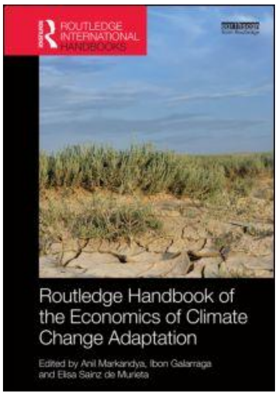

Routledge Handbook of the Economics of Climate Change Adaptation

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Climate Change and the Energy Sector

Publication details
https://www.routledgehandbooks.com/doi/10.4324/9780203095201.ch10
Alberto Ansuategi
Published online on: 23 Jan 2014

PART III

Adaptation in activity sectors

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10

CLIMATE CHANGE AND THE ENERGY SECTOR

Impacts and adaptation

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[2]PARTS OF THIS CHAPTER ARE BASED ON A BACKGROUND PAPER PREPARED BY THE AUTHOR FOR THE WORLD BANK WHITE PAPER ENTITLED "CLIMATE IMPACTS ON ENERGY SYSTEMS: KEY ISSUES FOR ENERGY SECTOR ADAPTATION" EDITED BY JANE EBINGER AND WALTER VERGARA (2011).

10.1 Introduction

The rise in the presence of the so-called greenhouse gases (GHG) in the Earth's atmosphere experienced in the past decades has caused a rise in the amount of heat from the sun withheld in it. This greenhouse effect has resulted in climate change, which is expected to increase average global temperature (global warming) and produce effects such as changes in cloud cover and precipitation, a rise in sea levels, melting of ice caps and glaciers and more frequent and severe extreme weather events. Thus, the rate of warming averaged over the last 50 years (0.13 °C ± 0.03 °C per decade) is nearly twice that for the last 100 years (IPCC, 2007). According to recent studies, some extreme weather events have changed in frequency and/or intensity over the last 50 years (Durack et al., 2012). There are suggestions of increased intense tropical cyclone activity in some regions (Webster et al., 2005) and emerging evidence of increased variability of climate parameters such as temperature and precipitations (Seager et al., 2012). There is also high confidence that hydrological systems are being affected due to increased run-off and earlier spring peak discharge in many glacier- and snow-fed rivers (Diffenbaugh et al., 2012). Melting of ice sheets, glaciers and ice caps has accelerated (Joughin et al., 2012) and, globally, sea levels have raised an average of 18 cm since the late 19th century at an accelerating rate of rise (Cazenave and Llovel, 2010).

Most of the GHG emissions that have triggered the changes described above are produced by the combustion of fossil fuels, with the global energy sector being a major producer of emissions. Nowadays, nearly 70% of global GHG emissions come from fossil fuel combustion for electricity generation, transport, industrial activity and heat in buildings or cooking in homes (IPCC, 2007). However, the energy sector is not only contributing to climate change, it is also vulnerable to climate impacts. Although the impacts on energy supply and demand are the most intuitive, climate change can also have direct effects on energy endowment, infrastructure and transportation, and indirect effects through other economic sectors. The potential economic damage of such impacts is by no means negligible. Ackerman and Stanton (2008) estimate that annual U.S. energy expenditures (excluding transportation) will be $141 billion higher in 2100 – an increase equal to 0.14% of GDP – in the business-as-usual case than they would be if today's climate conditions continued throughout the century.

This chapter provides an overview on climate impacts on energy systems and adaptation of energy systems to climate change. It is structured in four sections. After this brief introduction, Section 10.2 identifies climate vulnerabilities in the energy sector. Section 10.3 discusses main issues regarding adaptation to climate change in the energy sector. Finally, Section 10.4 draws some conclusions and suggests topics where more research would be valuable.

10.2 Impacts

A necessary condition for adaptation to climate change to be effective is to understand and be aware of how climate change impacts the energy sector. Most of the studies of the relationship between the energy sector and climate change have focused on both the climate impact of GHG emissions of the energy sector and the impact of climate mitigation policies on the energy sector. Only recently have some reviews been produced on climate change impacts on the energy sector. Some of these reviews have focused on sub-sectors such as renewable energy (Lucena et al., 2009), wind energy (Pryor and Barthelmie, 2010) and nuclear energy (Kopytko and Perkins, 2011) or the electricity market in general (Mideksa and Kallbekken, 2010). Other studies have reviewed climate vulnerability of the energy sector for specific regions of the world such as the United States (CCSP, 2007), Sub-Saharan African countries (Williamson et al., 2009) or Nordic countries (Fenger, 2007). Finally, two very recent studies (Ebinger and Vergara, 2011 and Schaeffer et al., 2012) provide a comprehensive assessment of the impact of climate change in energy systems. In this section, we summarize the contribution of all these studies.

A changing climate can lead to changes in (1) the amount of primary energy available, (2) the capacity to supply energy to consumers and (3) energy consumption patterns. In what follows, we will discuss them separately.

10.2.1 Changes in primary energy availability

Hydropower potential

According to Euroelectric (1997) the Gross Hydropower Potential (GHP) is defined as "the annual energy that is potentially available if all natural runoff at all locations were to be harnessed down to the sea level (or to the border line of a country) without any energy losses". As it is pointed out by Schaeffer et al. (2012), the evolution of GHP is an indicative measure of possible trends related to climate change, but it is not enough to draw conclusions about the actual impacts of changes in climate variables.[1] Thus, a complementary measure for such assessment would be the so-called Developed Hydropower Potential (DHP), which measures the actual potential of all existing hydropower stations. Hydropower potential depends directly on the hydrological cycle, that is, on the excess water that turns into runoff and on the seasonal pattern of the hydrological cycle. Therefore, the potential of hydrogeneration is impossible to assess without additional locally specific study. Lehner et al. (2005) take a model-based approach for analysing the possible effects of global change on Europe's hydropower potential at a country scale and conclude that for the whole of Europe the GHP is estimated to decline by about 6% by the 2070s, while the DHP shows a decrease of 7%–12%.

Wind power potential

Climate change may alter the geographical distribution and the variability of the wind and, depending on local conditions, we could have either positive or negative impacts of climate change on wind power potential. To quantify these effects, it is required the application of downscaling methodologies designed to extract projections with higher resolution of certain climate parameters from Global Climate Models. Some studies show that it is unlikely that mean wind speeds and energy density will change by more than the current inter-annual variability (± 15%) over most of Europe (Pryor et al., 2005; Bloom et al., 2008) and North America (Sailor et al., 2008) during the present century, but some studies suggest that changes over South America may be larger (Lucena et al., 2010).

Solar power potential

The solar energy reaching the surface of the planet in direct and scattered radiation form is determined by astronomical factors such as the length of the day or the solar declination and by other factors related to actual atmospheric conditions such as cloudiness and the presence of aerosols and water vapour. According to Salby (1996) cloudiness is the most important determinant of the solar radiation flux of the Earth-Atmosphere system. Again, the impact of climate change on solar power potential will not be the same in every region of the planet and there will be "gainers" and "losers". For instance, Bartok (2010) reports increase in solar radiation of 5.8% compared to the 1992–1996 time average in south-eastern Europe, whereas Cutforth and Judiesch (2007) report a decrease of incoming solar energy on the Canadian Prairie.

Wave energy potential

Waves are created by the transfer of energy from wind flowing over water bodies. Therefore, we can assert that wave energy, in common with wind energy and other renewables, will be sensitive to changes in climate. In some regions, impacts are expected to be positive. This is the case of the coast of mid-Norway (Vikebo et al., 2003). In other regions, such as the southern Californian coast (Cayan et al., 2009), impacts are expected to be negative.

Availability of biofuels

Changes in temperature, rainfall and levels of carbon dioxide may place new stresses in agricultural production in general and crops to produce biofuels in particular (Hatfield, 2010). The overall effect of climate change in biofuel availability is hard to predict since many key factors in agriculture production are affected. Higher levels of carbon dioxide can improve photosynthesis in certain crops (Bernacchi et al., 2007); temperature changes can affect either directly the rate of plant development (Hatfield et al., 2008) or indirectly modify factors such as soil conditions or incidence of pests. Extreme climate conditions, such as droughts, frosts and storms can also affect crops (Mishra and Cherkauer, 2010; Zhao and Running, 2010).

Availability of fossil fuels

Climate change will not directly affect the actual amount of fossil fuels, but it can have an impact on the access to and exploration for reserves of fossil fuels. Burkett (2011) discusses extensively how increased ocean temperature, changes in precipitation patterns and runoff, sea level rise, more intense storms, changes in wave regime and increased carbon dioxide levels and ocean acidity have the potential to independently and cumulatively affect coastal and offshore oil and gas exploration, production and transportation. Harsem et al. (2011) discuss the role played by climate change as one of the main factors influencing future oil and gas prospects in the Artic.

10.2.2 Changes in the capacity to supply energy to consumers

Apart from the effects on the energy generating potential, climate change may also have an impact on the capacity of the system to convert this potential into final energy to be supplied to consumers to meet different energy services. Impacts on energy supply can be classified into two groups: impacts on energy-transforming technologies and impacts on transmission, distribution and transfer of energy.

Impacts on energy-transforming technologies

The main focus here would be the impacts on long life-span facilities that will still be in operation when the new climate conditions occur.[2] Hydro-power plants with built reservoirs that are not designed to manage earlier increased flows due to seasonal shift (Vicuña et al., 2007), thermal power plants whose output and efficiency will be affected by variation of ambient temperature and humidity (Arrieta and Lora, 2005) or by variation in the quantity and/or quality of water resources for competing uses (Feeley et al., 2008; Durmayaz and Sogut, 2006), and energy facilities sited in coastal low-lying lands subject to more severe storm surges and coastal erosion (Neumann and Price, 2009) constitute examples of impacts on energy-transforming technologies.

Impacts on transmission, distribution and transfers

Extreme weather events induced by climate change may affect the transmission of energy through disruption of infrastructure. Landslides, flooding, permafrost thawing, extreme wind and ice loads and other extreme meteorological events can affect both transmission power lines and gas transmission systems (Kiessling et al., 2003; Vlasova and Rakitina, 2010). Energy distribution may also be affected by meteorologically induced factors such as fires or falling trees and heat waves that may induce power transformer failures and losses in substation capacity (Sathaye et al., 2011). Note also that some of the impacts could also be "positive", as it is the case of the opening of new shipping routes as Arctic sea ice melts (Valsson Trausti and Ulfarsson, 2011).

10.2.3 Changes in energy consumption patterns

One of the most obvious effects of climate change on energy consumption patterns is that higher temperatures will reduce demand for heating and will increase demand for cooling. Isaac and Van Vuuren (2009) have estimated global residential sector energy demand for heating and air conditioning in the context of climate change and have concluded that heating energy demand will decrease by 34% worldwide by 2100 and air conditioning demand will increase by 72%. Climate change will also likely affect energy sectors in other sectors such as transportation (increased air conditioning in private cars and refrigerated vans)[3] and agriculture (energy requirements for irrigation).[4]

10.3 Adaptation

Adaptation to climate change and its impacts is receiving increasing attention as a complementary response strategy to reducing net emissions of GHG (termed "mitigation" in the literature). While the main objective of adaptation solutions is to ensure the security of people and assets, in the case of the energy system, the primary objective is to guarantee the supply of energy, balancing production and consumption throughout time and space.

The process of adapting to climate change is complex and consists of a multitude of behavioural, structural and technological adjustments. Several typologies of adaptation measures have been proposed.[5] Here we describe and differentiate adaptation measures based on a set of attributes used in the studies mentioned above:

- Based on the *timing* of the action, adaptation measures may be **proactive** or **reactive**. A proactive approach aims to reduce exposure to future risks, for instance by new coastal power plant siting rules to minimize flood risk or installing solar photovoltaic technology to reduce effects of peak demand. A purely reactive approach aims only to alleviate impacts once they have occurred, for instance reinforcing existing energy infrastructure with more robust control solutions that can better respond to extreme weather-related service interruption.
- Based on the *nature of agents involved in the decision-making*, adaptation measures can be **private** or **public**. Some adaptation measures, such as protection of coastal areas from sea level rise, provide public benefits and therefore it is governments who provide this form of adaptation as a public good. In many other cases, however, adaptation measures offer private benefits that accrue to individuals or firms, and actions do not have to be directed centrally by a public authority. Note that this distinction can also be referred as autonomous or "market driven" versus planned or "policy-driven" adaptation.
- Based on the *spatial scope*, adaptation measures can be **localized** or **widespread**. Adaptation is primarily local, since the direct impacts of climate change are felt locally and responses have to address local circumstances. However, for these measures to be implemented, most often they must also be supported by national or even international policies and strategies. Thus, it can be said that a successful adaptation measure has to proceed at several levels simultaneously.
- Based on the *temporal scope*, adaptation measures can be **short-term** or **longer term**. This distinction can also be referred to as tactical versus strategic, or as instantaneous versus cumulative (Smit et al., 1999). In the natural hazards field it is referred to as adjustment versus adaptation (Smit et al., 2000). The distinction between short-run and long-run adaptation has to do with the pace and flexibility of adaptation measures.
- Based on the *form*, adaptation measures can be **infrastructural**, **behavioural**, **institutional**, **regulatory**, **financial** and **informational**. To be effective, adaptation measures have to work through a wide range of interrelated channels. Sectors that could

face significant climate risks are those with long-term planning and investment horizons and dependent on extensive infrastructure and supply chains. This means that some measures will aim at reducing the vulnerability of energy infrastructure to environmental change (**infrastructural measures**). Adaptation will in part occur autonomously, with individuals and societies switching to new technologies and new practices. This implies that another group of adaptation options will target the behaviour of economic and social agents (**behavioural measures**). Climate risk management requires high-level coordination. All levels of governments should ensure that policies and programmes take account of climate change and adaptation strategies. Stakeholders also need to be organized in civic bodies that are able to contribute to decision-making processes (**institutional measures**). As the impacts of climate change become more direct and critical economic sectors are affected, governments are more likely to resort to prescriptive regulation and controls to ensure that critical actors take appropriate action on adaptation (**regulatory measures**). The Stern Review (Stern, 2007) identified financial constraints as one of the main barriers to adaptation. Thus, there is scope for the uptake of adaptation action targeting better the use of available financial resources and instruments (**financial measures**). Last, but not least, an improved informational and knowledge base is a necessary step with a view to defining scientifically sound measures of adaptation to climate change (**informational measures**).

- Based on their *ability to face associated uncertainties and/or to address other social, environmental or economic benefits*, measures can be **no-regrets** options, **low-regrets** options or **win-win** options. **No-regrets** adaptation measures are those whose socioeconomic benefits exceed their costs whatever the extent of future climate change. **Low-regrets** adaptation measures are those for which the associated costs are relatively low and for which the benefits under projected future climate change may be relatively large. **Win-win** adaptation measures are those that minimize social risk and/or exploit potential opportunities but also have other social, environmental or economic benefits. This distinction is clearly related to the debate on "hard" versus "soft" adaptation options and the irreversibility that they imply. A key feature of "soft" adaptation measures, involving policies and instruments that are designed to change behaviour, is that they imply less inertia than "hard" engineering measures. Thus, in the face of uncertainties with regard to climate projections, the risk of "sunk-costs" is much lower for soft adaptation measures than for hard adaptation measures.

In what follows, we will use this typology of adaptation options to review the most important adaptation measures and strategies that could be found in the energy sector. The description will be structured in two main blocks of measures: measures aiming at **building adaptation capacity** and measures aiming at **delivering adaptation actions**.

10.3.1 Building adaptation capacity

A system's ability to undertake specific adaptation actions is largely a function of its adaptive capacity. Broadly, adaptive capacity reflects fundamental conditions such as access to information (research, data collecting and monitoring and awareness raising), supportive social structures (organizational development and institutions) and supportive governance (regulations, legislations and guidance).

Access to information

The energy sector is critically exposed to weather and climate events in one way or another. Thus, the potential for improving the performance of the energy sector by using the best weather and climate information is apparent (Troccoli, 2010). To make optimal adaptation decisions, decision makers require detailed information about the impacts of climate change in space and time. At present there are several areas where knowledge is inadequate. Hence, the complexity of climate information calls for cooperation in order to undertake basic research into future changes. Article 5 of the United Nations Framework Conference on Climate Change (UNFCCC) refers to the need for the international community to support and further develop climate research and systematic observation systems, taking into account the concerns and needs of developing countries. Reliable, systematic climate data helps countries determine their current climate variability and model future changes. The development of higher resolution regional models for developing countries is important for improved predictions as well as analysing the disparity between the model outcomes. This would help enhance capacity for reaching informed decision-making.

Climate adaptation measures in the energy sector are critically dependent on observations. There is a need to continue to provide reliable and timely observations as required by weather forecast models, to supplement them for high-resolution models and to verify them for the energy sector.

Experts also stress the importance of assuring consistency of data (Troccoli et al., 2010) in order to be used in energy demand and energy production models. Small errors might be amplified by the transfer models to unacceptable levels.

Ready and reliable access to data and forecasts of some weather services should also be facilitated using grid computing technology. This would be particularly useful for small companies in the energy sector and would also serve in the regulatory and scientific communities to carry out climate/energy research activities.

Research is also a central activity in building adaptive capacity. The development of effective policies to face climate change relies on greatly improved scientific understanding of global environmental processes and their interaction with socioeconomic systems. This requires an unprecedented interdisciplinary effort to generate the knowledge needed by decision makers in governments and vulnerable sectors, such as the energy sector, to manage the risks of climate change impacts. The proliferation of climate change research centres and programs both at the international and the national (or even regional) scale is a clear response of the scientific community to the challenge of building our capacity to respond to climate change.

All the above reinforces the view that generating data and knowledge is a necessary condition for effective action. However, it is also important to succeed in persuading businesses, communities and individuals to adjust their behaviour in ways that promote adaptation and limit emissions (UNEP, 2006).

Supportive social structures

Mainstreaming climate change adaptation at the strategic level requires that clear policies on adaptation are developed in broad consultation and participation of staff and supported by senior management. Adaptation to climate change is becoming increasingly important from the perspective of corporate governance, strategic risk assessment and community planning.

Regulation and pressure from informed investors and rating agencies as well as consumers lead to an increased demand for disclosure of environmental and climate-related risks. Initiatives such as the Carbon Disclosure Project[6] encourage industry to better identify and manage risks, including those posed by climate change, to support the investor in making decisions.

Local public institutions (local governments and agencies), civil society institutions (producer organizations, cooperatives, savings and loan groups, etc.) and private institutions (NGOs and private businesses that provide insurance or loans) have an important operational significance in the context of climate change adaptation (Agrawal et al., 2008). Given that adaptation is inevitably mainly local, the involvement of local institutions is critical to the planning and implementation of adaptation policies and projects.

Connor et al. (2005) have reported some recent efforts made by European countries legislating and creating councils of energy users, which work side-by-side with their national energy boards or regulatory bodies.

Multi-sectoral partnerships between governmental, private and non-governmental actors are also an important part of any adaptation strategy. The extensive list of platforms/networks on adaptation practices maintained by the UNFCCC secretariat and the Nairobi Work Programme partner organizations[7] constitutes an example of efforts made to offer supportive social structures to adaptation.

Supportive governance

There are many ways in which societies and economic sectors can adapt to climate change. However, such adaptation has to be supported by governments in a variety of ways. Governance for adaptation to climate change requires effective administrative executive bodies, and enabling legal and regulatory frameworks. Uncertainty and imperfect information, missing markets and financial constraints constitute reasons that explain the necessity of government support in helping to promote effective adaptation.

Governments have an important role in providing a clear policy framework to guide effective adaptation by social and economic agents in the medium and longer term. In particular, governments are responsible for contributing to the provision of high-quality climate information, establishing land use plans and performance standards, defining long-term policies for climate-sensitive public goods such as coastal protection or emergency preparedness, and providing a safety net for those least able to afford protection and/or insurance. In developing countries, governments also have an important potential role in building adaptive capacity through good development practice.

Integrated planning within the energy sector and with others such as the water sector is highly important (Haas et al., 2008). Energy and water systems are closely linked. On the one hand, the production/consumption of one resource cannot be achieved without making use of the other. On the other hand, climate change affects the supply of both resources. Therefore, policy makers cannot provide a good adaptation plan without integrating both sectors as parts of a single strategy.

International governance also plays an important role in building capacity for adaptation. Given that the most vulnerable countries are often among the poorest, international assistance for adaptation is critical. The international community has managed to create a range of funding streams to support adaptation in developing countries. Thus, we have The Global Environment Facility, which manages two separate, adaptation-focused Funds under the UNFCCC:

the Least Developed Countries Fund (LDCF) and the Special Climate Change Fund (SCCF), which mobilize funding specifically earmarked for activities related to adaptation, and the latter also to technology transfer. More recently set up has been the so-called "Adaptation Fund", established by the Parties to the Kyoto Protocol of the UNFCCC to finance concrete adaptation projects and programmes in developing countries that are Parties to the Kyoto Protocol. The Fund is financed with the 2% of the Certified Emission Reductions issued for projects of the Clean Development Mechanism and other sources of funding. According to the World Development Report 2010 (World Bank, 2010) current levels of finance for developing countries fall far short of estimated needs. Total climate finance for developing countries is $10 billion a year today, compared with projected annual requirements by 2030 of $30 to $100 billion for adaptation.

10.3.2 Delivering adaptation actions

In the previous section, we described the framework within which adaptation actions can be delivered. Here, we will discuss effective responses made by stakeholders to the threats and opportunities of a changing climate.

Preventing effects or reducing risks

As indicated by the IPCC in its Fourth Assessment Report, certain short- and medium-term effects of climate change will be almost unavoidable. We have already seen in the previous section that climate change can have potential impacts on the energy production, energy transmission and supply and energy requirements. Therefore, some adaptive actions should try to alleviate or minimize these negative effects. Now we are going to offer several examples of "hard" and "soft" adaptation measures in the energy sector intended to minimize negative impacts due to long-term changes in meteorological variables and extreme events.

In many cases, the high vulnerability of energy infrastructure to environmental change is due to the fact that these infrastructures have a long lifespan and the risk of climate change related impacts was not factored into their design. A "hard" adaptation strategy is to invest in protective infrastructures to physically protect the energy infrastructure from the damages and loss of function that may be caused by climate change extreme events. Measures involve improving the robustness of offshore installations that are vulnerable to storms, building dikes and desilting gates, increasing dam heights, enlarging floodgates, improving the design of turbines to withstand higher wind speeds, installing mobile ventilation and refrigeration, burying or re-rating the cable of the power grid, etc.

There are also four types of "soft" adaptation strategies. A first option for adapting energy infrastructure to climate change is to reconsider the location of investments. For instance, Neumann and Price (2009) state that a key vulnerability of the U.S. energy infrastructure is that much of it is concentrated along the Gulf Coast, where hurricanes are fairly common during the summer and the fall. It is pointed out that if climate change leads to more frequent and intense storm events in the Gulf region, this concentration of energy infrastructures along the Gulf Coast could be particularly costly, and it could be in the interest of energy producers to shift their productive capacity to safer areas. Note that, as Paskal (2009) mentions, substantial investment in new emerging infrastructure is likely to take place in the next decades as a result of scheduled decommissioning, revised environmental standards, stimulus spending and new development. Location decisions of these new investments should take into account the impact of a changing environment in the infrastructure.

A second "soft" measure for minimizing the impact of climate change to energy systems consists in anticipating the arrival of a climate hazard through the development of meteorological forecasting tools inside the energy companies or improving the communication with meteorological services. These measures will require complementary actions such as the support of emergency harvesting of biomass in the case of an alert for rainfall or temperature anomalies. Here we would also include measures intended to hedge costs of protecting energy infrastructure if a disaster does strike. An example of such type of measures in the energy sector is the Deepwater Gulf of Mexico Pipelines Induced Damage Characteristics and Repair Options (DW RUPE) project (Stress Subsea, Inc., 2005). DW RUPE is a Joint Industry Study, including the U.S. Minerals Management Service and eight operating companies to address deepwater pipeline repairs. The implementation of repair plans to ensure functioning of distributed solar systems after extreme events would also constitute an example of anticipatory measures to minimize losses.

A third group of "soft" measures for minimizing the impact of climate change to energy systems comprises all the changes in the operation and maintenance of existing infrastructures. The management of on-site drainage and run-off of mined resources, changes in coal handling due to increased moisture content and the adaptation of plant operation to changes in river flow patterns constitute examples of this group of measures.

Finally, the fourth group of "soft" measures comprises technological changes and improved design of infrastructures. Examples include the improved design of wind and gas turbines in order to cope with changing climate conditions or the introduction of new biofuel crops with higher tolerance to high temperatures and water stress.

It is worth noting here that all these measures imply integrating future climate risks into every decision-making process. Thus, adaptation would be mainstreamed into all relevant policy interventions and planning and management decisions. This means that decision makers must consider future climate projections when deciding on issues such as coastal land-use planning, hazard management or emergency preparedness, and that these policies and plans should be regularly updated and upgraded.

Sharing responsibilities for losses and risks

Preventing losses/risks is not the only way the energy sector can adapt to climate change. It can also try to share responsibilities for losses and risks.

Insurance is an important tool to deal with risk. However, weather-related insurance has always posed a challenge to the insurance sector. These difficulties may be exacerbated by the increasing risk and unpredictability of extreme weather associated with climate change.

Even in developed countries, the climate insurance market is limited by poor information and understanding of risks by both insurance companies and potential clients. Nevertheless, even in these countries, insurance must be a key element in any climate change adaptation strategy.

It should be evaluated whether certain private actors/sectors that provide public services such as the energy sector need to be covered by compulsory standard weather-related insurance. In cases where insurance is not available, for example for infrastructures located in flood plains, publicly supported insurance schemes may be required. Due to the cross-border effects of climate change, there may be benefits in promoting international insurance as opposed to national or regional schemes.

When considering insurance as an adaptation strategy to deal with climate change, the Weather Risk Management Facility (WRMF) should be mentioned. The WRMF is a joint International Fund for Agricultural Development (IFAD) and World Food Programme (WFP) initiative to support the development of weather risk management instruments in developing countries. The WRMF has recently produced an overview of the issue of weather index insurance (WRMF, 2010). Index insurance, as defined in the report, "is a financial product linked to an index highly correlated to local yields". In contrast to traditional crop insurance, index insurance covers the risk of adverse environmental conditions (e.g., rainfall deficit) as opposed to suboptimal yields or production. As such, there's no threat of moral hazard as those who realize poor yields under favourable conditions cannot benefit from an insurance payout. Furthermore, as index insurance is based upon a verifiable indicator, it is eligible for reinsurance, which further spreads the risk.

The report highlights the potential benefits of index insurance for agricultural risk management at a range of scales (e.g., individual farmers to government agencies or relief organizations), but also notes some of the challenges. These include the complexity of establishing an index insurance market, which is dependent upon access to reliable environmental monitoring data and the ability to cultivate and maintain consistent market demand. Nevertheless, the report showcases a number of case studies where index insurance markets have been developed, often with success.

Energy diversification can be seen as an adaptation measure to increase resilience within the energy sector in responding to anticipated impacts of climate change. One approach would be to further expand the portfolio of energy sector (adoption on new forms of energy production such as solar, wind and hydro power).

Exploiting opportunities

Fortunately, as will be illustrated below, some opportunities exist to decrease the vulnerability of the energy sector to weather extremes and climate variability. For instance, ageing of existing infrastructures may open a new window of opportunity to build a more decentralized energy structure, preferably based on locally available renewable energy sources situated in secure locations. This would reduce the probability of suffering large-scale outages that result when centralized power systems are compromised. This sort of regional, network-based system might also prove more flexible and adaptive, and therefore more able to cope with the increasing variability and unpredictability caused by environmental change.

Another opportunity arises from urban design and land use planning. More than half of the world's population now lives in cities. According to the United Nations' estimates, the population living in urban areas is projected to pass from 3.49 billion in 2010 to 6.29 in 2050. This implies that cities are important and growing consumers of energy. Thus, urban policy and land use planning will play an important role in improving resilience of the energy system. In most cases, this strategy will take place through demand side management: building design (insulation, orientation), codes and standards (efficiency standards for appliances) and change of consumption patterns (district heating/cooling, flexible working hours, etc.). There is a wide range of examples of urban initiatives to reduce energy consumption and improve resilience (ETAP, 2006).

But there are also supply-side opportunities to be exploited from increasing urbanization. The electricity industry (Acclimatise, 2009) recognizes that it will face major challenges in providing new generation capacity and supply reliability within urban areas and that in the future they will need to develop a new supply and demand system where consumers can also be suppliers with a variety of home generators.

10.4 Conclusions

In the past decades, most studies on the relationship between climate change and the energy sector have focused on emissions from or mitigation by the energy sector. However, climate change is also expected to affect both energy supply and demand, and research on the adaptation options of the sector to the effects of climate change is surprisingly scant. In this chapter, we have offered a broad review of the main issues involved in the adaptation of the energy sector to climate change.

Based on this review, it is possible to draw some tentative conclusions about what the potential impacts of climate change will imply for the energy sector:

1. The major current risk for both supply and use is from episodic disruptions related to extreme weather events.
2. In many cases, "soft" and/or "hard" adaptation measures can reduce risks and prospects of negative consequences for energy supply and use.
3. Successful adaptation activities require the cooperation of a wide range of organizations and individuals.
4. Improving knowledge about vulnerabilities and possible risk management strategies is essential for effective climate change risk management in the energy sector.
5. "Climate-proofing" current and future energy systems should be mainstreamed among decision makers.
6. Climate change will very likely have significant effects on the potential power for many renewable energy sources, such as wind-power and hydro-power, and these potential changes should be considered in both siting and design decisions.
7. In regions where increases in average temperatures and temperature extremes are expected to increase the demand for electricity for cooling, measures to increase supply in general and peak load supply in particular should be considered.
8. Energy demand management should also be implemented as an adaptation measure.

Notes

1 Note that GHP does not take into account technical and economical feasibility of harnessing that energy.
2 Short life-span facilities will have much more margin for technological advances and/or relocation and, therefore, climate impacts will be much lower.
3 Parker (2005) estimates that the use of air conditioning reduces the efficiency of vehicles by around 12% at highway speeds.
4 Burt et al. (2003) studied current and future energy requirements for irrigation in California, including the projected loss of water from the state's reservoir system due to changed timing of snowmelt and surface water runoff. Assuming that the lost capacity would be replaced with groundwater, they calculated an increase in groundwater pumping energy of 163 GWh.

5 Burton et al. (1993), Stakhiv (1993), Carter et al. (1994), Smit et al. (1999, 2000), UKCIP (2007), and OECD (2008) provide some useful distinctions and discuss the nature of adaptation processes and forms.

6 http://www.cdproject.net

7 Available at http://unfccc.int/adaptation/nairobi_work_programme/

References

Acclimatise (2009), "Building Business Resilience to Inevitable Climate Change", *Carbon Disclosure Project Report*. Global Electric Utilities, Oxford.

Ackerman, F. and E.A. Stanton (2008), "The Cost of Climate Change: What We'll Pay if Global Warming Continues Unchecked", Natural Resources Defence Council, New York.

Agrawal, A., C. McSweeney and N. Perrin (2008), "Local Institutions and Climate Change Adaptation", Social Development Notes No 113, World Bank, Washington.

Arrieta, F.R.P. and E.E.S. Lora (2005), "Influence of Ambient Temperature on Combined-Cycle Power-Plant Performance", *Applied Energy* 80(3): 261–272.

Bartok, B. (2010), "Changes in Solar Energy Availability for South-Eastern Europe with Respect to Global Warming", *Physics and Chemistry of the Earth* 35: 63–69.

Bernacchi, C.J., B.A. Kimball, D.R. Quarles, S.P. Long and D.R. Ort (2007), "Decreases in Stomatal Conductance of Soybean under Open-Air Elevation of CO_2 are Closely Coupled with Decreases in Ecosystem Evapotranspiration". *Plant Physiology* 143: 134–144.

Bloom, A., V. Kotroni and K. Lagouvardos (2008), "Climate Change Impact of Wind Energy Availability in the Eastern Mediterranean using the Regional Climate Model PRECIS", *Natural Hazard and Earth System Sciences* 8(6): 1249–1257.

Burkett, V. (2011), "Global Climate Change Implications for Coastal and Offshore Oil and Gas Development", *Energy Policy* 39: 7719–7725.

Burt, C.M., D.J. Howes and G. Wilson (2003), "California Agricultural Water Electrical Energy Requirements", ITRC Report No R03-006. Prepared for the California Energy Commission. http://www.itrc.org/reports/reports.htm

Burton, I., R.W. Kates and G.F. White (1993), *The Environment as Hazard,* Guildford Press, New York.

Carter, T.P., M.L. Parry, H. Harasawa and N. Nishioka (1994), *IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations,* University College London, London.

Cayan, D., M. Tyree, M. Dettinger, H. Hidalgo, T. Das and E. Maurer (2009), *Climate Change Scenarios and Sea Level Rise Estimates for the California 2009 Climate Change Scenarios Assessment*. California Climate Change Center; 2009. CEC-500-2009-014-D.

Cazenave, A. and W. Llovel (2010), "Contemporary Sea Level Rise", *Annual Review of Marine Science* 2: 145–173.

CCSP (2007), *Effects of Climate Change on Energy Production and Use in the United States. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research*. Thomas J. Wilbanks, Vatsal Bhatt, Daniel E. Bilello, Stanley R. Bull, James Ekmann, William C. Horak, Y. Joe Huang, Mark D. Levine, Michael J. Sale, David K. Schmalzer, and Michael J. Scott (Eds.). Department of Energy, Office of Biological & Environmental Research, Washington, DC, USA. 160 pp.

Connor, H., R. Gould, R. Janssen and C. Rynikiewicz (2005), "New Governance Imperatives for Energy Planning in Liberalised European Markets?", Proceedings of the ECEEE 2005 Summer Study, panel 1, Volume I, pp. 223–230, Mandelieu, France, May 31–June 3, 2005.

Cutforth, H.W. and D. Judiesch (2007), "Long Term Changes to Incoming Solar Energy on the Canadian Prairie", *Agricultural and Forest Meteorology* 145: 167–175.

Diffenbaugh, N., S.M. Scherer and M. Ashfaq (2012), "Response of Snow-Dependent Hydrologic Extremes to Continued Global Warming", *Nature Climate Change* doi:10.1038/nclimate1732.

Durack, P.J., S.E. Wijffels and R.J. Matear (2012), "Ocean Salinities Reveal Strong Global Water Cycle Intensification During 1950 to 2000", *Science* 336(6080): 455–458.

Durmayaz, A. and O.S. Sogut (2006), "Influence of Cooling Water Temperature on the Efficiency of a Pressurized-Water Reactor Nuclear Power Plant", *International Journal of Energy Research* 30(10): 799–810.

Ebinger, J. and W. Vergara (Eds.) (2011), *Climate Impact on Energy Systems: Key Issues for Energy Sector Adaptation*, ESMAP, The World Bank, Washington.

ETAP (2006), "Development of Eco-Cities in the World", Environmental Technologies Action Plan. http://ec.europa.eu/environment/etap/pdfs/june06_ecocities.pdf

Euroelectric (1997), *Study on the Importance of Harnessing the Hydropower Resources of the World,* Union of the Electric Industry (Euroelectric), Hydro Power and other Renewable Energies Study Committee, Brussels.

Feeley, T J., T.J. Skone, G.J. Stiegel, A. McNemar, M. Nemeth, B. Schimmoller, J.T. Murphy and L. Manfredo (2008), "Water: A Critical Resource in the Thermoelectric Power Industry", *Energy* 33(1): 1–11.

Fenger, J. (Ed.) (2007), *Impacts of Climate Change on Renewable Energy Sources: Their role in the Nordic Energy System,* Nordic Council of Ministers, Copenhagen.

Haas, L.J.M., K. Schumann and R. Taylor (2008), *Climate Adaptation: Aligning Water and Energy Development Perspectives*, International Hydropower Association.

Harsem, O., A. Eide and K. Heen (2011), "Factors Influencing Future Oil and Gas Prospects in the Arctic", *Energy Policy* 39: 8037–8045.

Hatfield, J.L. (2010), "Climate Impacts on Agriculture in the United States: The Value of Past Observations", Chapter 10 in D. Hillel and C. Rosenzwieg (Eds.), "*Handbook of Climate Change and Agroecosystems: Impact, Adaptation and Mitigation*". Imperial College Press, London UK.

Hatfield, J.L., K.J. Boote, P. Fay, L. Hahn, C. Izaurralde, B.A. Kimball, T. Mader, J. Morgan, D. Ort, W. Polley, A. Thomson and D. Wolfe (2008), Agriculture. In *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States.* A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC. 362 pp.

IPCC (2007), *Climate Change 2007: Synthesis Report*. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. R. K. Pachauri and A. Reisinger (Eds./Core Writing Team). IPCC, Geneva, Switzerland.

Isaac, M. and D.P. van Vuuren (2009), "Modeling Global Residential Sector Energy Demand for Heating and Air Conditioning in the Context of Climate Change", *Energy Policy* 37(2): 507–521.

Joughin, I, R.B. Alley and D.M. Holland (2012), "Ice Sheet Response to Oceanic Forcing", *Science* 338(6111), 1172–1176.

Kiessling, F., P. Nefzger, J.F. Nolasco, and U. Kaintzyk (2003), *Overhead Power Lines: Planning, Design, Construction*. Springer.

Kopytko, N. and J. Perkins (2011), "Climate Change, Nuclear Power, and the Adaptation-Mitigation Dilemma", *Energy Policy* 39: 318–333.

Lehner, B., G. Czisch and S. Vassolo (2005), "The Impact of Global Change on the Hydropower Potential of Europe: A Model-Based Analysis", *Energy Policy* 33: 839–855.

Lucena, A.F.P., A.S. Szklo and R. Schaeffer (2009), "Renewable Energy in an Unpredictable and Changing Climate", *Modern Energy Review* 1: 22–25.

Lucena, A.F.P., A.S. Szklo, R. Schaeffer and R.M. Dutra (2010), "The Vulnerability of Wind Power to Climate Change in Brazil", *Renewable Energy* 35: 904–912.

Mideksa, T.T. and S. Kallbekken (2010), "The Impact of Climate Change on the Electricity Market: A Review", *Energy Policy* 38: 3579–3585.

Mishra, V. and K.A. Cherkauer (2010), "Retrospective Droughts in the Crop Growing Season: Implications to Corn and Soybean Yield in the Midwestern United States". *Agricultural and Forest Meteorology* 150(7–8): 1030–1045.

Neumann, J.E. and J.C. Price (2009), *Adapting to Climate Change: The Public Policy Response: Public Infrastructure*, RFF Report, Washington, DC.

Organisation for Economic Co-operation and Development (2008), *Economic Aspects of Adaptation to Climate Change: Costs, Benefits and Policy Instruments,* OECD, Paris.

Parker, D.S. (2005), *Energy Efficient Transportation for Florida,* Energy Note FSEC-EN-19, Cocoa, Florida: Florida Solar Energy Center, University of Central Florida. Available at: http://www.fsec.ucf.edu/Pubs/energynotes/en-19.htm

Paskal, C. (2009), *The Vulnerability of Energy Infrastructure to Environmental Change*, Briefing Paper, Chatham House, The Royal Institute of International Affairs.

Pryor, S.C. and R.J. Barthelmie (2010), "Climate Change Impacts on Wind Energy: a Review", *Renewable and Sustainable Energy Reviews* 14: 430–437.

Pryor, S.C., R.J. Barthelmie and E. Kjëllstrom (2005), "Analysis of the Potential Climate Change Impact on Wind Energy Resources in Northern Europe using Output from a Regional Climate Model", *Climate Dynamics* 25: 815–835.

Sailor, D.J., M. Smith and M. Hart (2008), "Climate Change Implications for Wind Power Resources in the Northwest United States", *Renewable Energy* 33(11): 2393–2406.

Salby, M.L. (1996), *Fundamentals of Atmospheric Physics,* Academic, San Diego, CA.

Sathaye, J., L. Dale, G. Fitts, P. Larsen, K. Koy, S. Lewis, and A. Lucena (2011), *Estimating Risk to California Energy Infrastructure from Projected Climate Change*. California Energy Commission. Publication number: CEC-500-2011-xxx.

Seager, R., N. Naik and L. Vogel (2012), "Does Global Warming Cause Intensified Interannual Hydroclimate Variability?" *Journal of Climate* 25(9): 3355–3372.

Schaeffer, R., A.S. Szklo, A.F.P. de Lucena, B.S.M.C. Borba, L.P.P. Nogueira, F.P. Fleming, A. Troccoli, M. Harrison and M.S. Boulahya (2012), "Energy Sector Vulnerability to Climate Change: A Review", *Energy* 38: 1–12.

Smit, B., I. Burton, R.J.T. Klein and R. Street (1999), "The Science of Adaptation: A Framework for Assessment", *Mitigation and Adaptation Strategies for Global Change* 4: 199–213.

Smit, B., I. Burton, R.J.T. Klein and J. Wandel (2000), "An Anatomy of Adaptation to Climate Change and Variability", *Climatic Change* 45: 223–251.

Stakhiv, E. (1993), *"Evaluation of IPCC Evaluation Strategies"*, Institute for Water Resources, U.S. Army Corps of Engineers, Fort Belvoir, VA, draft report.

Stern, N. (2007), *The Economics of Climate Change: The Stern Review,* Cambridge University Press, Cambridge.

Stress Subsea, Inc. (2005), *Deep Water Response to Undersea Pipeline Emergencies,* Final Report, Document N° 221006-PL-TR-0001, Houston, TX.

Troccoli, A. (Ed.) (2010), *Management of Weather and Climate Risk in the Energy Industry*, NATO Science Series, Springer, Dordrecht.

Troccoli A., M.S. Boulahya, J.A. Dutton, J. Furlow, R.J. Gurney and M. Harrison (2010), "Weather and Climate Risk Management in the Energy Sector", *Bulletin of the American Meteorological Society* 91(6): 785–788.

United Kingdom Climate Impacts Programme (2007), *Identifying Adaptation Options*, UKCIP Technical Report, UKCIP, Oxford.

United Nations Environment Programme (2006), *Raising Awareness of Climate Change*, UNEP, Nairobi.

Valsson Trausti, T. and G.F. Ulfarsson (2011), "Future Changes in Activity Structures of the Globe under a Receding Arctic Ice Scenario", *Futures* 43: 450–459.

Vicuña, S., E.P. Maurer, B. Joyce, J.A. Dracup and D. Purkey (2007), "The Sensitivity of California Water Resources to Climate Change Scenarios", *Journal of the American Water Resources Association* 43(2): 482–498.

Vikebo, F., T. Furevik, G. Furnes, N.G. Kvamsto and M. Reistad (2003), "Wave Height Variations in the North Sea and On the Norwegian Continental Shelf, 1881–1999", *Continental Shelf Research* 23: 251–263.

Vlasova, L. and G.S. Rakitina (2010), "Natural Risk Management in the Gas Transmission System of Russia and Contribution of Climate Services Under Global Climate Change". In A. Troccoli (Ed.), *Management of Weather and Climate Risk in the Energy Industry*, NATO Science Series, Springer.

Weather Risk Management Facility (2010), *The Potential for Scale and Sustainability in Weather Index Insurance for Agriculture and Rural Livelihoods*, International Fund for Agricultural Development and World Food Programme, Rome.

Webster, P.J., G.J. Holland, J.A. Curry and H.R. Chang (2005), "Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment", *Science* 309: 1844–1846.

Williamson, L.E., H. Connor and M. Moezzi (2009), *"Climate-Proofing Energy Systems"*, Helio-International.

World Bank (2010), *World Development Report: Development and Climate Change*, The World Bank, Washington DC.

Zhao, M. and S.W. Running (2010), "Drought-Induced Reduction in Global Terrestrial Net Primary Production from 2000 through 2009", *Science* 329: 940–943.