

Available online at www.sciencedirect.com

ScienceDirect

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

Modeling residential water and related energy, carbon footprint and costs in California

Alvar Escrive-Bou^{a,b,*}, Jay R. Lund^a, Manuel Pulido-Velazquez^b

^a Center for Watershed Sciences, University of California, Davis, One Shields Avenue, Davis, CA 95616, USA

^b Research Institute of Water and Environmental Engineering, IIAMA, Universitat Politècnica de València, Camí de Vera S/N, 46022 València, Spain

ARTICLE INFO

Article history:

Available online 3 April 2015

Keywords:

California
Carbon footprint
Greenhouse emissions
Residential water-use
Water-energy nexus
Water-energy conservation strategies

ABSTRACT

Starting from single-family household water end-use data, this study develops an end-use model for water-use and related energy and carbon footprint using probability distributions for parameters affecting water consumption in 10 local water utilities in California. Monte Carlo simulations are used to develop a large representative sample of households to describe variability in use, with water bills for each house for different utility rate structures.

The water-related energy consumption for each household realization was obtained using an energy model based on the different water end-uses, assuming probability distributions for hot-water-use for each appliance and water heater characteristics. Spatial variability is incorporated to account for average air and household water inlet temperatures and price structures for each utility. Water-related energy costs are calculated using averaged energy price for each location. CO₂ emissions were derived from energy use using emission factors.

Overall simulation runs assess the impact of several common conservation strategies on household water and energy use. Results show that single-family water-related CO₂ emissions are 2% of overall per capita emissions, and that managing water and energy jointly can significantly reduce state greenhouse gas emissions.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

The increasing awareness of the high consumption of energy in the water sector has attracted considerable attention to water-energy interdependences. Most attention has focused on individual large consumers such as inter-basins transfers or energy-intensive water pumping or desalination. However, most overall water-related energy consumption happens

inside households (Reffold et al., 2008), a large and heterogeneous group of small users. Water-related residential end-uses are responsible of 5.4% of all electricity and 15.1% of all natural gas used in California (CEC, 2005). Most of this energy is for heating water. This implies that a significant proportion of total per capita GHG emissions are directly related to household water end-uses.

Water scarcity is attracting attention to conservation programs as a cost-effective source of water. California's

* Corresponding author at: Center for Watershed Sciences, University of California, Davis, One Shields Avenue, Davis, CA 95616, USA. Tel.: +1 530 400 9656.

E-mail address: alesbou@gmail.com (A. Escrive-Bou).

<http://dx.doi.org/10.1016/j.envsci.2015.03.005>

1462-9011/© 2015 Elsevier Ltd. All rights reserved.

Senate Bill X7-7 sets an overall goal of reducing per capita urban water-use by 20% by 2020. At the same time, Assembly Bill No. 32 would require the state to adopt a statewide greenhouse gas emissions limit equivalent to statewide GHG emissions in 1990 to be achieved by 2020. Even with the realization of water and energy linkages, no strategy has directly linked residential water and energy conservation synergies.

Advances in metering for residential water-uses have increased attention to how and when households use water (DeOreo et al., 1996). We can now observe, predict and assess the end-use consequences of conservation policies and rebate programs (Cahill et al., 2013; Rosenberg, 2007). Water end-use measurements also support energy consumption calculations for household microcomponents, and from energy use and emission factors, greenhouse gas emissions can be assessed. Few studies have dealt with this issue: Fidar et al. (2010) presented a method to quantify and analyze energy consumption and carbon emissions from increasing water efficiency in England; Beal et al. (2012) assessed the energy demand and related carbon emissions from residential appliances and fixtures using data from 252 households in Australia; Kenway et al. (2013) calibrated a model for water, water-related energy, CO₂ emissions and costs for a specific family household in Brisbane, Australia; and Abdallah and Rosenberg (2014) modeled the heterogeneity of residential water and energy linkages for four different datasets in the United States (US) with different appliance efficiency levels.

Residential water-use depends on the price paid by customers, geographic conditions, household composition, water using appliance technology and other behavioral characteristics (Arbués et al., 2003). Although the studies cited above do not explicitly examine the effects of geography and pricing on customer water-use and water-related energy and greenhouse gas emissions. Accounting for heterogeneity in household water and water-related energy use due to household characteristics, technology, users' behaviors and external factors—such as weather or water rates—this study develops a model of household water end-uses, water-related energy and greenhouse gas emissions, including water and energy costs paid by customers, to estimate overall values locally and for the state of California. The study also evaluates the potential of several water and energy conservation actions under different objectives and for different locations.

In Section 2 of the paper we present the proposed methods for assessing water end-use, water-related energy, and GHG emission models, and the scenarios considered; Section 3 presents the results for each model output; Section 4 presents the discussion of results; and lastly we present overall conclusions.

2. Methods

2.1. Overall description

The model was built in four steps, as shown in Fig. 1. First, probability distributions for parameters affecting water-use were obtained for 10 California cities. A water end-use model

(described in Table 1) was used for Monte Carlo simulations of a large sample (2500 households) for each location.

With probability distributions for parameters affecting water-related energy use—water heater characteristics—and from the water end-uses obtained before, by applying hot water probability distributions, we estimated water-related energy use for each household through Monte Carlo simulations.

From end-uses for each customer, water and water-related energy costs were obtained applying different rates for each city. Finally, GHG emissions were estimated for each water end-use for each household in each city using GHG emission factors reported by each energy utility. Each step and method is described in detail below.

2.2. Water end-use model

Using water end-uses patterns from a sample of over 700 single-family homes across ten water utilities throughout California collected by Aquacraft Inc. (DeOreo et al., 2011) we built a Monte Carlo-based model using probability distributions for parameters affecting end water-uses (Cahill et al., 2013). Total household use (Eq. (1) in Table 1) was then adjusted for each water utility to match local annual average use because the houses from which we extracted the probability distributions do not represent perfectly local average household use.

Each factor in the end-use models (Eqs. (2)–(9) in Table 1) was randomly sampled for each household using probability distributions given by their histograms for each water utility to capture local water-use variability. Parameters included: (i) household characteristics such as number of residents, technological values for appliances or outdoor areas, etc.; (ii) users' behaviors such as shower length, number of dishwasher cycles per week, etc.; (iii) climatic data is included to estimate irrigation necessities for outdoor use. Final results came from 2500 Monte Carlo household simulations¹ for each utility.

2.3. Water-related energy model

Our energy model only accounted for energy used by the household water heater because this is the main household water-related energy use. Energy used by the utility to procure water for the household can be estimated separately. So the first step was to obtain the hot water draws for water end-uses.

A few studies have analyzed household hot water-use patterns. We used a probability distribution of hot water draws from data by Mayer et al. (2003) on East Bay Municipal Utility District (details provided in Supporting Information).

With these hot water end-uses, water heater energy use was estimated using the WHAM equation (Lutz et al., 1998) defined as the summed energy content of hot water drawn from the heater plus energy expended to recover from standby losses.

¹ 2500 samples were taken because it was a relative large amount of samples to obtain consistent results—same main statistics—with different runs, and at the same time that keep a reasonable computational time.

Download English Version:

<https://daneshyari.com/en/article/1053498>

Download Persian Version:

<https://daneshyari.com/article/1053498>

[Daneshyari.com](https://daneshyari.com)