pour l’Environnement (EPE).

Preface

A storm is mounting. You were alerted about the approaching severe weather conditions by the weather forecaster. You're now sitting in front of your monitors trying to decide how many power units to commit. The precise power mix, whether it is more economical to run more hydro instead of wind for instance, is also key but you don't have much time to take a decision. With a combination of modeling tools and expert knowledge, you're trying to figure out whether the thick deck of clouds will make the 100 MW solar power plant ramp down within minutes or hours. And can some of this shortfall be partly compensated by the newly installed 150 MW wind farm? Meanwhile, gas generators will most likely be safe, but will there be enough time to start them up and avoid that horrific black out?

It has been a long day, but luckily the effects of this weather event have been well handled, as many tools were available to assess this situation and act on it efficiently. The seasonal forecast had predicted that such storms would be likely this month; thus the maintenance department had performed preventive maintenance in advance. However, it makes you wonder whether storms like this will become more frequent and impactful in the future. Already we are seeing an increasing number of meteorologically derived disasters. Warmer temperatures, as projected decades from now by climate models, will very likely bring even more severe events. It is almost a no-brainer to factor these climate effects into energy sector risk management decision-making. But exactly how to do this may not be straightforward.

It is the purpose of this book to provide the meteorological knowledge and tools to improve the risk management of energy industry decisions, ranging from the long-term finance and engineering planning assessments to the short-term operational measures for scheduling and maintenance. Most of the chapters in this book are based on presentations given at the inaugural International Conference Energy and Meteorology (ICEM), held in the Gold Coast, Australia, 8–11 November 2011 (see http://www.icem2011.org). The main aim of the conference was to strengthen the link between Energy and Meteorology, so as to make meteorological information more relevant to the planning and operations of the energy sector. The ultimate goal would be to make the best use of weather and climate data in order to achieve a more efficient use of energy sources. This book seeks to realize the same objective.

It is worth highlighting the close connection, in terms of temporal and spatial scales, between decisions in the energy industry on the one hand and natural meteorological events on the other. Indeed, decisions in the energy industry extend from the tiny temporal scales related to electrical instabilities, to the short-term typical of supply and demand balancing, to the longer terms typical of maintenance through to planning. Similarly, meteorological phenomena occur over essentially all time and space scales from the tiny scales of turbulence, to the short-term and small-scale events such as tornadoes, to the longer/larger hurricanes, through to climate change via El Niño. Often there is a strong link between a particular meteorological phenomenon and its implications for the energy sector. Thus, for instance, a hurricane, which typically lasts several days and affects an area of a few thousand kilometres, will be factored in energy operational and maintenance decisions over the span of a number of days, and with an advance notice of several days (hurricanes can be predicted several days in advance).

The book is structured to emphasize the role of the energy industry in terms of meteorological requirements. Indeed, unlike the more standard approach, which begins by presenting meteorological information, as if the latter was in search of a purpose, here we have genuinely attempted to put energy in the driver's seat. Such order is also reflected in the titles of the book parts, as with *Why Should the Energy Industry be Concerned About Weather Patterns?* of Part One.

There is no doubt that Energy and Meteorology is a burgeoning inter-sectoral discipline. It is also clear that the catalyst for the stronger interaction between these two sectors is the renewed and fervent interest in renewable energies, especially wind and solar power. This connection is also apparent from the content of the book. However, it must be realised that weather and climate information is also critical to managing the energy supply from other energy sectors (e.g., off-shore oil operations) as well as understanding and estimating energy demand. We have tried to stress this broader dependency in various parts of the book.

The book could not have come together without the ICEM 2011 meeting. Hence, we are indebted to the superb support of Elena Bertocco, the extraordinary organizational role of Aurélie Favennec, the efficient work of the steering and scientific organising committee, and the keen contributions of the conference delegates during an intense and fascinating week along the beautiful ocean shore of the Gold Coast of Australia.

It is a great pleasure to acknowledge the tremendous assistance of Danielle Stevens who has indefatigably and very diligently been assembling the book, even when prodding was needed to obtain responses from chapter authors. We are also indebted to Pierre Audinet for his strong support in shaping this book and for suggesting what we believe is an appropriate and attractive book title. We also wish to thank all the authors of the book for chipping in and helping to carry out thorough reviews of all chapters of this book.

We do hope you will enjoy this book. Happy reading!

Alberto Troccoli
Laurent Dubus
Sue Ellen Haupt

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Part I

Why Should the Energy Industry be Concerned About Weather Patterns?

A New Era for Energy and Meteorology

Beverley F. Ronalds, Alex Wonhas and Alberto Troccoli

Abstract In this chapter it is argued that the successful transformation of the world's energy systems depends on enhanced interplay between the meteorological and energy sciences. Key drivers of the energy transformation are described and the likely attributes and challenges of our future energy system are outlined. We identify a framework and give examples of ways in which a new cross-disciplinary science that truly combines energy and meteorological expertise will significantly reduce the risks and costs inherent in energy infrastructure. The need for this cross-disciplinary science is urgent given the scale and complexity of current and future energy infrastructure and its increasing vulnerability to the vagaries of the weather. Short-term opportunities to foster a much closer collaboration between energy and meteorology are also discussed.

1 The Energy Picture Today

The world runs on energy. The developed and, increasingly, the developing world relies on oil for personal mobility and for global trade. The equipment in offices and homes is powered by electricity. Industry often uses natural gas for process heat in manufacturing. As a result, some of the largest global companies are in the energy business. Nonetheless, around 20 % of the world's population does not yet have adequate access to energy (IEA 2011).

Global energy demand in 2010 reached 12,000 Mtoe, an increase of about 70 % compared to 30 years earlier (Fig. 1, IEA 2011). Australia, for instance, is an important exporter of coal, gas and uranium. The value of Australia's coal and liquefied natural gas (LNG) exports has increased four-fold over the last decade

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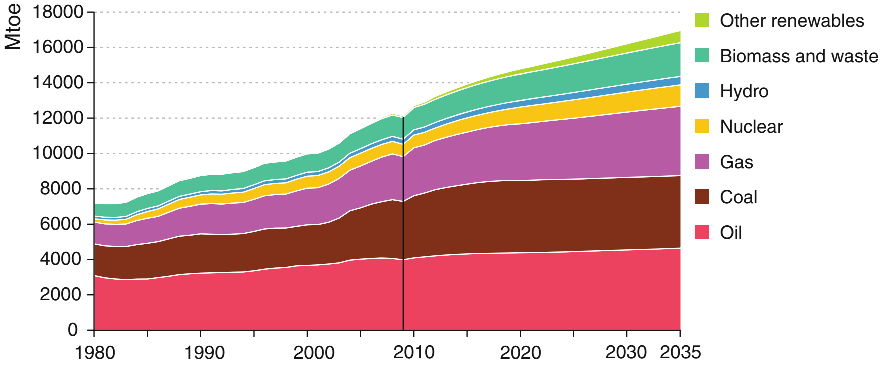


Fig. 1 Historical and projected changes in World primary energy demand by fuel. Fossil fuels are projected to maintain a central role in the primary energy mix but their share is projected to decline. The projections are based on the so-called New Policies Scenario, a set of broad policy commitments and plans which address energy security, climate change and local pollution, and other pressing energy-related challenges (IEA 2011)

(Australian Government 2011), and LNG projects currently under development will again more than triple Australia's export capacity in the next 5 years (Australian Government 2012). This growth in export mainly feeds energy demand from Asia.

With a number of countries including Australia having experienced 'peak oil' in their domestic production, global oil trade particularly from the Middle East and North Africa will also remain vital, and will cause an increased balance of trade burden for importers if the price of oil rises over time as forecast.

The 2011 World Energy Outlook (WEO) (IEA 2011) predicts global demand for energy will continue to grow, mainly because of the expected robust growth in population in Asia and Africa (Fig. 2). Such increase in demand is projected to be around 35 % over the quarter-century to 2035, corresponding to an estimated total energy demand of about 16,500 Mtoe (Fig. 1). However, factors like energy efficiency and carbon penalty policies introduce uncertainties to this projection.

What sources of energy will be used to meet such a substantial increase in demand? This is an area where uncertainties are even larger, especially because we live at a time when technological development is occurring at a fast pace. Consider for example the recent dramatic increase of shale or coal seam gas production or the strong decline in the cost of photovoltaic (PV) modules. However, to counterbalance these rapid technological advances, the lifetime of some power plants can extend to 40–50 years, as in the case of coal power stations, and this longevity slows the overall transition of the energy system.

In spite of these uncertainties, projections of how various technologies could contribute to the energy mix to meet the expected demand a few decades out, such as those produced by the International Energy Agency (IEA), help guide planning and investment in the energy sector. For instance, the IEA's projection shows that demands for all types of energy technologies are expected to increase in

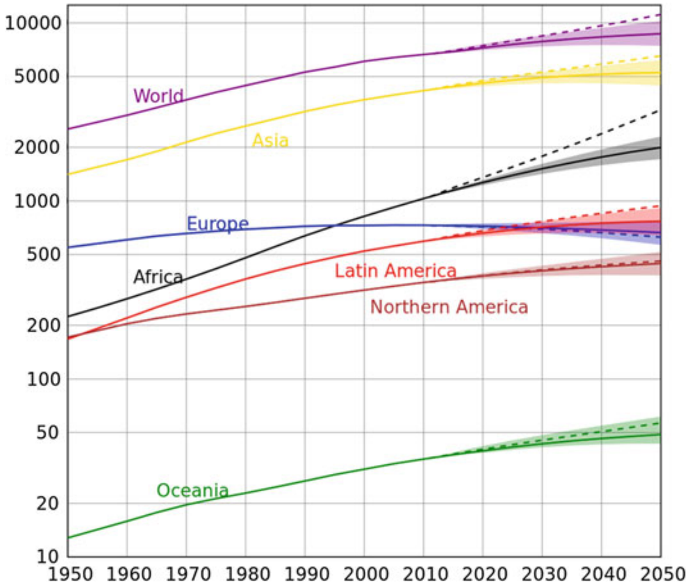


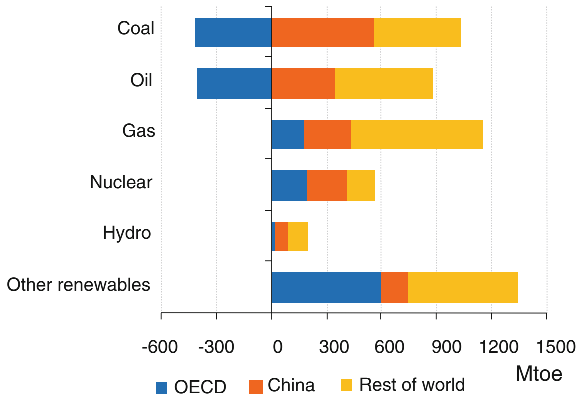
Fig. 2 Historical and projected population evolution globally and in different continents (World Population Prospects, UN Development Office, from http://en.wikipedia.org/wiki/World_population). The *vertical axis* is logarithmic and is in millions of people. Note the wider x-axis range compared to that in Fig. 1

non-OECD (Organisation for Economic Cooperation and Development) countries, while demand for coal and oil should decline in the OECD (Fig. 3). In particular, gas, nuclear and renewable energies are projected to partially replace coal and oil in OECD countries. Non-OECD countries, however, will require energy from all these sources to meet their increasing demand. It is important to note that over the same period renewable energy capacity is expected to triple globally. This is especially driven by the power sector where their share should rise from 19 % in 2008 to 32 % in 2035 (IEA, WEO 2010).

Energy systems interact with the climate in both directions. Mainly through their emissions, energy systems may modify the global temperature and other meteorological variables. Meteorology, hence both weather and climate, in turn affect planning and operations of energy systems. These interrelationships will only become more complex as both energy systems and the climate continue to evolve, and will impact energy demand (load characteristics) as well as supply (mitigation measures, water supplies, etc.). Adapting to climate change will also have consequences for energy supply.

Fossil fuels are the major source of greenhouse gas emissions. According to the Global Carbon Project (GCP 2011), emissions in 2010 were the highest in human history and the concentration of CO_2 in the atmosphere is about 40 % above that at the start of the Industrial Revolution, with a corresponding increase in global temperatures of about 0.8 °C (IPCC 2007).

Fig. 3 Projected changes in incremental global primary energy demand. Demand for all types of energy increases in non-OECD countries, while demand for coal and oil declines in the OECD. The projections are based on the so-called New Policies Scenario, a set of broad policy commitments and plans which address energy security, climate change and local pollution, and other pressing energy-related challenges (IEA, World Energy Outlook 2010)



With the expansion of energy systems there is also an increased vulnerability of these systems to severe weather and climate events. This chapter explores ways in which the energy industry can benefit from a deeper interaction with meteorology—which includes weather and broader climate science. Indeed, the intersection between energy and meteorology is the leitmotif of this book.

2 Vulnerability of Energy Systems to the Current Climate

Leaving aside projected changes in climate means and extremes, energy systems are already exposed to the vagaries of the weather. Naturally, most renewable energies are affected by weather and climate, but oil, coal, gas and even nuclear energy systems are, in different ways, also vulnerable to meteorological conditions (e.g. hurricane Katrina's impact on the Gulf of Mexico's oil production). Indeed, intense weather and climate conditions are expected to increasingly and critically influence the efficiency and economics of all energy systems.

According to Munich Re statistics, meteorological, hydrological and climatological catastrophic events have seen a marked increase since the 1980s (Fig. 4). While such events may not directly impact energy systems, they can be so large that they create shocks to the energy supply–demand balance. As a simple example, an extremely high temperature will induce exceptional air-conditioning use. However, to date focus has been on increasing energy supplies to satisfy industrial and societal demand for energy, by managing the risks perceived to be of immediate concern but without systematically accounting for risks posed by current and future climate changes (Ebinger and Vergara 2011; Schaeffer et al.

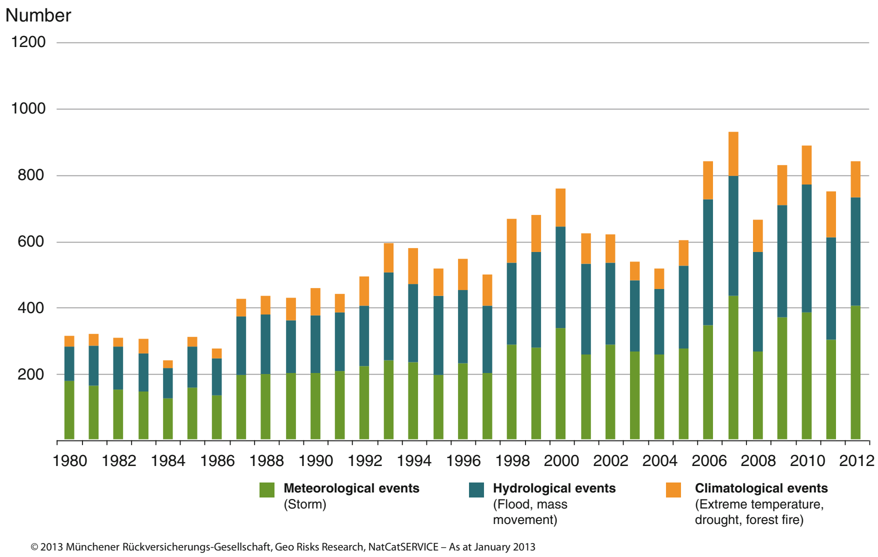


Fig. 4 Weather catastrophes worldwide 1980–2012: number of events (NatCatService, Munich Re, 2012, available from http://www.munichre.com/touch)

2012). It is important, therefore, to highlight some specific examples of the many ways in which weather and climate affect energy systems: these and others will also be expanded in the rest of the book.

2.1 Coal Production and Flooding

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, "Meteorology and the Energy Sector" by Plummer et al.).

2.2 Oil Industry and Storms

Hurricanes, and storms in general, can cause widespread disruption to the oil and gas industry. For instance hurricane Katrina in 2005, the costliest natural disaster in the history of the United States, caused, amongst the many damages, oil spills from 44 facilities throughout southeastern Louisiana (http://en.wikipedia.org/wiki/Hurricane_Katrina). In 1982, the North Atlantic Ocean Ranger storm caused an oil rig to capsize and resulted in the death of the entire 84 people crew (Froude and Gurney 2010).

2.3 Nuclear Energy and Heatwaves

Nuclear power stations rely on water flows for their cooling. Warm and hot weather may cause cooling water to reach temperatures too high for the water to be effective. 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). In addition, such higher temperatures returned to rivers can result in damage to flora and fauna.

2.4 Gas Demand and Market Response

Sudden changes in meteorological variables such as temperature can have a large impact on energy price, induced by factors such as supply shortages or speculation. For instance, day-ahead gas price can vary by 80 % or more within days as a response to severe cold weather events which lead to a sudden increase in demand for heating (Troccoli 2010).

2.5 Wind and Solar Energy Grid Integration

Wind and solar power are entirely reliant on meteorological conditions to function. Highly variable weather conditions on timescales of minutes or shorter can cause disruptions to grid operations. For instance, excessive changes, or ramp rates, in power supply from wind or solar energy installations may lead to their curtailment to avoid the grid reaching its capacity limits (e.g. Sayeef et al. 2012).

3 Transforming Our Energy System: Challenges and Opportunities

In shaping our energy future we need to address risks of, and barriers to, the transformation of the energy sector. We can specify three very simple goals for energy: to be ‘clean’ (low emissions), ‘secure’ (available and affordable) and to

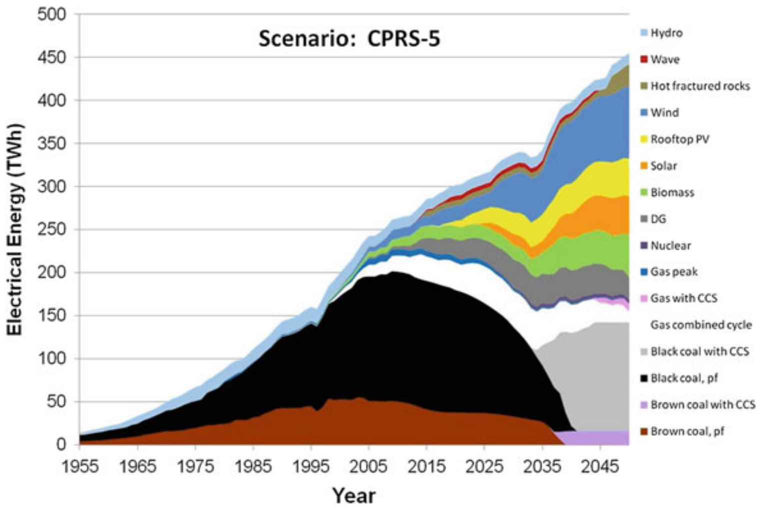


Fig. 5 One scenario for achieving 60 % emissions cuts in Australia by 2050

underpin prosperity. Achieving these goals in the coming decades will require a transformation of the energy system. IEA (2011) estimates the investment required worldwide in energy supply infrastructure over the period to 2035 to be $38 trillion (2010 dollars), that is, around 60 % of the current global annual gross domestic product (GDP), or an average of more than 2 % of GDP annually. Exactly how this transformation will develop depends on many factors including the physical environment, community opinion, government policies, market forces and technological innovation. Indeed, we have already been witnessing part of this transformation with, for instance, the burgeoning of the renewable power sector.

There is no silver bullet to achieve these energy goals. Modelling globally, and for particular economies, gives the common message that a range of new technologies will be required. CSIRO's modelling in Fig. 5, for example (Hayward et al. 2011) shows the evolution of the electricity generation mix in Australia under one particular scenario. The specific scenario presented here is based on the 'carbon pollution reduction scheme' (CPRS), a cap and trade scheme designed to achieve a 5 % GHG emissions reduction from 2000 levels by 2020 and a 60 % reduction by 2050. The scheme was proposed in Australia in 2008 and has since been replaced by a different carbon pricing scheme. The other key scenario assumptions about future demand and technology costs were the mid-range assumptions at the time. For a detailed overview of the scenario assumptions, see (Hayward et al. 2011).

Historically, Australia has relied on its abundant coal resources supplemented by hydroelectricity. Over the past decade, wind and biomass have entered the mix, as a result of targets for renewable energy generation set by the Government. The use of natural gas for electricity generation has also grown significantly due to both its lower emissions and its flexibility in supporting uptake of variable generation.

In future, we may still see significant fossil fuel use through the development of carbon capture and storage (CCS) technologies, but we will also see dramatic increases in renewable energy generation, including wind, biomass, large and small-scale PV, concentrated solar thermal, geothermal (e.g. hot-fractured rock technologies) and ocean renewable energy (e.g. wave energy).

The rainbow of future supply options in Fig. 5 is very exciting for energy engineers but it also poses large challenges. The first challenge is that variability in the energy generation will play a greatly increased role in our future energy mix. In the scenario depicted in Fig. 5, 38 % of electricity generated in 2050 will be from variable sources (Hayward et al. 2011). Energy will also come from more diverse and geographically distributed sources than in the past. This diversity may also lead to markedly different grid infrastructure. Furthermore, it will depend on less mature and, at least initially, more expensive technologies: a key goal therefore is to accelerate the reduction of costs through ‘learning by doing’. A rapidly evolving technology landscape creates high technical and commercial risks, which are particularly difficult to deal with given that investments in energy infrastructure are necessarily large (of the order of billions of dollars) and long term (of the order of a few decades).

In Australia, the daily power demand profile is becoming more ‘peaky’, largely due to increasing use of electrical goods such as air-conditioners. In turn, these larger peaks have led to a grid with comparatively poor utilisation, where large investments accommodate just a few large peaks every year to ‘keep the lights on’ during those rare occasions. Emerging demand management techniques—at an individual home or facility or across the grid—are needed to improve network asset utilisation and energy end-use efficiency. CSIRO, for example, has developed building energy management software that ‘learns’ a building’s energy requirements and then balances thermal comfort, running costs and greenhouse gas emissions associated with commercial air-conditioning systems. Energy savings of up to 30 % have been achieved in buildings in Australia and the USA.

Solving the energy puzzle involves more than new energy supply and demand technologies. It will also require public acceptance of new technologies and behaviour change to fully utilise the benefits these technologies offer. Indeed, energy investors and research organisations regularly undertake various outreach activities including publications (e.g. Wright et al. 2009) and community-based discussion groups designed to encourage individuals to be better informed and empowered about energy options.

4 A Step-Change in Meteorology and Energy Linkages

There have always been important links between energy and meteorology but these interactions need to be stepped up to a new level of inter-connectedness to facilitate an efficient transformation of the energy sector and underpin the associated capital investment.

Tables 1 and 2 outline the energy value chain and give examples of key energy–meteorology linkages. Table 1 is presented from the perspective of the life cycle of a single energy facility, whereas Table 2 focuses mostly on the electricity system, which is where much of the enhanced interdependency between energy and meteorology lies. In each element of the energy value chain, better understanding of energy–meteorological linkages will drive multi-billion dollar investment decisions: several examples of these are given in the tables and below, including referring to later chapters in this book.

Table 1 Energy facility life cycle: some interactions with meteorology

	Phase	PLANNING	DEVELOPMENT		OPERATION	
			Design	Construction	Production	Export
Balance	Energy Supply	Resource characterisation	Design loads: extreme cyclic	Schedule optimisation	Operability / Disruptions / Efficiency	
					Supply / Demand forecasting	
	Energy Demand	Usage patterns Systems response			Grid integration Price optimisation	

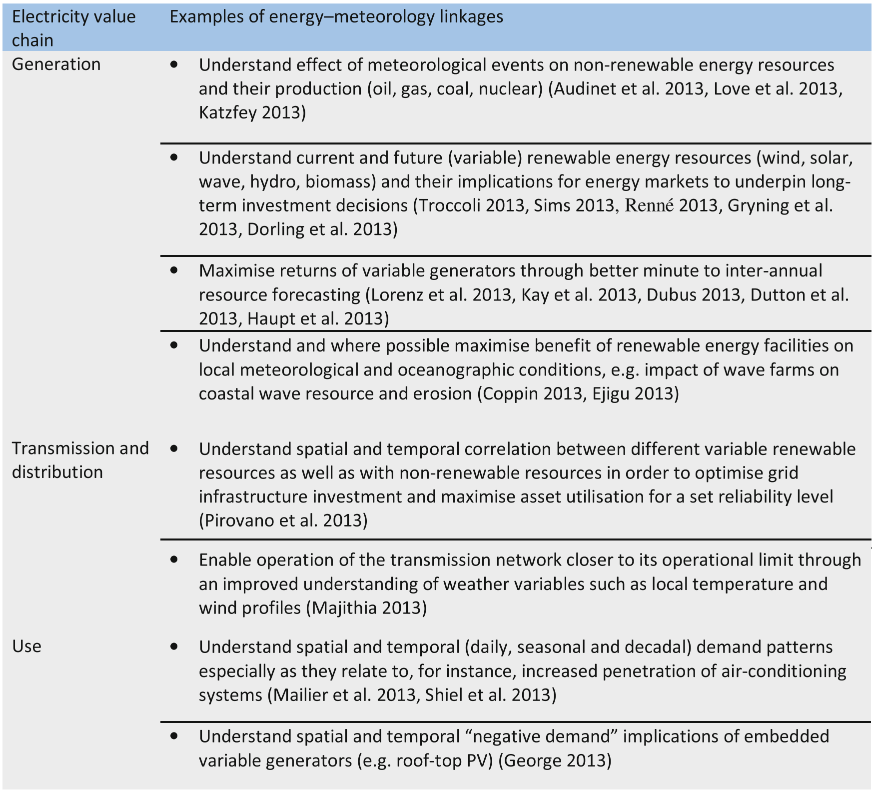
4.1 Energy Facility, Policy and Planning

Resource characterisation is a key element of the planning process for an energy production plant and, for many energy sources, the resource parameters are closely related to climate factors. This is more evident for weather-based resources such as wind and solar energy. In these cases, atmospheric observations and modelling are combined and used in conjunction with prospecting tools in order to identify high-power-yield wind and solar farm sites, as undertaken by companies such as WindLab Systems, a CSIRO spinoff. Energy supply needs to be balanced with demand, and climate considerations are also important in understanding the ongoing role of an energy facility over its lifetime in satisfying energy demand; examples include the evolution of usage patterns and attributes of the overall energy system to which the facility is contributing. Climate variability across the full range of temporal and spatial scales is also a critical consideration for governments in setting advantageous policy parameters to ensure an optimum future energy system.

4.2 Energy Facility Construction

In the facility development phase, offshore oil and gas platforms (Fig. 6) are a good example of where meteorological and oceanographic (met-ocean) factors dictate design and construction. Critical met-ocean actions include extreme loads (e.g. the 100-year return storm), and cyclic loads that can cause material fatigue

Table 2 Energy–meteorology linkages in the electricity system. Links to other chapters in this volume have been highlighted



Electricity value chain	Examples of energy–meteorology linkages
Generation	• Understand effect of meteorological events on non-renewable energy resources and their production (oil, gas, coal, nuclear) (Audinet et al. 2013, Love et al. 2013, Katzfey 2013)
	• Understand current and future (variable) renewable energy resources (wind, solar, wave, hydro, biomass) and their implications for energy markets to underpin long-term investment decisions (Troccoli 2013, Sims 2013, Renné 2013, Gryning et al. 2013, Dorling et al. 2013)
	• Maximise returns of variable generators through better minute to inter-annual resource forecasting (Lorenz et al. 2013, Kay et al. 2013, Dubus 2013, Dutton et al. 2013, Haupt et al. 2013)
	• Understand and where possible maximise benefit of renewable energy facilities on local meteorological and oceanographic conditions, e.g. impact of wave farms on coastal wave resource and erosion (Coppin 2013, Ejigu 2013)
Transmission and distribution	• Understand spatial and temporal correlation between different variable renewable resources as well as with non-renewable resources in order to optimise grid infrastructure investment and maximise asset utilisation for a set reliability level (Pirovano et al. 2013)
	• Enable operation of the transmission network closer to its operational limit through an improved understanding of weather variables such as local temperature and wind profiles (Majithia 2013)
Use	• Understand spatial and temporal (daily, seasonal and decadal) demand patterns especially as they relate to, for instance, increased penetration of air-conditioning systems (Mailier et al. 2013, Shiel et al. 2013)
	• Understand spatial and temporal “negative demand” implications of embedded variable generators (e.g. roof-top PV) (George 2013)

failure. Being able to accurately forecast ‘weather windows’ is essential in scheduling offshore installation activities, especially when the day-rate of a large crane vessel might be millions of dollars. These challenges are becoming more acute as petroleum exploration and production moves to harsher environments to sustain global demand.

4.3 Energy Facility Operation and Maintenance

Weather patterns again have many influences on an energy facility’s operation phase. Weather forecasts are important in tuning production for demand, in scheduling maintenance and in maximising plant efficiency. Weather can also cause sudden disruptions. Shifting our focus again from the specific facility to the overall energy system, weather plays a key role in forecasting and hence balancing energy supply and demand across a diverse set of energy sources.

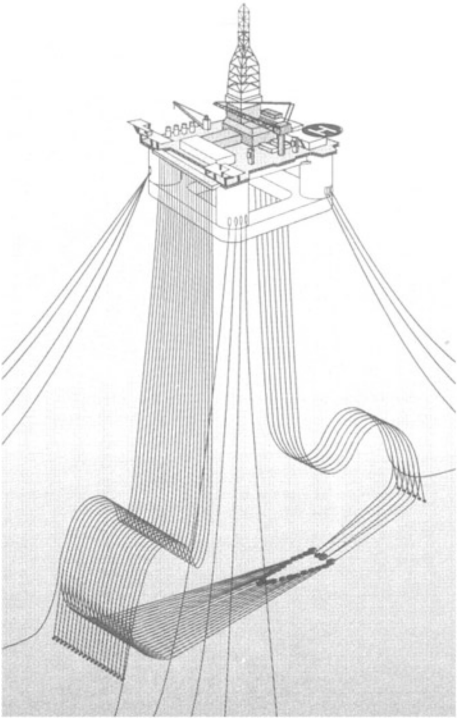


Fig. 6 Floating offshore petroleum production platform

4.4 *Energy Transport*

Transmission and transfer of energy can extend over very long distances (of the order of thousands of kilometres) and are therefore likely to be exposed to a variety of meteorological events. Exceedingly strong winds, icing, avalanches, landslides, flooding as well as high temperatures are all examples of weather events which can cause transmission power line malfunctioning or even failures (Schaeffer et al. 2012; "Combining Meteorological and Electrical Engineering Expertise to Solve Energy Management Problems" by Pirovano et al.).

Moreover, injection of growing quantities of variable energy sources into the grid has an impact on the electrical load of transmission lines. Variability in generation occurs across a range of timescales, from sub-second flicker to climate change-induced decadal trends. Such variability has to be understood, predicted and managed at an individual facility to maximise financial returns to the operator as well as system-wide to ensure regional security and reliability of supply. Energy storage (e.g. hydro or batteries) or demand-side management techniques can also be used to improve dispatch of variable energy sources to the grid. Again, weather forecasting tools provide a way to ensure optimum incorporation of storage in the grid (see "Unlocking the potential of renewable energy with storage" by Coppin).

4.5 Energy Use

Finally, the demand side of energy use, already affected by meteorological variables such as temperature and humidity, will become increasingly dependent on weather and climate impacts, in particular due to the large-scale adoption of air-conditioning and roof-top PV systems. In Brisbane Australia, for example, air-conditioning penetration has increased from 23 to 72 % over a period of 12 years (Simshauser et al. 2011). Such increased reliance on air conditioning creates a significant exposure to future climate change.

Together, these various factors will significantly extend energy–meteorology linkages across the whole value chain. Tailored weather and downscaled climate information will be required to fully understand and manage our future energy system. Investors, facility designers and system operators alike will request reliable data to inform the large future investments into our energy system and to ensure security and reliability of the system at affordable prices.

5 Conclusions

Energy and meteorology are central to understanding and solving our global sustainability needs. Indeed, the interdependencies between energy and meteorology are amplifying as we develop, build and operate new technologies and philosophies for energy production and use to deliver the triple goals of clean, secure and wealth-creating energy. Bringing energy and meteorological experts together in new ways to create a new depth of understanding—perhaps a new interdisciplinary science—is therefore critical to improved risk management of the energy value chain.

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