Energy Economics 46 (2014) 531–538

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

Integrated assessment of climate impacts and adaptation in the energy sector☆

Juan-Carlos Ciscar *, Paul Dowling

Institute for Prospective Technological Studies (IPTS), Joint Research Center (JRC), European Commission, Seville, Spain

ARTICLE INFO

Article history:
Received 21 March 2013
Received in revised form 4 July 2014
Accepted 10 July 2014
Available online 17 July 2014

JEL classification:
Q4
Q47
Q5
Q51
Q54
C68

Keywords:
Climate impacts
Energy sector
Integrated assessment models
Climate adaptation

ABSTRACT

From an engineering perspective, climate change can affect the energy sector in a number of ways, such as changes in the efficiency of power plants and increases in peak demand due to higher cooling demand in hotter summers. This article reviews how integrated assessment models have estimated the impacts of climate in the energy sector, including the modelling of adaptation. While most of the literature has considered changes in space heating and cooling demand, few models have studied the impacts on the supply side of the energy sector. The article also reviews the main findings of the related literature. A number of knowledge gaps and possible research priorities are identified. Modelling possible adaptation measures and assessing the effects of climate extremes on the energy infrastructure are topics that require further attention.

1. Introduction

Understanding how climate change can affect the economy is essential for the design of adaptation policies, which aim at minimizing the adverse effects of climate change and exploiting potential benefits. This understanding is also relevant to justify greenhouse gas (GHG) emissions mitigation policies.

A changing climate would affect society and the economic system[1] through multiple channels, such as altering agricultural yields, affecting coastal areas or changing energy expenditure. The energy system indeed may be one of the sectors of the economy potentially most affected by climate change.[2]

Both energy demand and supply can be altered by climate change. Warmer winters can reduce space heating demand[3] and hotter summers can raise cooling demand. The supply side of the energy sector may also experience positive and negative impacts. For instance, hydroelectricity output may be enhanced in some regions thanks to increased rainfall patterns, but thermoelectric power may become more vulnerable due to lower summer flows and higher water temperatures (Rübbelke and Vögele, 2011; Van Vliet et al., 2012). The availability of water can also become an issue under future climate change (Koch and Vögele, 2009). The energy sector will require more water for power plant cooling in a warmer future, while water supply might become scarcer. Furthermore, all those climate induced impacts in the energy sector are likely to resonate widely throughout the rest of the economy as energy is a key input to many other sectors.

The literature on how climate change affects the energy system can be divided into two strands. Firstly, some authors have assessed the statistical relationship between climate and energy variables.[4] Due to data limitations these studies typically focus on a sector or sub-sector of a system and have a regionally limited basis. Auffhammer and Mansur (2014) review this literature strand, which is called empirical literature (Fisher-Vanden et al., 2013).

Secondly, other authors have implemented the findings of the empirical literature into broader modelling systems, called integrated assessment

☆ Note: The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

* Corresponding author at: Institute for Prospective Technological Studies (IPTS), Edificio Expo, C/Inca Garcilaso, 3, E-41092 Sevilla, Spain. Tel.: +34 954 488 318.
E-mail address: juan-carlos.ciscar@ec.europa.eu (J.-C. Ciscar).

[1] General references addressing the economic impacts of climate change are e.g. the Stern review (Stern, 2007), Hanemann (2008) Hitz and Smith (2004) and Vivid Economics (2013) and Sue Wing and Lanzi (2014).

[2] See e.g. Mideska and Kallbekken (2010) and Mastrandrea and Tavoni (2013).

[3] Space heating represents more than half of household energy use in temperate counties (IEA, 2004).

[4] Those functions are also known in the literature as reduced-form formulations or exposure-response functions.

http://dx.doi.org/10.1016/j.eneco.2014.07.003

models (IAMs, see e.g. Arigoni and Markandya, 2009). This approach integrates the empirical literature functions into large-scale models. That is for instance the case of the IMAGE integrated assessment model (Isaac and van Vuuren, 2009) and the POLES global energy model (Dowling, 2013).

The purpose of this article is to review the second strand of the literature, combining an economic and an engineering perspective, which are necessary in order to try to overcome the disconnect between the empirical literature and the integrated assessment models, as noted by Fisher-Vanden et al. (2013).

The article is organised in five sections, including this introduction. Section 2 presents and discusses the list of possible climate impacts on the energy system that ideally could be represented in the models. Section 3 reviews the state of the art of the modelled impacts in the energy sector. Section 4 deals with the knowledge gaps that arise when comparing the existing literature with the ideal framework depicted in Section 2, proposing several priorities for future research. Section 5 concludes.

2. Impacts on the energy system

This section analyses how climate change could affect the energy system from an engineering perspective. Changes in temperature and availability of water are important channels through which the energy system can be impacted. Impacts have been classified into three categories: impact on energy demand, impacts on energy supply and other collateral impacts, which include e.g. the effects on energy infrastructures.

2.1. Impacts on energy demand

The key energy demand impact is on space conditioning. Energy demand is determined by a series of factors, including temperature. Temperature is usually captured in the demand equations in terms of heating degree days (HDDs) and cooling degree days (CDDs). For instance, the demand for fuel to heat buildings depends on the HDDs, which is defined as the number of degrees that a day's average temperature is below a certain desired temperature or threshold. It is expected that higher average temperatures will reduce space heating demand for residential and commercial buildings in winter and increase cooling demand in summer. The degree to which one effect offsets the other in the balance of buildings' energy demand depends on a complex interplay between various parameters at regional scale. Temperature and humidity are two key parameters upon which thermal comfort is based, together defining the boundaries of the comfort zone from which space heating and cooling demand rise. Other factors that influence the climate's impact on energy demand in buildings are the thermal characteristics of the building stock (e.g. insulation and type of heating system), the local settings (e.g. urban heat island effect and extreme climate events that are more likely to occur in specific regions), cultural differences, human behaviour and adaptability, household income and population ages (e.g. Olonscheck et al., 2011).

2.2. Impacts on energy supply

A set of climate impacts (driven by changes in temperature and water availability) on the supply side of the energy system can be foreseen, such as on the efficiency and cooling water availability of thermoelectric generation, the availability of hydropower resources, and the supply of a variety of renewable electricity technologies. For instance, as oil refineries are large consumers of water, changes in water availability will change the economics and output of a refinery.

The power generation sector can be extremely vulnerable to climate change (e.g. ADB, 2012), in particular thermal (including nuclear) and hydropower stations. Lower rainfall may reduce the water supply available for power plant cooling, thereby affecting plant availability. In extreme cases this could lead to forced outages. Thermal power plants use steam to produce electricity, and the thermodynamic process involved relies heavily on the supply of cooling water, which is provided by adjacent rivers and lakes. Climate change may reduce run-off and river discharge in certain regions and this would force power plants to operate at a reduced capacity (Ebinger and Vergara, 2011; van Aart et al., 2004). Moreover, if the temperature of the ambient water and the wet-bulb temperature of the surrounding atmosphere shift due to climate change, the thermodynamic efficiency of the thermal power plants is altered (Van Vliet et al., 2012; Kehlhofer et al., 2009).

The power technology mix can matter for the incidence of energy supply vulnerability, because of the differential thermal efficiencies and cooling water requirements of different generation technologies and types of extant cooling infrastructure. If the GHG emissions policies shift the generation mix toward more water-dependent technologies, then climate impacts could have a larger potential to constrain the ability to mitigate climate change. That could be the case of carbon capture and sequestration (CCS) technologies (expected to make a growing and significant contribution to the energy mix in the future), which are large consumers of water and could as much as double water consumption per kWh (Ebinger and Vergara, 2011).

Hydropower generation could be also affected. The supply of water available for hydropower depends on precipitation, absorption and evaporation of surface water, all of which are likely to be influenced by climate change. Hydropower plants fed by snowmelt are to be affected although to differing degrees than those fed by rainwater.

The seasonality of river flows is likely to vary because, in a warmer climate, water that would otherwise be stored as snow would enter river systems earlier in the year. The potential for this extra water to be used for hydroelectric generation depends on the relationship between changes in the seasonality of water availability, the energy demand profile and the capacity of run-of-river and reservoir dams. Regional and local climate variations are extremely important for hydropower, and an accurate capturing of these effects requires mapping hydropower plant locations onto maps of surface water availability.

Hydropower plants that are used to balance intermittent power supply (i.e. wind) may receive more demand for their output if renewable resources are affected by climate change. On the other hand hydro plants that have enough spare capacity to balance shortages from other sources will be a valuable tool in managing climate change induced impacts on the energy system.

Climate change can also affect the supply and cost of biomass and biofuels for energy uses. Agriculture yields would be affected by changes in temperature, precipitation, atmospheric CO_2 levels and prevalence of pests on crop yields. Climate change is also likely to change the availability and suitability of certain lands for crop production and wood product harvesting from forests.

Power generation from other renewables could also be altered by climate change. Wind power is a highly site specific energy source. Changes in the average speed and variability in wind at the site of wind power plants will change the amount of wind-powered electricity available. Wind speeds also directly influence wave formation, thus changes in wind speeds due to climate change will have an influence on the energy available from waves.

Water vapour content and cloud cover affect the amount of solar radiation reaching the Earth's surface. The ambient temperature affects the electrical efficiency of a solar photovoltaic cell. While climate data on cloudiness from climate models may be difficult to obtain, the relationship between temperature and photovoltaic efficiency is well documented, whereby an increase in temperature leads to a very uniform decrease in electrical efficiency.

2.3. Other impacts in the energy sector

Climate change is likely to have impacts not only on the energy resources themselves but also on the accessibility of those resources. Changes to ice cover in Arctic regions may increase the accessibility to new resources and improve the economics of extraction of known