Science of the Total Environment 497–498 (2014) 711–724

Contents lists available at ScienceDirect

Science of the Total Environment

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

Evaluating options for balancing the water–electricity nexus in California: Part 2—Greenhouse gas and renewable energy utilization impacts

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HIGHLIGHTS

- Part I presents a spatially and temporally resolved model of California's surface reservoirs.
- Part II presents GHG emissions and grid renewable penetration for water availability options.
- In particular, the energy signature of water supply infrastructure is delineated.
- Different pathways for securing California's water supply are developed quantitatively.
- Under baseline conditions, portfolios capable of securing surface reservoir levels emerge.
- Under climate change conditions, the water supply must be carefully selected to allay emissions.

ARTICLE INFO

Article history:
Received 23 February 2014
Received in revised form 8 June 2014
Accepted 15 June 2014
Available online 30 July 2014

Editor: Simon Pollard

Keywords:
Water–energy nexus
Climate change
Renewable energy
Greenhouse gas
Securing water resources
California

ABSTRACT

A study was conducted to compare the technical potential and effectiveness of different water supply options for securing water availability in a large-scale, interconnected water supply system under historical and climate-change augmented inflow and demand conditions. Part 2 of the study focused on determining the greenhouse gas and renewable energy utilization impacts of different pathways to stabilize major surface reservoir levels. Using a detailed electric grid model and taking into account impacts on the operation of the water supply infrastructure, the greenhouse gas emissions and effect on overall grid renewable penetration level was calculated for each water supply option portfolio that successfully secured water availability from Part 1. The effects on the energy signature of water supply infrastructure were found to be just as important as that of the fundamental processes for each option. Under historical (baseline) conditions, many option portfolios were capable of securing surface reservoir levels with a net neutral or negative effect on emissions and a benefit for renewable energy utilization. Under climate change augmented conditions, however, careful selection of the water supply option portfolio was required to prevent imposing major emissions increases for the system. Overall, this analysis provided quantitative insight into the tradeoffs associated with choosing different pathways for securing California's water supply.

1. Introduction and Background

Concerns about climate effects on water availability combined with increasing demands in various regions are driving interest in diversifying the water supply portfolio. Many regions in the world are expected to exhibit decreased water availability due to the impacts of climate change on regional hydrology and weather patterns (Boithias et al., 2014; Charlton and Arnell, 2011; Li et al., 2010; López-Moreno et al., 2014; Olmstead, in press; Pingale et al., 2014; Vairavamoorthy et al., 2008). A number of relevant studies have been performed for the water supply system of California in particular, due to its particular susceptibility to climate change impacts on water supply availability. Connell-Buck et al. (2011), Zhu et al. (2005), Tanaka et al. (2006), and Lund et al. (2003) investigated the effects of warmer and drier climates on water supply using the CALVIN model and outlined potential adaptation measures with respect to energy. Coupled with population growth and projected increases in demand in many regions, the need for more prudent water management strategies and options for usable water supply has been identified. However, reliance on the historical paradigm of precipitation-based and groundwater supplies may not be enough to meet increasing demands. Many alternative options for water supply

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http://dx.doi.org/10.1016/j.scitotenv.2014.06.071
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are currently available, including but not limited to: urban water conservation, purification and reuse of treated wastewater, and desalination of seawater or brackish water using membrane or thermal processes. The accessibility of these options varies significantly by region, and their implications for water availability, energy usage, and greenhouse gas emissions depend strongly on the characteristics of a given region.

Certain aspects of the energy consumption and greenhouse gas impacts of different options to stabilize the water supply have been characterized. Many studies focus on the energy requirements of the fundamental physical processes and operation of associated facilities utilizing these options, and their subsequent economic impact.

Characterizing and reducing the energy consumption of desalination processes has been an active topic of interest. Al-Karaghouli and Kazmerski (2013) provided a review of the energy consumption of various desalination processes, with costs characterization using conventional and different renewable energy resources. Subramani et al. (2011) also outlined devices and novel technologies to minimize membrane desalination energy consumption, as well as a short discussion of renewable energy utilization. Kesieme et al. (2013) compared the economics of different seawater desalination processes in Australia in the context of available waste heat and materials costs, concluding that membrane desalination was the most cost effective option due to the lower cost materials, even with the presence of a carbon tax. Additionally, many studies have investigated the concepts for novel desalination plant and process configurations, including energy recovery and integration with dedicated renewable energy resources for reducing fossil fuel energy consumption and related emissions (Ong et al., 2012; Shaffer et al., 2012; Wang and Chung, 2012; Yılmaz and Söylemez, 2012; Al-Zahrani et al., 2012; Peñate and García-Rodríguez, 2011).

The energy and emissions footprint of water reuse has also been examined. The process energy consumption and diurnal behavior of water reuse processes (microfiltration, reverse osmosis, advanced oxidation) have been examined by Sobhani (2011), taking into account real-world plant operating constraints. An review of the energy intensity of water reuse and recovery was also given by Plappally and Lienhard (2012) for in-operation systems, ranging from between 0.33 and 1.86 kWh/m^3 depending on pumping requirements and system topography. Kajenthira et al. (2012) cite the lower energy consumption of wastewater reuse as rationale for prioritizing this option over desalination. However, the authors did not consider the additional trunk line construction cost for non-potable or indirect potable reuse of reclaimed water.

While the literature on the energy consumption of different options exists, most of these studies focus on characterizing and comparing the energy consumption of the fundamental physical processes in isolation. Little consideration is given to impacts arising from the manner in which these options impact the energy intensity of the water supply system (conveyance, etc…) that they are implemented into and the associated emissions impacts. These systematic effects are equally as important as the fundamental processes in influencing the holistic energy and emissions impact of securing the water supply with different options.

Additionally, the emissions impacts of deploying different options have typically been calculated using static factors for linking energy consumption with emissions, and have not captured the sensitivity of electric grid operation and evolution. This is especially important in the context of hydropower contribution uncertainty under climate change.

Finally, studies which examine renewable energy integration with water supply options also assume that renewable resources can be solely dedicated to these loads. This is not the case in practice, as renewable energy resources installed on the grid will serve the bulk grid load, therefore the emissions intensity of water supply options must take this into account. Few studies have compared different options on a basis that takes these sensitivities into account.

Capturing the scale of the options required to stabilize surface water reservoir levels was the focus of the first part of the study. This analysis represents the second of two parts, and is aimed at the following for this system:

- Comparing the *holistic* energy and emissions impacts of option portfolios that successfully stabilized major surface water reservoir levels, under historical (baseline) and climate-change augment conditions, taking into account operational effects on the water supply system, accurate scale, and electric grid evolution.
- The implications of securing the surface water reservoir levels for the ability of the system to meet renewable energy utilization goals.

With this comparison, quantitative insight into the factors that must be taken into account when choosing between different water supply options in the holistic context can be obtained.

2. Model description

The models used to carry out the energy impact analysis for stabilized reservoir levels from Part 1 are described here. The tools used in this part of the study consist of models for the energy consumption of individual water supply stabilizing options, capturing the effect of water supply infrastructure loads, and a detailed electric grid balancing model. Each of these tools is described as follows.

2.1. Water supply infrastructure energy impacts

Supplying water to end users for various uses in different regions across the state involves a number of processes to transport water to demand regions and treat it for use and environmental discharge. All of these processes use energy, and for components such as conveyance, have different energy impacts depending on their spatial distribution. In order to more accurately quantify the energy impact of implementing options to stabilize reservoir levels, the effect of these options on the energy usage of water supply infrastructure components must be captured. To accomplish this, the energy intensity of the operation of these infrastructure components must be factored into the model.

2.1.1. Conveyance

The primary water supplies for the state of California are equally distributed on a spatial basis across the state. A majority of the primary water supplies are sourced from precipitation/snowpack and river inflows in the northern and eastern regions of the state. A large portion of the water demand, especially for urban uses, is not located in proximity to these regions. The urban water demand is heavily biased towards the coastal regions where major cities are located. Therefore, energy must be used to transport water from these supply sources to demand regions.

Conveyance to most areas in northern California from supply regions requires very little energy, since it is based on gravity-driven flow through natural rivers. Only a small amount of pumping energy is required for transporting water across flat valley floors in certain regions. Conveyance to southern California, however, requires a relatively large amount of energy. The urban water demand is heavily focused in the South Coast and Colorado River regions, with the former containing 49% of the state's population (Anon., 2009a). Transporting water into this region requires pumping of water over long distances and over the Tehachapi Mountain Range, which poses a significant elevation barrier.

This study uses average factors for conveyance to meet the demand in each hydrologic region as outlined by the California Energy Commission (CEC) (Anon., 2005) as presented in Table 1. These factors represent the pumping energy usage of major conveyance projects such as the State Water Project. As a reference, the locations of these regions are presented in Fig. 1.