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System dynamics evaluation of household water use behavior and associated greenhouse gas emissions and environmental costs: A case study of Taipei city

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ABSTRACT

Taiwan is an island surrounded by sea and only 19 % of its freshwater usage is for domestic applications. A system dynamic model was developed to investigate interactions between household water use behaviors (toilet flushing, clothes washing, bathing/showering, and cleaning) and associated greenhouse gas emissions and environmental costs. Six hundred and fifty face-to-face interviews were conducted in 12 districts of Taipei. The results showed that the respondents’ individual attributes were not significantly related to water use behaviors. The highest volume of water was used for cleaning (27.7 %), followed by clothes washing (26.2 %), bathing/showering (26.1 %), and toilet flushing (20.0 %). Five water management scenarios with 5 %-20 % reductions in water volume from different water use behaviors were simulated. The maximum reduction in water use (6.27 t) was found in the fifth scenario (20 % reduction), which reflected the priority the respondents gave to save water if its price increased. 27.2 % of respondents had water saving appliances; 20.5 % and 16.4 % of the appliances were toilets and shower heads, respectively. The environmental cost of GHG emissions associated with water use behavior was US$0.001/t, causing an 8% increase in water price. A better understanding of household water use behaviors is needed to develop bottom-up strategies or measures for sustainable water management. Water saving measures or strategies would lead to targets being met in a short time.

1. Introduction

There are more than 50,000 islands in the world, accounting for one sixth of the global land area [1] and more than 740 million people live on these islands [2]. Small islands comprising over one sixth of the global land area are facing struggles associated with global climate change. Taiwan has a population of 23.8 million and an average GDP of US$ 27,437/capita in 2020 [3]. The unique topographical and geological characteristics in Taiwan affect water availability, water use and conservation. About two thirds of the island is mountainous, which means that water flows into the ocean quickly and cannot easily be stored. Total rainfall is hugely different in the dry and wet seasons (November to April and May to October, respectively), leading to water shortages in the dry season. In addition, extreme events such as typhoons increase the deposition of sand and rock in rivers and reservoirs, gradually reducing their storage volumes and increasing water turbidity. Furthermore, the groundwater in southern Taiwan has been over-pumped for years due to the development of agricultural and aquacultural industries. Domestic use accounts for only 19 % of freshwater usage, with industry and agriculture accounting for 9 % and 72 % respectively [4]. Taiwan is already struggling to meet the growing demand for water, particularly in summer. The residential water demand will continue to grow due to urbanization.

Households are high consumers of water and are therefore important sites for water conservation [5,6]. Domestic water consumption in most developed countries is higher than the 85 or 100 L/d specified as being sufficient to fully meet household water requirements [7]. It ranges from as low as 120 L/capita/d in the Netherlands [8], to 144 L/capita/d in the UK [9], 250 L/capita/d in Taiwan [10], and 371 L/capita/d in the USA [11]. Researchers have investigated household water consumption by types of appliance [12], and behavior [13]. Previous findings confirm that attributes including gender [14], age [15], education [16], and income [17] significantly affect household water consumption. Women are more likely to participate in environmental behavior and activism such as water resources conservation. Age is inversely related to environmental concern; in other words, younger people are more likely to engage in environmental behaviors [18]. However, Chenoweth et al. [7] reported that older water users were slightly more likely to consider water saving options. People with a higher level of education often consume more water [19]. In one
study, as income level increased, so did reported participation in water conservation [18]. Household water use can help make water consumption a key indicator of human behavior [20]. Water saving behavior can be sorted into similar groups based on location (indoor or outdoor), and behavior type (efficiency, curtailment or maintenance) [21]. However, water use behavior has not been fully assessed even though it can lead to considerable reductions in water consumption [13].

Household water use is frequently assessed by questionnaire or established models. Yu et al. [19] used a face-to-face interview method to estimate residential water use associated with three types of behavior: bathing, cooking, and cleaning. They found a strong correlation between water use and energy consumption. Chenoweth et al. [7] investigated the links between household water consumption and well-being in southern England via a household survey. The results showed that actual water use appears to be unlinked to willingness to adopt water saving measures. Wolter [18] conducted a survey in Oregon and found that environmental concern and sociodemographic attributes predicted water conservation behaviors. Daioglou et al. [22] modeled domestic water demand at the end-use level and indicated that cooking was the main end-use function. Other functions, such as space heating and cooling appliances, become more important. Ren et al. [23] developed a tool to predict energy consumption at the end-use level and related greenhouse gas (GHG) emissions of Australian households. Researchers further compared energy-related GHG emissions from the water systems of various cities without analyzing the behavior of end-users [24–26]. The pumping, treatment and distribution processes in water systems are the major contributors to GHG emissions [27]. GHG emissions is a prominent environmental indicator that primarily determines the sustainability of urban water systems. Studies have indicated that water conservation at the household level is one of the effective ways to reduce GHG emissions originating from water systems.

Fig. 1. Water supply for 12 districts in Taipei city.
System dynamics (SD) modeling has been used to evaluate environmental and water systems at various scales. The SD model, introduced by Jay Forrester in the 1960s, is a well-established methodology for understanding, visualizing and analyzing complex dynamic feedback systems [29]. It attempts to quantify qualitative aspects without altering the accuracy of the original statement, providing a much more explicit basis for communication [30]. SD models are useful for considering dynamic interrelationship among variables within social and economic systems [31]. Water resources (quantity and quality) are integrated with five sectors that drive industrial growth: population, agriculture, economy, nonrenewable resources, and persistent pollution [32]. An SD model was used to increase public understanding of the value of water conservation in Las Vegas [33]. The results of SD model simulations show that water scarcity, unlike other limitations such as nonrenewable resources and persistent pollution, results in severe problems within a short time of its occurrence [34]. Qi and Chang [35] proposed an SD model based on a coupled modeling structure that takes into account the interactions among economic and social dimensions, offering a realistic platform for practical use. A reservoir balance SD model was developed and presented for the Pedra ‘e Othoni reservoir in Italy to assess resilience to climate and development changes [36]. An SD model to evaluate the water-energy-food nexus at the household scale was developed by Hussien et al. [37]. The model successfully estimated a water-energy-food demand and the impact of change in user behavior, diet, income, family size, and climate. More work is needed to develop systematic and detailed approaches to assess household water use in terms of GHG emissions and environmental costs.

The aim of this study was to develop an integrated SD model addressing the interactions between household use and GHG emissions at the household scale. Taking Taipei city as a case study, the model captures more water use behaviors including toilet flushing, clothes washing, bathing/showering, and cleaning than previous studies. The number of water saving appliances and the priority given to saving water with different appliances were also innovatively evaluated in this study. The potential GHG emissions were internalized into environmental costs to reflect increases in the water price. The price of water has a direct influence on household water use [38,39] unlike tax [40]. Otherwise, water has been considered as a natural resource with little economic and utilization values [41]. This kind of research is needed to better understand household behaviors regarding the use of potable water. Globally, emissions of GHG can be mitigated by taking a bottom-up approach.

2. Materials and methods

2.1. System boundaries used in this study

Taipei city, which has a high water quality standard (total coliform < 1 CFU/mL, turbidity < 0.1 NTU, heavy metal and nitrite nitrogen are none detected [42]), was taken as a case study. The city has 12 districts (Fig. 1) and 2.69 million residents with US$48,400/capita GDP on average [3]. GHG emissions from the water supply system have been evaluated in several published studies as noted in the Introduction. This study focused on GHG emissions caused by different household water use behaviors. Respondents were asked to complete a questionnaire about their water use. The results of the questionnaire were incorporated into an SD model. The water quality in households reached the government’s quality standard with little variation and therefore is not discussed in this study.

2.2. The survey

Face-to-face surveys can be clearly structured, flexible and adaptable [43]. In this study, at least 384 questionnaires were required when applying a convenience sampling method with a 95 % confidence interval. Therefore, six hundred and fifty face-to-face interviews were conducted during the spring vacation (April 1 to April 8) of 2018 in different districts of Taipei city. The questionnaire, which could be completed within 5 min, consisted of three sections. The first section collected information about the houses owned by the respondents, such as age and floor area. It was based on a survey of Hong Kong residents [44]. The second section contained seventeen questions about the respondents’ water use behavior. The questions were designed with reference to Shan et al. [45] and covered frequencies of bathing/showing, drinking water, and cleaning. The number of water saving appliances (e.g., low-flow taps and/or shower heads, dual-flush toilet) was also recorded. The respondents were also asked about the priority they would give to saving water if the water price increased. The final section elicited the respondents’ socio-economic information, such as gender, income, age, and education.

2.3. Formulation of system dynamics model

An SD model is constructed from building blocks (variables) and includes four main components: stocks, flows, connectors, and converters (Fig. 2). Stock variables, symbolized by rectangles, are the state variables and they represent the accumulation water in the system. Flow variables, symbolized by valves, are the rate of change in stock variables and they represent those activities and decision functions that fill up or drain the stocks. Converters, represented by circles, are intermediate variables used for miscellaneous calculations. Finally, the connectors, represented by simple arrows, are information links representing the cause and effects within the model. An example relating to household water volume is as follows. The overall volume of water used for clothes washing depends on the water price used each time and the frequency of clothes washing (Fig. 2). The mathematical mapping of an SD stock-flow diagram occurs via a system of differential equations, which are solved numerically in the simulation. The specifications of the SD model are shown in Table S1. Six equations were modeled using STELLA software in this study. The year 2018 was taken as the base time and 12-year simulations (from 2019 to 2030) with a step size time variable of 1 year were modeled.

2.4. Calculation of water volume and its associated GHG emissions

Household water use in Taiwan can be divided into five major categories: toilet flushing, clothes washing, bathing/showering, cleaning, and other uses [10]. The categories of cleaning and other uses were frequently confused by respondents in pretests of the survey and were integrated in this study. The detailed calculations of water volume are described below.

2.4.1. Calculation of water use volume

The formula to calculate water use volume was based on Yu et al. [19] and redesigned as follows:

\[ V_{\text{flush}} = \alpha(f_{\text{ta}} \times Q_{\text{ta}}) + \beta(f_{\text{tf}} \times Q_{\text{tf}}) \times P \times 365 \]  

(1)

where \( V_{\text{flush}} \) is water volume used for toilet flushing (L/y), \( f_{\text{ta}} \) and \( f_{\text{tf}} \) are the frequency of toilet flushing (times/capita/d), \( Q_{\text{ta}} \) and \( Q_{\text{tf}} \) are the water volume of toilet flushing (L/times), \( \alpha \) is the percentage of households that own water saving toilets, \( \beta \) is the percentage of households without water saving toilets, equal to 1 − \( \alpha \), \( P \) is the population of Taipei city, equal to 2,688,430 in 2018 [46], and 365 is the conversion factor from year to day.

\[ V_{\text{cloth}} = f_{\text{c}} \times Q_{\text{c}} \times P \times 365 \]  

(2)

where \( V_{\text{cloth}} \) is water volume used for clothes washing (L/y), \( f_{\text{c}} \) is the frequency of clothes washing (times/capita/d), and \( Q_{\text{c}} \) is the water volume of clothes washing (L/times). Clothes washing is not classified with/without water saving appliances by the government in 2018.
where $V_{\text{bath}}$ is bath/shower volume (L/y, with or without water saving appliances), $f_{s\alpha}$ and $f_{s\beta}$ are the frequency of taking a shower (times/capita/d), $Q_{s\alpha}$ and $Q_{s\beta}$ are the water volume of taking a shower (L/times), $f_b$ is the frequency of taking a bath (times/capita/d), and $Q_b$ is the water volume of taking a bath (L/times).}

$$V_{\text{bath}} = [\alpha(f_{s\alpha} \times Q_{s\alpha}) + \beta(f_{s\beta} \times Q_{s\beta})] \times (f_b \times Q_b) \times P \times 365 \quad (3)$$

$V_{\text{clean}}$ and $V_{\text{other}}$ are water volume for cleaning and other purposes, respectively (L/y).

### 2.4.2. Calculation of GHG emissions

Therefore, GHG emissions from household water use can be calculated as follows:

$$GHG = V_i \times 1.7 \times 10^{-4} \quad (5)$$

where $V_i$ is water volume and $i$ can stand for toilet flushing, clothes washing, bathing/showering, or cleaning (L/y). One ton of tap water has been reported to produce 0.17 kg CO$_2$-eq GHGs in 2018 [47]; therefore, the converting factor is $1.7 \times 10^{-4}$ t CO$_2$-eq/L/y in this study.

### 2.5. Calculation of environmental cost

The GHG calculations are mainly used to represent environmental costs as monetary values. The environmental costs ($EC_{GHG}$, US$) of GHG emissions can be calculated as follows [48]:

$$EC_{GHG} = \sum (P_i \times Qcf_i \times (1 + r)^{-t}) \quad (6)$$

where $P_i$ is the carbon price at year $t$ (US$/t CO$_2$-eq). For the year of 2018, the carbon price announced by the European Union Emission Trading Scheme (EU ETS) was 5.76 EUR/t CO$_2$-eq (equal to 7.02 US$/t CO$_2$-eq) [49]. $Qcf$ is the GHG emission from unit water volume each year (t CO$_2$-eq/y), and $r$ is the discount rate of 4.0 % [48].

Therefore, the water price in terms of the environmental costs of GHGs is as follows:

$$\text{Water Price} = (PV + EC_{GHG}) \times (A + 1) \quad (7)$$

where $PV$ is the operating and maintenance costs (US$) and $A$ is the external profits of the water department. Currently, the operating and maintenance costs in Taiwan are US$0.33/t and basic external profits for the water company should be 8% [50].

### 2.6. Water saving scenarios

It is known that water saving measures and/or appliances can reduce water usage by 5%–20% [51]. Therefore, this study simulated five different water management scenarios (Fig. 3): 5%, 10%, 15% and 20% reductions in water volume from different water use behaviors, and a scenario to reduce 20% water volume in which respondents gave priority to saving water if the water price increased.

### 3. Results and discussion

#### 3.1. Results of the survey

An effective water management system must be accepted by the public [52]. The 650 randomly sampled people resided in 12 different districts of Taipei city. Among the questionnaires, 409 (63%) were suitable for analysis; 37% were excluded due to non-responses. As shown in Table 1, 30% of the sample was male and 70% was female; 40.5% of the respondents had four family members (i.e., two children in the family); 65.7% of the respondents were educated to college level; and 48.1% were aged between 16 and 25. The monthly income of half of the respondents ranged from US$667 to US$1,667.

The respondents’ individual attributes (gender, age, education, and income) were cross-analyzed with their water use behaviors. It is interesting that 73% of the respondents said they took less than 30 s to wash their hands, 1–3 min for cleaning, and 3–5 min to take a bath/shower. The UNICEF [53] suggests to scrub all surfaces of the hands for at least 20 s to protect against coronavirus (COVID-19) which was successfully controlled in Taiwan. The promotion of population’s awareness of hand washing will still provide the greatest benefit to mitigate the pandemic [54]. Male respondents took shorter showers than female respondents in this study. High school students took longer baths/showers than college students did, confirming the finding of Yu et al. [19] that older people use less bathing water. Respondents with
an income level between US$667 and US$1667 would take 10–20 min
shower, versus other respondents (5–10 min). The water used for
clothes washing and shower is greater for lower-income areas [55]. In
other words, higher levels of income demonstrated more engagement
in water conservation behaviors [56,57]. Rosinger et al. [58] found
that income was linearly associated with tap water consumption among US
citizens; however, the individual attributes were not significantly re-
lated to water use behaviors in this study.

3.2. Water volumes associated with different water use behaviors

In this study, 27.7 % of water volume was used for cleaning, fol-
lowed by clothes washing (26.2 %), bathing/showering (26.1 %), and
toilet flushing (20.0 %) (Fig. 4). In the Netherlands, a population survey
indicated that the main end uses of household water were showering
(40 %), toilet flushing (28 %), and clothes washing (12 %) [8]. An
analysis of the North American Residential End Uses of Water study
indicated that the top three indoor end uses of water were toilet
flushing (26.7 %), clothes washing (21.7 %), and showering (16.8 %)
[59]. The amount of water for lawn and landscape irrigation is rapidly
increasing in the US and is estimated at a total of 9 billion gallons per
day nationwide [56]. Average water end use consumption in Australia
has been reported as showering (25 %), outdoor uses (21.9 %), taps
(19.0 %), clothes washing (17.6 %), and toilet flushing (12.7 %) [60].
Garden watering and showering are two of the largest contributors
to water use in households in Australia [61]. In Poland, water used for
showering and clothes washing accounts for 40 % and 12 % of total
household water use, respectively [45]. Showering is the greatest
consumer of domestic water in Portugal, accounting for 38 % of total
water consumption [13]. Taiwan’s Water Resources Agency [62] found
that toilet flushing (27 %), clothes washing (21 %), and bathing/
showering (20 %) were the highest contributors to household water use
(Fig. 4). In this study, the volume of water used for toilet flushing had
reduced to 7 %, perhaps because of an increase in the use of water
saving appliances during the past 10 years. Other water use behaviors
were increased.

As shown in Table 2, 27.2 % of respondents had water saving ap-
pliances; 20.5 % and 16.4 % of the appliances were toilets and shower
heads, respectively. Asian countries, like Korea, Japan and Taiwan, had
20–24 % water saving toilets; however, other Europe countries had
higher percentage of using water saving toilet [63]. A saving of 3 L can

| Characteristic          | Definition                        | Respondents (%) |
|------------------------|-----------------------------------|-----------------|
| Income                 | Respondent’s monthly income       | No answer       |
|                        | < US$667 (13.7)                   | US$667–1667     |
|                        | (13.2)                            | (54.0)          |
|                        | 16–25 (48.1)                      | 31–40 (14.5)    |
| Age                    | Respondent’s age                  | 26–30 (11.2)    |
|                        | < 15 (1.3)                        | 41–50 (15.3)    |
|                        | 16–25 (48.1)                      | 51–60 (9.1)     |
|                        | 26–30 (11.2)                      | > 61 (0.5)      |
| Education              | Respondent’s education level in   | High school     |
|                        | years                             | (2.0)           |
|                        | Undergraduate (65.7)              | Graduate (19.1) |
| Gender                 | Respondent’s gender               | Male (29.5)     |
|                        | Female (70.5)                     | 2 (10.4)        |
| Family member          | Number of family members          | 3 (15.3)        |
|                        | 393                               | 4 (40.5)        |
| Total Responses        |                                    | 5 (17.0)        |
|                        |                                    | 6 (8.4)         |
|                        |                                    | 7 (1.8)         |
be made each time a water saving toilet is used. Most respondents reported using 48 L and 150 L each time for clothes washing and bathing, respectively. Family size and seasons were positive related to frequency of clothes washing [19]. Taking a shower with or without a water saving shower head would save ca. 30–60% water compared to bathing. Showering frequency rather than duration played a dominant role in use of water for bathing [19]. The participants in this study used 49.7 L/d for cleaning. The average volume of water used for cleaning was 40.3 L/d in Taiwan in the past 10 years [62]. Water use efficiency can be significantly increased by the installation of more efficient water use devices [13]. For example, solar hot water systems are marketed to households on the basis of reduced energy costs through reduced GHG emissions [64]. Some households adopt water saving appliances and practices to continue their high consumption habits [56, 65].

3.3. Results of different water saving scenarios

Kenway [66] found that behavioral changes play a vital role in water savings and GHG emissions. Different water use behaviors will have their own best water saving scenarios. As shown in Fig. 5, the highest reduction in water volume (6.27 t) was reached in the fifth scenario, in which 1.1 t was saved during the study period. The reduction in water used for clothes washing was highest in the fourth scenario, in which 1.4 t was saved. The volume of water used for clothes washing may be limited by the size of washing machines that only work when there is a full load. Other water use behaviors would be related to the targets for water use reduction. The volume of water used for bathing/showering and cleaning would reduce by 0.4–1.9 and 0.4–2.5 t, respectively, in the different scenarios. Shove’s [67] work on changes in showering practices in the UK over time is particularly important. Domestic water saving may be increased through economic incentives, technical improvements, or policy instruments and regulations [41]. In sum, establishing water saving targets for different water use behavior depending on water prices would be more efficient than a single target, which is frequently applied by the government. As water reuse systems are less efficient than conventional water supply systems [68] this option is not suggested in this study.

3.4. Results of environmental costs

The environmental cost of GHG emissions from water use behavior was US$0.001/t in 2018. The direct and indirect costs of water management in Taiwan are ca. US$0.3/t and US$0.01/t, respectively [50]. The direct costs are incurred by purifying, treating, supplying, and managing water resources. The indirect costs include employee training, disaster losses, retirement, and interest. The water price would be increased to US$0.33/t (according to Eq. (7)) after monetizing the environmental costs of GHG emissions (US$0.001/t). An 8% increase was accepted by respondents in this study if the government keeps providing clean and safe water resources in Taiwan. The majority (80%) of survey respondents are willing to pay 100–240% of the household monthly water bill for reliable water service in Bandung, Indonesia [69]. Houven et al. [70] suggested that households are willing to pay approximately US$3–30 per month for improvements in water access. Expenditure on water in Taiwan was the third from last when Indonesia [69]. Houven et al. [70] suggested that households are willing to pay approximately US$3–30 per month for improvements in water access. Examining the efficiency of different water use scenarios was not suggested in this study.

Table 2. Water volume and frequency used for different water use behaviors.

| Water use behavior | With/without water saving appliance (%) | Frequency (time/capita/d) | Water volume (L/time) |
|--------------------|----------------------------------------|--------------------------|----------------------|
| Toilet flushing    | With (20.5 %)                           | 5.7                      | 9                    |
|                    | Without (79.5 %)                        | 5.7                      | 12                   |
| Clothes washing    | With (16.4 %)                           | 0.997                    | 41.4                 |
|                    | Without (83.6 %)                        | 1.1                      | 83.3                 |
| Bathing            | -                                      | 1.775                    | 48                   |
| Showering          | With                                   | 0.4                      | 150                  |

Fig. 5. Water volume reduction from different water use scenarios.

Fig. 6. Water volume reduction from 2019–2030 in the fifth scenarios.
4. Conclusions

Taiwan is a small island surrounded by sea. Domestic water use accounts for only 19% of total freshwater usage in Taiwan. GHG emissions from water systems have received attention as a prominent environmental indicator in recent years. An integrated SD addressing the interactions between household water use and GHG emissions was therefore developed in this study. Taking Taipei City as a case study, the model captures different behaviors including toilet flushing, clothes washing, bathing/showering, and cleaning. Potential GHG emissions were represented as environmental costs to reflect an increase in water price. A total of 650 face-to-face interviews were conducted during the spring vacation (April 1 to April 4) of 2018 in 12 districts of Taipei City. The results revealed that the respondents’ individual attributes were not significantly related to water use behaviors. The largest volume of water (27.7%) was used for cleaning, followed by clothes washing (26.2%), bathing/showering (26.1%), and toilet flushing (20.0%). Five different water management scenarios with 5–20% reductions in water volume from different water use behaviors were modeled. It is appropriate to establish water saving targets within 5 years. The maximum reduction in water use (6.27 t) was found in the fifth scenario, which reflected the priority respondents gave to saving water if the water price increased. The environmental cost of GHG emissions associated with water use behavior was US$0.001/t, causing an 8% cost increase, which was acceptable to the respondents in this study. Further research of this kind is needed to better understand household behaviors regarding the application of water saving strategies or measures.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jwpe.2020.101409.

References

[1] C. Marín, L.M. Alves, A. Zervos, 100% RES-A Challenge for Island Sustainable Development, (2005) http://issuu.com/pubclipresco/docs/island100res/19.
[2] W. Leal Filho, F. Manrique, R. Mohoe, V. Schulte, Climate-Smart Technologies: Integrating Renewable Energy Efficiency in Mitigation and Adaptation Responses, Springer Science & Business Media, 2013.
[3] National Statistics, The Latest Indicators, (2020) (Accessed 10 May 2020),https://www.stat.gov.tw/point.asp?index=1.
[4] W.F. Yang, The Current and Future Development of Water Resources Utilization in Taiwan, (2010) https://go.gov.tw/eyAyt.
[5] K.S. Fielding, Y. Kasteren, W. Louis, B. McKenna, S. Russell, A. Spinks, Using individual household survey responses to predict household environmental outcomes: the cases of recycling and water conservation, Resour. Conserv. Recycl. 106 (2016) 90–97.
[6] S. Jiang, J. Wang, Y. Zhao, S. Lu, H. Shi, F. He, Residential water and energy nexus for conservation and management: a case study of Tianjin, Int. J. Hydrogen Energy 41 (2016) 15919–15929.
[7] J. Chenoweth, A. López-Avilés, S. Morse, A. Druckman, Water consumption and subjective wellbeing: an analysis of British households, Ecol. Economic. 130 (2016) 186–194.
[8] V. Vinis, Dutch Drinking Water Statistics 2012: The Water Cycle from Source to Tap, Vereniging Dutch Waterbedrijven in Nederland, Rijswijk, 2012.
[9] Consumer Council for Water, Delving into Water: Performance of the Water Companies in England and Wales 2010-11 to 2013-14, Consumer Council for Water, Birmingham, 2015.
[10] Water Resources Agency, Technologies for Saving Household Water Manual, Taipei (2007).
[11] J.F. Kenny, N.L. Barber, S.S. Hutson, K.S. Linsley, J.K. Lovelace, M.A. Maupin, Estimated use of water in the United States in 2005, U.S. Geological Survey Circular 1344, (2009).
[12] R.D. Williss, R.A. Stewart, K. Panuwatwanich, S. Jones, A. Kyriakides, Alarming visual display monitors affecting shower end use water and energy conservation in Australian residential households, Resour. Conserv. Recycl. 54 (2010) 1117–1127.
[13] P. Vieira, C. Jorge, D. Covas, Assessment of household water use efficiency using performance indices, Resour. Conserv. Recycl. 116 (2017) 94–106.
[14] Y. Tong, L. Fan, H. Niu, Water conservation awareness and practices in households receiving improved water supply: a gender-based analysis, J. Clean. Prod. 141 (2017) 947–955.
[15] K. Rathnayaka, H. Malano, M. Arora, B. George, S. Maheepala, B. Nawaratna, Predication of urban residential end-use water demands by integrating known and unknown water demand drivers at multiple scales II: model application and validation, Resour. Conserv. Recycl. 118 (2017) 1–12.
[16] B. Yu, J. Zhang, A. Fujiwara, Representing in-home and out-of-home energy consumption behavior in Beijing, Energy Policy 39 (2011) 4168–4177.
[17] Z. Yang, S. Wu, H.Y. Cheung, From income and housing wealth inequalities to emissions inequality: carbon emissions of households in China, J. Hou. Built. Environment. 32 (2016) 231–252.
[18] E.A. Wolters, Attitude-behavior consistency in household water consumption, The Social Sci. J. 51 (2014) 455–463.
[19] M. Yu, C. Wang, Y. Liu, G. Olson, H. Bai, Water and related electrical energy use in urban households: influence of individual attributes in Beijing, China, Resour. Conserv. Recycl. 130 (2018) 190–199.
[20] D.T. Kopinas, A. Spyropoulos, C.S. Lapidou, A methodology for synthetic household water consumption data generation, Environ. Model. Softw. 100 (2018) 46–66.
[21] S. Kneebone, K. Fielding, L. Smith, It’s what you do and where you do it: perceived similarity in household water saving behaviours, J. Environ. Psychol. 55 (2018) 1–10.
[22] V. Daoioglou, B.J. Van Ruijven, D.P. Van Vuuren, Model projections for household energy use in developing countries, Energy 37 (2012) 661–615.
[23] Z. Ren, G. Foliente, W. Chan, D. Chen, M. Ambrose, P. Paevere, A model for predicting household end-use energy consumption and greenhouse gas emissions in Australia, Int. J. Sustain. Build. Technol. Urban Dev. 4 (2015) 212–220.
[24] G. Venkatesh, A. Chan, H. Bratbo, Understanding the water-energy-carbon nexus in urban water utilities: comparison of four city case studies and the relevant influencing factors, Energy 75 (2014) 153–166.
[25] C.D. Beal, E. Bertone, R.A. Stewart, Evaluating the energy and carbon reductions resulting from resource-efficient household stock, Energy Build. 55 (2012) 422–432.
[26] S.J. Kenway, R. Scheidegger, T.A. Larsen, P. Lant, H.P. Rader, Water-related energy in households: a model designed to understand the current state and possible measures, Energy Build. 58 (2013) 378–389.
[27] X. Yu, R. Ghasemizadeh, I. Padilla, J.D. Meeker, J.F. Gordero, A. Alshawabkeh, Socio-demographic patterns of household water-use costs in Puerto Rico, Sci. Total Environ. 524–525 (2015) 300–309.
[28] C.L. Cheng, Study of the inter-relationship between water use and energy conservation for a building, Energy Buildings 34 (2002) 261–266.
[29] W. Zhao, H. Ren, V.S. Rotter, A system dynamics model for evaluating the alternative of type in construction and demolition waste recycling center-the case of Chongqing, China, Resour. Conserv. Recycl. 55 (2011) 933–944.
[30] J.W. Forrester, Policies, decisions and information sources for modeling, Eur. J. Operational Res. 59 (1992) 43–58.
[31] X.L. Zhang, Y.Z. Wu, L.Y. Shen, M. Skitmore, A prototype system dynamic model for assessing the sustainability of construction projects, Int. J. Proj. Manage. 32 (2014) 66–76.
[32] S. Simonovic, World water dynamics: global modelling of water resources, J. Environ. Manage. 66 (2002) 249–267.
[33] K.A. Stave, A system dynamics model to facilitate public understanding of water management options in Las Vegas, Nevada, J. Environ. Manage. 67 (2003) 303–313.
[34] T. Kojiri, T. Hiro, J. Koyama, M. Kusunoki, T.S. Chong, World continental modelling for water resources using system dynamics, Phys. Chem. Earth 33 (2008) 304–311.
[35] C. Qi, N.B. Chang, N.B. System dynamics modelling for municipal water demand estimation in an urban region under uncertain economic impacts, J. Environ. Manage. 92 (2011) 1628–1639.
[36] S. Mereu, J. Šulák, A. Trabucco, A. Daccache, L. Vamvakeridou-Lyroudia, S. Renoldi, A. Virdis, D. Savić, A. Spikes, J. Kenny, A. Alshawabkeh, Socio-demographic patterns of household water-use costs in Puerto Rico, Sci. Total Environ. 524–525 (2015) 300–309.
[37] S. Decarlo, J. Vásquez, J. Kenny, P. Parente, A. Alshawabkeh, Socio-demographic patterns of household water-use costs in Puerto Rico, Sci. Total Environ. 524–525 (2015) 300–309.
[38] S. Decarlo, J. Vásquez, J. Kenny, P. Parente, A. Alshawabkeh, Socio-demographic patterns of household water-use costs in Puerto Rico, Sci. Total Environ. 524–525 (2015) 300–309.
