Impacts of Climate Change on Global Electricity Production and Consumption: Recent Literature and a Useful Case Study from California

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Abstract

Climate change affects both energy demand and energy supply through various parameters. These parameters include warmer air and water caused by higher temperatures, changes in flow of rivers, snowfall and ice accretion, coastal inundation, wildfires, soil conditions, cloudiness and wind speeds. Increases in energy demand and supply loss create a combined problem for ensuring an adequate supply of fuels and electricity. Projections of these parameters combined with those of energy demand and supply over the next century are needed to improve our understanding of the increased vulnerability of the energy sector. In addition, a detailed physical layout of the various facilities is necessary to understand the exposure of energy infrastructure to the climate-related challenges. Despite a potentially significant impact on energy demand and supply, the international literature base on these topics is very limited particularly in the developing countries and on the supply component. As a result, this presentation reports on selected international quantitative evaluations of energy demand, qualitative evaluations of energy supply impacts, and related policy implications. Given the limited amount of literature on this subject, we discuss an approach that we have used for evaluating the impact of climate change on the California energy demand and supply systems. We believe this method could provide insights and form the basis for "bottom-up" evaluations in other countries.

Table 1 shows the hydro-meteorological and climate parameters for selected energy uses. This table indicates the various connections between the sets of parameters. For example, changes in air temperature would affect electricity generation efficiency including that of solar PV panels and the demand for cooling and heating. Robust evaluation of energy supply and demand impacts should examine each of the listed parameters while also taking into consideration the interconnections between them. Warmer temperatures may affect generation, transmission and transformer substations leading to a compounded impact.

A number of papers discuss how cooling and heating energy use will be affected by projected changes in temperature. Previous analyses of climate impacts on demand has shown that the overall impact of higher temperatures is likely to reduce demand for heating more than the effect of increased cooling load.

Adjusting for other variables such as income and energy price is also important in assessing the effect of temperature increases. A recent publication (Petrick et al. 2010)[1] evaluates residential data for 157

[1] Petrick S., K. Rehdanz, and R. Tol (2010). *The impact of temperature changes on residential energy consumption.* Kiel Institute for the World Economy, No. 1618.

countries over three decades and shows that energy use declines due to rising temperatures indicating that reduction in heating has played a more important role than the increase in air conditioning load.

An analysis using the POLES Model for Europe (EU27) also notes that only a limited literature develops the discussion of these issues, and no definitive conclusions exist about quantified evaluations of these impacts and their respective costs (Mima et al. 2010)[2]. Mina et al. (2010) This paper estimate that European energy expenditures on supply-side resources will be $65 billion higher in 2100 – or0.08 percent of GDP – in one climate change scenario. Conversely, energy expenditures on the demand side are projected to decrease by $480 billion for heating and increase by $10 billion for cooling. Another paper by Isaac and Van Vuuren (2009)[3] estimates that global heating energy demand decreases by 800-1000 Mtoe while cooling demand increases by 80-100 Mtoe by 2100.

Table 1: Hydro-meteorological and Climate Parameters for Select Energy Uses

Hydro-meteorological and/or climate parameter	Select energy uses
Air temperature	Turbine production efficiency, air source generation potential and output, demand (cooling/heating), demand simulation/modeling, solar PV panel efficiency
Rainfall	Hydro-generation potential and efficiency, biomass production, demand, demand simulation/modeling
Wind speed and/or direction	Wind generation potential and efficiency, demand, demand simulation/modeling
Cloudiness	Solar generation potential, demand, demand simulation/modeling
Snowfall and ice accretion	Power line maintenance, demand, demand simulation/modeling
Humidity	Demand, demand simulation/modeling
Short-wave radiation	Solar generation potential and output, output modeling, demand, demand simulation/modeling
River flow	Hydro-generation and potential, hydro-generation modeling (including dam control), power station cooling water demands
Coastal wave height and frequency, and statistics	Wave generation potential and output, generation modeling, off-shore infrastructure protection and design
Sub-surface soil temperatures	Ground source generation potential and output
Flood statistics	Raw material production and delivery, infrastructure protection and design, cooling water demands
Drought statistics	Hydro-generation output, demand
Storm statistics (includes strong winds, heavy rain, hail, lightning)	Infrastructure protection and design, demand surges
Sea level	Offshore operations, coastal energy infrastructure

Formal analysis of impacts of climate change on energy supply infrastructure is extremely limited. Studies exist for the UK, Brazil, and the US state of Alaska, but there may be other studies currently being conducted elsewhere. Lawrence Berkeley National Laboratory (LBNL) is in the process of completing a "bottom-up" study for California. The results of which are described below. This multi-year research effort included participation by utility companies in a technical advisory role.

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[2] Mima S. and Criqui P. (2010). *Analysis of Europe energy system in the POLES model A1B case under future climate change. Draft Report*, LEPII, Grenoble.

[3] Isaac M. and D. Van Vuuren (2009). Modeling global residential sector energy use for heating and air conditioning in the context of climate change. *Energy Policy*

Our study examined the impact of climate change on California energy infrastructure, including the San Francisco bay region. We estimated second-order impacts on power plant generation, transmission line and substation capacity during heat spells, wildfires near transmission line corridors and a limited study of sea level encroachment on power plants, substations and natural gas facilities.

We conclude that negative impacts on electricity infrastructure can be avoided, if climate change is anticipated and sufficient adaptation measures are employed. These measures might include installing new generation, substation, and transmission capacity, improving energy efficiency, and increasing investments in cooling equipment and wildfire mitigation strategies.

More specifically, the study finds that higher temperatures will decrease the capacity of existing natural gas fired power plants to generate electricity during particularly hot periods in the future. The estimated decrease in capacity varies by region, emission scenario, climate model, and plant type. During the hottest periods in August (at the end of the century) and under the high emission scenario (A2), our models estimate a decrease in simple cycle natural gas power plants generating capacity of3%-6% in California and 3%-4% in the San Francisco region. Under similar conditions, our models suggest diminished transformer and substation capability—between 2 and 4% across California and between 2 and 3% in the San Francisco region with a small increase in transmission line carrying capacity.

Climate change and fire risk may pose a more difficult challenge to the electric utilities. Our work, building on the results of existing fire studies, suggests that higher temperatures resulting from climate change will increase fire risk to transmission lines in California, including the San Francisco region. For example, the likelihood of fires occurring next to large transmission lines is expected to increase dramatically in parts of California and San Francisco at the end of the century, under some climate scenarios. It should be noted that fires do not always cause electricity outages—they more often increase electricity maintenance costs and decrease transmission line efficiency. In addition, rising sea levels at the end of the century could flood as many as 25 power plants, scores of electricity substations and numerous natural gas facilities located along the coast of California and within the San Francisco region. Properly anticipated however, flooding could be avoided by building dykes, moving plants to higher elevations and other preventative actions. We also conducted site visits to several power plants and learned that the vertical resolution of California coastal topography is of a coarse resolution, which makes estimating impacts at the local level very difficult. We also learned that electricity infrastructure was occasionally not located at the latitude and longitude reported in the database that was supplied to us.

We concluded that electric utilities can deal with anticipated climate change, but we also recognize that the level of system capacity needed to do this may be difficult to quantify and finance. It is clear that utility engineering practices traditionally used to determine generation or transmission capacity may need to be revised. Similarly, utility tariff setting guidelines may need to be altered to finance the necessary infrastructure to maintain system reliability. In short, uncertainty about climate change is likely to pose both institutional and scientific challenges of a type that go beyond the scope of the current study. These institutional challenges may present as large a problem to the electricity system of California as the economic costs of anticipated climate change described in this study.