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Estimating impacts of warming temperatures on California's electricity system

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ABSTRACT

Despite a clear need, little research has been carried out at the regional-level to quantify potential climate-related impacts to electricity production and delivery systems. This paper introduces a bottom-up study of climate change impacts on California's energy infrastructure, including high temperature effects on power plant capacity, transmission lines, substation capacity, and peak electricity demand. End-of-century impacts were projected using the A2 and B1 Intergovernmental Panel on Climate Change emission scenarios. The study quantifies the effect of high ambient temperatures on electricity generation, the capacity of substations and transmission lines, and the demand for peak power for a set of climate scenarios. Based on these scenarios, atmospheric warming and associated peak demand increases would necessitate up to 38% of additional peak generation capacity and up to 31% additional transmission capacity, assuming current infrastructure. These findings, although based on a limited number of scenarios, suggest that additional funding could be put to good use by supporting R&D into next generation cooling equipment technologies, diversifying the power generation mix without compromising the system's operational flexibility, and designing effective demand side management programs.

1. Introduction

Climate change affects both energy demand and supply through various impacts including: warmer air and water temperatures; changes in snowfall and ice accretion; changes in river flows; coastal inundation; increased wildfire activity; altered soil conditions, cloudiness, and wind speeds. Climate-related impacts to energy systems can affect access, storage, and delivery of fuels as well as the reliability of the electricity system (CCSP, 2007; Lucena et al., 2009, 2010; World Bank, 2011; Karl et al., 2009; Wiser et al., 2011; Schaeffer et al., 2012). Despite a potentially significant impact on energy demand and supply, the literature base on these topics is still limited, but evolving, particularly for the electricity sector. For a comprehensive review of climate change impacts on energy systems, please see World Bank (2011).

IPCC (2011) and Schaeffer et al. (2012) indicated that renewable electricity production may be particularly sensitive to the impacts of climate change. However, performance of thermal power plants also varies according to weather conditions including pressure, air and water temperature, and humidity (e.g., see Kehlhofer et al., 2009). Thermal plant production losses increase when temperatures exceed standard design criteria (e.g., see Erdem and Sevilgen, 2006; Maulbetsch and DiFilippo, 2006). Electricity generation facilities may also be negatively affected by impacts related to extreme weather events, changes in access to cooling water, and inland flooding (Durmayaz and Sogut, 2006; CCSP, 2007; Kopytko and Perkins, 2011). A limited number of studies have discussed the general relationship between temperature and electricity transmission and distribution infrastructure, finding that increased temperatures can accelerate the aging of transformers, lead to efficiency losses, and create power system reliability issues (e.g., Askari et al., 2009; Swift et al., 2001; Li et al., 2005). Despite a clear need, little or no known research has been carried out at the regional-level to quantify potential climate-related impacts to these systems during peak load periods when the system is at its operating limit. This study attempts to fill this gap for the U.S. state of California and proposes a bottom-up methodology that could be applied to other regions.

In California, climate researchers report that average temperatures are expected to warm significantly over the twenty-first

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century, especially in inland areas, and during the summer (Cayan et al., 2009). Researchers also project an increase in the frequency, magnitude, and duration of heat waves (Miller et al., 2007), which can have significant impacts on energy supply and demand.

Changing ambient temperatures affect the output capacity of California natural gas-fired power plants as warmer, less-dense input air decreases the overall efficiency of gas turbines (Maulbetsch and DiFilippo, 2006). In addition to affecting the available capacity of gas-fired power generation, higher ambient temperatures can decrease the carrying capacity of electricity transmission and distribution (T&D) systems and the capacity of the transformers that make up substations. Finally, heat wave conditions often lead to increased consumer demand and, therefore, directly affect the frequency and duration of peak electricity system loads. Climate change may impact other forms of electricity generation in California, including hydropower (e.g. Vicuña et al., 2008 and Hamlet et al., 2009) and wind generation. California has no coal-fired power plants. The vast majority of California's thermal power plants are natural gas-fired (see Sathaye et al., 2012). Accordingly, a major feature of this paper discusses how natural gas-fired generation might be impacted by hotter summer conditions.

The magnitude and timing of these impacts are highly uncertain, vary by region, and depend on the deployment of new technologies (IPCC, 2011; Gellings and Yeager, 2004). Integration of future climate/weather parameters (e.g. high temperature extremes) with spatially-explicit technical information about various energy facilities is important first step to evaluate the overall exposure of energy/electricity infrastructure to climate-related effects. The focus of this analysis is on the possible impacts to California's electricity supply and delivery infrastructure (for the purposes of this study, energy infrastructure includes California's natural gas-fired power generation facilities and electric transmission and distribution system) and consumer demand during peak periods when the system is pushed to its operational limit. It is important to note that this study projects impacts of climate change on the *current* amount and location of energy infrastructure as well as the *current* population of California. Although limited, this type of static analysis is consistent with much of the recent literature on this subject (e.g., see Lehner et al., 2005; Vicuña et al., 2008; Hamlet et al., 2009; Lucena et al., 2009) because it allows researchers to focus on impacts from climate change rather than many other highly uncertain variables (e.g., population growth, technology progress and deployment) that will also change in the future.

The schematic presented in Fig. 1 illustrates analysis stages and procedures for evaluating the entire range of climatic impacts on California's energy infrastructure, where boxes with thicker borders represent analysis components in this study of climate change impacts on California energy infrastructure. Please see Sathaye et al. (2012) for an analysis of additional energy system impacts related to increased incidences of wildfire activity and sea level rise.

The objectives of this study are limited to an: (1) assessment of the possible impacts that increased air temperature may have on the performance of natural gas-fired generation, substations, and major transmission lines and (2) estimate of how higher temperatures might affect peak period electricity demand.

This paper is organized as follows. California's energy infrastructure and peak electricity conditions are discussed in Section 2; Section 3 provides an explanation of the methodological procedures and model assumptions used in this analysis. Section 4

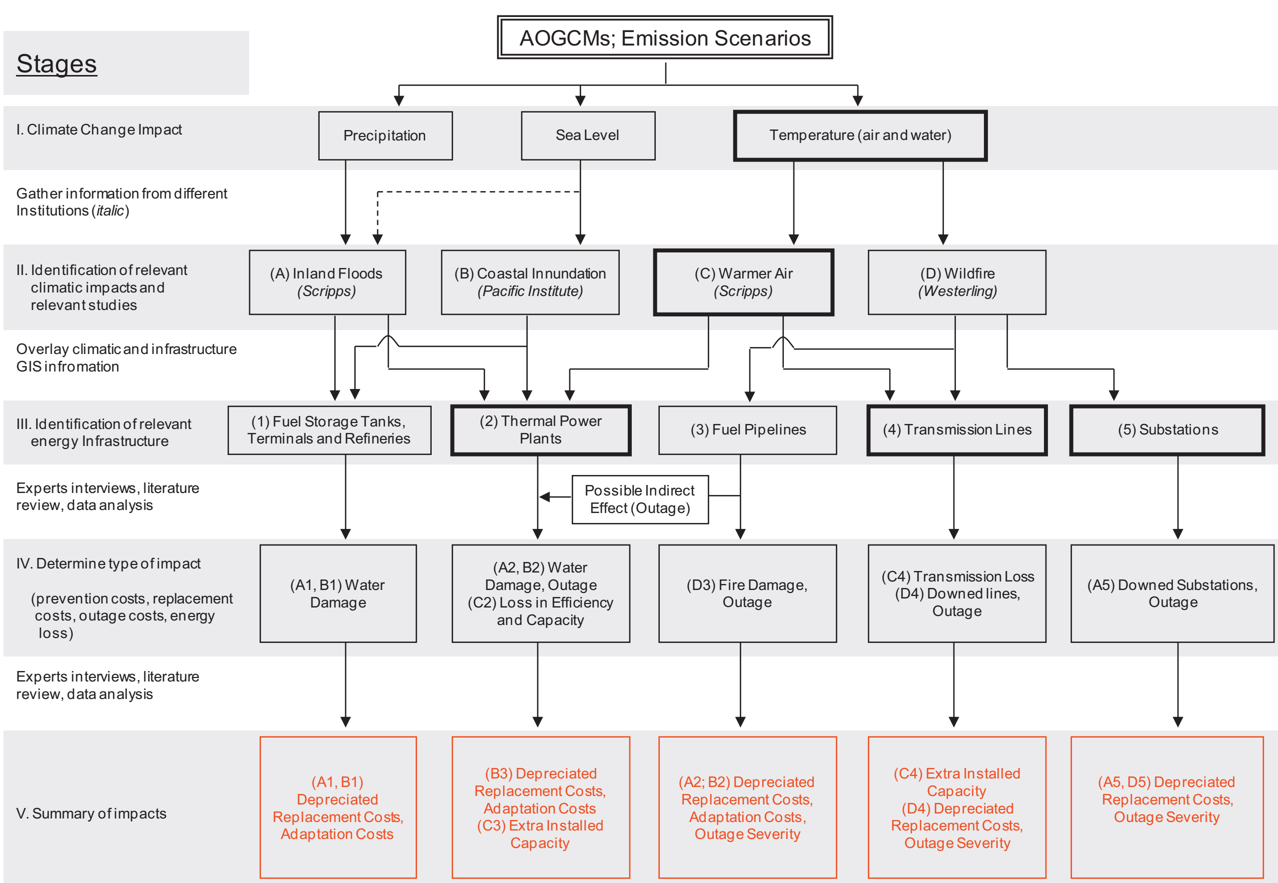

Fig. 1. Stages in the analysis of impacts of climate change on energy infrastructure.