Greenhouse gas emission estimations for Depok’s (West Java, Indonesia) middle-class household water end-uses

R P Adriani¹, G A Kristanto¹ and M A Pratama¹,²
¹ Civil Engineering Department, University of Indonesia, Jl. Margonda Raya, Depok, 16424, Indonesia
² Corresponding author: adhiraga@eng.ui.ac.id

Abstract. The rising concentration of greenhouse gases (GHG) is highly associated with climate change. Previous studies showed that end-use household water consumption contributes 58% of the total GHG emissions from the water sector. We attempted to calculate the GHG emissions associated with household end-uses from an area that uses groundwater as the main water source. Data were collected from 100 households in the Cinere subdistrict of Depok, West Java. Questionnaire surveys and interviews were conducted to obtain data related to each type of water end-use consumption and energy consumption from water appliance usage. Existing GHG emissions were calculated based on the water and energy consumption data. The results showed that the average end-use household water consumption for the study area was 214.3 liters per capita per day. The GHG emission associated with household water end-uses was found to be 0.379 kg CO₂ per capita per day and mainly resulted from water heating. Two intervention scenarios to minimize GHG emissions were evaluated. The first scenario—retrofitting water-related appliances and exhibiting water-conscious behavior—could reduce GHG emissions by 1%, whereas the second scenario—replacing electric and gas water heaters to solar water heaters—could reduce emissions by 66%.

1. Introduction
Indonesia is a country with one of the highest populations worldwide; in 2017, its population growth reached 1.34% [1]. In the midst of this population growth, it is estimated that the size of the country’s middle class—currently consisting of about 74 million people—will double by 2020 [2]. Along with the rapid increase in Indonesia’s population, the consumption of clean water in the domestic sector will also increase. According to one study, the relationship between the level of accessibility to clean water and the level of domestic water consumption has a positive correlation. In other words, the increasing access to clean water or the development of water infrastructure in a country will result in a significant increase in domestic water consumption [3]. An increase in water consumption can potentially result in increased greenhouse gas (GHG) emissions [4].

Studies on the relationship between water and energy (also called the water–energy nexus) in water treatment, water end-uses, and domestic wastewater treatment have been discussed in-depth and extensively in the state of California in the United States (US) [5,6]. The energy intensity required for water end-use is greater than that required for water treatment and wastewater treatment combined [5]. It was also estimated that 58% of total water-related energy was used in residential areas, with water heating and water pumping as the main forms of energy consumption [5].

Studies on the contribution of water end-uses in the household sector to GHG emissions have also been carried out in several developed countries, such as Australia, the United Kingdom (UK), Japan, and China [7,8,9]. While most studies conducted in developed countries throughout the year have tended
to focus on emissions from energy consumption due to water heating and pumping activities, studies that have been done in developing countries, such as Vietnam, have been more focused on the pattern of the consumption of clean water, emissions resulting from water and wastewater treatment, and efforts to reduce these emissions through water savings [3,7,8].

As one of the countries that committed to reducing GHG emissions in the Paris Agreement, Indonesia is targeting a 29% reduction in emissions by 2030 [10]. However, despite its importance and significance, the water sector is rarely discussed in the national plan for emissions reduction. Thus, this study attempts to quantify the GHG emissions originating from clean water end-uses and to identify the activities that most contributed the total emissions. To estimate these emissions, however, it is necessary to initially obtain the quantity and pattern of clean water consumption at the household level. Thus, in this study, a survey was first administered to quantify clean water consumption and identify the pattern. Thereafter, the GHG emissions originated by clean water end-uses were estimated. Finally, several scenarios were developed to evaluate the effectiveness of GHG emission-reduction strategies. By understanding of the potential for reducing emissions from each mitigation strategy, the results of this study can become the basis in developing climate change mitigation policies related to water end-uses management and energy efficiency to achieve the target of reducing Indonesia’s GHG emissions by 2030.

2. Study method

2.1. System boundary

The system boundary used in this study is shown in Figure 1. Based on the predetermined boundary system, the GHG emissions estimation conducted in this study included the indirect GHG emissions originating from the energy needs of household appliances (e.g., washing machines, pumps, electric water heaters, and automatic dishwashers) and the direct GHG emissions derived from the use of fuel for water heaters and for boiling water for drinking.

![Figure 1. System boundary of this study.](image)

2.2. Scope of water consumption

The activities related to water end-use at the household level included in this study were the following:

- **Bathing** using a shower, a bathtub, or another reservoir
- **Drinking** using dispenser or boiled water
- **Dishwashing** by hand or automatically using a dishwasher
- **Doing laundry**, done by hand or automatically using washing machine
- **Using the toilet**, including the squatting type or closet type, and cleaning the toilet (e.g., flushing and spraying) after use
- **Gardening** using a hose/pot flush/dipper for potted plants or yards.
- **Car washing**, including washing vehicles at home using either a hose or bucket
- **Ablution**, limited to water needed for daily prayers five times a day (for Muslim households)
2.3. Water consumption survey

The primary data needed were the water consumption patterns and energy consumption related to water use, and these were obtained through a questionnaire survey that was divided into two stages: the pilot survey and the main survey. Meanwhile, the secondary data used was in the form of emissions factors and equipment specifications related to water use. The pilot survey and the main survey were carried out in the Cinere subdistrict of Depok. The pilot survey was conducted to obtain an initial overview at the location of the object of study, to allow for the questionnaire content to be adjusted if necessary, and to facilitate discharge testing. The pilot survey was conducted from February 26, 2019, to March 10, 2019, with 10 respondents selected through purposive sampling. Then, the main survey was conducted from March 26, 2019, to May 19, 2019, with 100 respondents chosen randomly. The inclusion criteria were respondents who were permanent homeowners (i.e., not those in boarding/rental houses), were a minimum 15 years of age, and had a monthly household expenditure in the range of Rp 1,500,000.00 to Rp 5,000,000.00, to fit the middle-class category [2]. Questionnaires were distributed door to door and online.

2.4. Water consumption calculation

In general, the approaches to calculating the consumption of clean water in this study were as follows:

- a. Based on the type of equipment used, the amount of water required for each use was multiplied by the frequency of usage and the duration of usage.
- b. All collective water-use activities (such as the use of washing machines) were converted to obtain the water consumption per person per day.
- c. The water flow rate from a tap was generalized based on the results of the pilot survey. In the pilot survey, simple flow rate measurements were conducted following the study, which was done in Harbin, China [11]. The measurement was carried out using a stopwatch, calculator, and container (1 liter / 1.5 liter).

2.5. GHG emission calculation

As previously mentioned, two types of emissions were calculated in this study: indirect GHG emissions originating from the electricity consumption of household appliances, and direct emissions originating from the use of fuel for water heaters and boiling water for drinking. To obtain the electricity consumption of each appliance, the frequency and duration of equipment usage were multiplied by the power of the appliance. The energy consumption efficiency of each type of water heater was assumed using the average value of from Air-Conditioning, Heating, and Refrigeration Institute (AHRI)-certified water heaters [12], and the efficiency of solar water heaters were assumed based on the energy consumption of electric-boosted solar water heaters [7]. Then, GHG emissions were calculated by multiplying electricity consumption (E_e) by emission factors (EF_e). The GHG emissions used in this study were the values published by the Ministry of Energy and Mineral Resources (ESDM). Depok, which is supplied by the Java–Madura–Bali electrical system, has an electricity emissions factor value of 0.862 kg CO_2/kWh [13]. Emissions from electricity consumption (E_e) can be calculated using the following equation:

\[ E_e = E_c \times EF_e \]  

(1)

Water is assumed to be heated from 25°C to 43°C for bathing purposes [14] and 100°C for drinking purposes. For emissions originating from water heating (E_F), GHG emissions can be calculated using the Intergovernmental Panel on Climate Change (IPCC) [16] equation, as follows:

\[ E_F = F_c \times NCV \times EF_F \]  

(2)

where \( F_c \) is fuel consumption, \( NCV \) is the net calorific volume of the fuel, and \( EF_F \) is the emission factor based on the type of fuel used. The fuel calculated in this study was liquified petroleum gas (LPG) with an NCV value of 47.3 Tj/Gg LPG and an \( EF_F \) value of 2.98 kg CO_2/kg LPG [15].
3. Results and discussion

3.1. Water consumption
The average daily water consumption in the Cinere subdistrict was found to be 214.3 liter/capita/day, and the average water consumption for each activity is shown in Figure 2. The largest water-consuming activity is bathing activity, which accounts for 35% of total water consumption.

![Figure 2. Average water consumption by activity in the Cinere subdistrict (L/capita/day, %).](image)

3.2. GHG emissions
The average GHG emissions (including direct and indirect emissions) from Cinere subdistrict household water end-uses was found to be 0.379 kg CO₂/capita/day or 138 kg CO₂/capita/year. The result in this study was lower than the study conducted in the UK[8], where the GHG emission from energy consumption in household water end-uses reached 2,830 kg CO₂/capita/year. This is due to the larger number of water-heating uses (i.e., washing machines, dishwasher, and bathing) in the UK. The largest contributor of GHG emissions in this study was found to be water heater usage, which accounts for 78% of total GHG emissions. The average GHG emission from each source is shown in Figure 3.

![Figure 3. Household water end-uses’ GHG emissions, by source.](image)
3.3. Scenario evaluation

Based on the GHG emissions of existing conditions/business-as-usual (BaU) scenarios, two intervention scenarios were evaluated. The first intervention scenario, which focuses on reducing water consumption as a whole, involves retrofitting water-related appliances and ensuring water-conscious behavior. The second scenario focuses on the largest GHG emission contributor in household water end-use and involves replacing electric and gas water heaters with solar water heaters.

Changes made in the first intervention scenario were based on the difference between the existing conditions and the best practices or water-efficient appliance standards (Table 1). Regarding washing machine usage behavior, about 24% of the total respondents stated that they do their laundry using a washing machine at less than 50% capacity. Because of that, in the best-practice scenario, it was assumed that in one cycle of a washing machine, a minimum of 75% of the total washing machine capacity would be used by everyone. While toilets do not consume any energy in their usage, a change of toilet can lead to a reduction of water consumption. Based on WaterSense [16], a water-efficient toilet has a flushing volume of less than 4.8 liters/flush or 1.28 gallons/flush. However, the existing conditions in the Cinere subdistrict show that the majority of toilets used still have a flushing volume of 6 liters/flush or, in some cases, 14 liters/flush. Even though the majority of respondents have dual-flush toilets, they always use the highest flushing volume. Because of that, in this scenario, it is assumed that all the toilets in the Cinere subdistrict would be retrofitted to a 4.8 liter/flush toilet.

**Table 1.** Changes made to household water end-uses in scenario one.

| Activity     | Component     | Existing        | Standard/ Best Practice | Source          | Changes Made |
|--------------|---------------|-----------------|-------------------------|-----------------|--------------|
| Bathing      | Flow rate     | 3.9 liters/minute | 7.6 liters/minute       | WaterSense      | No           |
| Drinking     | Consumption   | 2 liters/capita/day | 2 liters/capita/day     | Ministry of Health RI | No           |
| Dishwashing  | Flow rate     | 4.8 liters/minute | 5.7 liters/minute       | WaterSense      | No           |
| Laundry      | Behavior      | Varies by cycle | Full capacity each cycle | Energy Star     | Yes          |
| Toilet       | Flushing volume | 14 liters and 6 liters | 4.8 liters             | WaterSense      | Yes          |

In the second intervention scenario—replacing electric and gas water heaters with solar water heaters—the solution would be phased in over a period of time. There are two options in the second intervention scenario: realistic phasing and optimistic phasing. Realistic phasing (Table 2) is based on the projection that by year 2030, 30% of water-heating energy consumption in Indonesian households will be provided by solar water heaters [17] and that the percentage of electricity consumption until 2050 will increase.

**Table 2.** First scenario (realistic phasing).

| Water Heater Energy Source | 2019 | 2020 | 2025 | 2030 |
|----------------------------|------|------|------|------|
| LPG                        | 7.5% | 6.9% | 3.4% | 0.0% |
| Electricity                | 75.5%| 75.0%| 72.5%| 70.0%|
| Solar                      | 17.0%| 18.2%| 24.1%| 30.0%|
Optimistic phasing, in contrast, uses the assumption that by 2030, all households will use solar water heater. The optimistic phasing process in the replacement of electric and gas water heaters with solar water heaters as an energy source is shown in Table 3.

Table 3. First scenario (optimistic phasing).

| Water Heater Energy Source | Projection Year |
|----------------------------|-----------------|
|                            | 2019 | 2020 | 2025 | 2030 |
| LPG                        | 7.5% | 6.3% | 0.0% | 0.0% |
| Electricity                | 75.5%| 69.2%| 37.7%| 0.0% |
| Solar                      | 17.0%| 24.5%| 62.3%| 100% |

A comparison of GHG emissions from each scenario (Figure 4) was carried out to determine the best way to reduce GHG emissions from household water end-uses. The first scenario leads to GHG emissions of 0.376 kg CO$_2$/capita/day, reducing GHG emissions by 1% from the BaU condition. Meanwhile, the realistic phasing of the second scenario achieved an 8% emissions reduction. The second scenario with optimistic phasing has the largest GHG emission reduction, which is a reduction by 66% from the BaU condition if it were to be implemented. It is supported by the fact that solar hot water system has the lowest energy demand than that of gas and electricity system, thus its GHG emission is the most efficient [17].

![Figure 4. Comparison of GHG emissions from the intervention scenarios.](image)

4. Conclusion
Depok’s middle-class households with water consumption of 214.3 liters/capita/day, emit 0.379 kg CO$_2$/capita/day or 138 kg CO$_2$/capita/year from household water end-uses. The best intervention scenario for reducing GHG emissions or climate change mitigation from household water end-uses in Depok is replacing electric and gas water heaters with solar water heaters.

References
[1] Badan Pusat Statistik Indonesia 2018 *Statistik Indonesia Tahun 2018* (Jakarta: BPS)
[2] Rastogi V, Tong D, Tamboto E and Simburisit T 2013 *Asia’s Next Big Opportunity: Indonesia’s rising middle-class and affluent consumers* (Boston: The Boston Consulting Grup (BCG))
[3] Otani T, Toyosada K and Shimizu Y 2015 *CO$_2$ Reduction Potential of Water Saving in Vietnam*
Water (Switzerland) 7 2516–26

[4] Ofwat 2010 Playing Our Part - Reducing Greenhouse Gas Emissions in the Water and Sewerage Sectors (Birmingham: Ofwat (The Water Services Regulation Authority))

[5] Wolff G, Cohen R and Nelson B 2004 Energy down the drain: The Hidden Costs of California’s Water Supply (Oakland, California: Nature Resources Defence Council Pasific Institute)

[6] Griffiths-sattenspiel B and Wilson W 2009 The Carbon Footprint of Water (Portland: River Network)

[7] Beal C D, Bertone E and Stewart R A 2012 Evaluating the energy and carbon reductions resulting from resource-efficient household stock Energy Build. 55 422–32

[8] Hackett M J and Gray N F 2009 Carbon Dioxide Emission Savings Potential of Household Water Use Reduction in the UK J. Sustain. Dev. 2 36–43

[9] Shimizu Y, Dejima S and Toyosada K 2012 The CO2 emission factor of water in Japan Water (Switzerland) 4 759–69

Shimizu Y, Toyosada K, Yoshitaka M and Sakaue K 2012 Creation of Carbon Credits by Water Saving Water (Switzerland) 4 533–44

[10] Kementrian Lingkungan Hidup dan Kehutanan 2017 Summary: Nationally Determined Contribution (NDC) and its Progress of Implementation (Jakarta: Ministry of Environment and Forestry)

[11] Lu T 2007 Research of domestic water consumption: a field study in Harbin, China (Leicestershire, UK: Water, Engineering and Developmeny Centre Department of Civil and Building Engineering)

[12] Hong B and Howarth R W 2016 Greenhouse gas emissions from domestic hot water: Heat pumps compared to most commonly used systems Energy Sci. Eng. 4 123–33

[13] Ministry of Energy and Mineral Resources Indonesia 2016 Electricity Interconnection System Greenhouse Gas Emission Factor (Jakarta: Ministry of Energy and Mineral Resources) (in Bahasa Indonesia)

[14] National Standardization Agency of Indonesia 2005 Tata cara perencanaan sistem plambing (Jakarta: Badan Standardisasi Nasional Indonesia)

[15] Agus F, Santosa I, Dewi S, Setyanto P, Thamrin S, Wulan Y C, Suryaningrum F 2013 Pedoman Teknis Penghitungan Baseline Emisi dan Serapan Gas Rumah Kaca Sektor Berbasis Lahan: Buku I Landasan Ilmiah (Jakarta: Badan Perencanaan Pembangunan Nasional, Republik Indonesia)

[16] EPA 2017 Water Efficiency Management Guide Bathroom Suite EPA 832-F-17-016d

[17] Kenway S J, Priestley A, Cook S, Seo S, Inman M and Gregory A 2008 Energy Use in the Provision and Consumption of Urban Water in Australia and New Zealand (CSIRO: Water for a Healthy Country National Research Flagship)

Acknowledgments
This work was funded through the Grant PITTA B (contract number: NKB-0755/UN2.R3.1/HKP.05.00/2019) from the Directorate of Research and Community Service University of Indonesia.