Estimation of household greenhouse gas emissions from different activities in Bintang Alam, Karawang Regency, Indonesia

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Abstract. Since the Sustainable Development Goals (SDG’s) declaration in 2015, nations have attempted to meet the 17 goals, one of which is addressing climate change. In this respect, current conditions have brought forth a significant challenge to the environment, global economy, and human health. This study aimed to analyze greenhouse gasses from household activities in the Bintang Alam housing complex, Indonesia. Data on waste were collected based on Indonesia National Standard 19.3964.1994, while data on fuel consumption from waste transportation to landfills were collected through interviews. Data on household consumption of water and electricity as well as demographics were gathered using questionnaires. The waste reduction model and the IPCC (Intergovernmental Panel on Climate Change) method were used in the estimation. Results showed that solid waste management, wastewater management, clean water production, and electricity consumption resulted in emissions of 1,634.26; 89.13; 381.24, and 4,122.87 tons CO₂/year, respectively. The total GHG emissions were 6,227.5 ton CO₂/year or an equivalent of 4,151.6 ton CO₂/household/year or 1,149.60 ton CO₂/person/year. To reduce GHG emissions, electricity-saving through behavioral changes, a shift to energy-saving household appliances and waste management through recycling and composting should be encouraged. If these practices were applied, GHG emissions in the study site would decline to 1,619.15 ton CO₂/year, accounting for a 26% reduction in total current emissions.

1. Introduction
Since the Sustainable Development Goals declaration in 2015, nations have endeavored to satisfy the 17 goals related to climate change. Climate change has caused significant challenges to the environment, global economy, and human health [1], with some studies reporting that it has contributed to temperature rises, rain, and ice melting in the North Pole [2][3].

The increase in the earth’s temperature has also been experienced in Indonesia [2][4], where the rise of greenhouse gas (GHG) emissions have led to a more considerable amount of warm waves reflected by the earth and absorbed by the atmosphere [5]. The total GHG emissions in Indonesia reaches 1,154,126 Gg CO₂/year in 2017 [6]. Multiple human activities, such as those carried out in the industrial sector, households, or commercial events, emit GHGs [7]. Therefore, a necessary task is to identify activities associated with GHG generators so that priority-of-scale measures to mitigate these can be put into practice. This identification is correlated with Indonesia’s commitment to reduce GHG emissions, with the country targeting a reduction totaling 26% to 41% under international aid [8]. The problem is that studies on GHG emissions at the Indonesian household level and types of activities remain considerably limited [9][10][11][12][13][14][15].
Accordingly, the current research analyzed the GHGs emitted from household activities, such as waste management, grey and black water management, drinking water consumption, and electricity use. The sample consisted of households in the Bintang Alam housing complex located in Telukjambe village, a sub-district of East Telukjambe in Karawang Regency, Indonesia. Bintang Alam has a population of 5,500 or 1,500 households, who have an average income of Rp 5,000,000 (US$1 = Rp14,800 in 2020 [16]). The housing complex is close to Citarum River (around 200 m); thus, various pollutants discharged into the water body are expected to affect the river’s water quality. This study also formulated recommendations regarding the mitigation of emission practices, policymaking to convert the area into a sustainable model zone.

2. Methods

2.1. Data collection
Data on waste composition were collected based on Indonesia National Standard 19.3964.1994. Data on fuel consumption from waste transportation by truck to landfills were acquired through interviews. The consumption of water supplied through local government-metered providers (PDAM in Bahasa Indonesia), monthly household electricity consumption, and demographic data on the residents were determined using questionnaires. Fifty questionnaires were distributed randomly to the sampled households.

2.2. GHG emissions
GHG emissions in solid waste management, grey and black water management, drinking water production, and electricity sectors were estimated. Emissions from landfill waste disposal were estimated using the WARM model [17][18]. GHG emissions from non-transported waste were estimated using equation (1):

\[
Emisi \, CO_2 = (W \times EF_{CO_2})
\]

Where, \( W \) is the weight of solid waste (ton/year), and \( EF_{CO_2} \) refers to the emission factor of \( CO_2 \) (MTCO\textsubscript{2}/ton). The emission factors considered in the study are presented in Table 1.

The GHG emissions generated by wastewater management were emissions from black water and grey water management. The emissions from such management were estimated using an IPCC-generated method. The difference in GHG emissions from black water and grey water depends on BOD (biochemical oxygen demand) per capita in wastewater (Table 2). The GHGs emitted from wastewater management were \( CH_4 \) and \( N_2O \), for which emission levels were estimated via equations (2) to (6):

\[
TOW = P \cdot BOD \cdot 0.001 \cdot I \cdot 365
\]

Where, \( TOW \) is the total organic liquid waste in annual inventory (kg BOD/year), \( P \) denotes the population of a country of interest concerning annual inventory (person), \( BOD \) refers to the BOD per capita (g/person/day), 0.001 is the conversion from gram BOD to kilogram BOD, and \( I \) pertains to the correction factor as an added BOD variable from industry to sewer systems (assigned a value of 1.25 for collected waste and 1.00 for uncollected waste).
Table 1. Emission factors for estimating GHG emissions from uncollected waste

| Material                    | Emission factor (MTCO₂e/ton) |
|-----------------------------|-------------------------------|
| Mixed paper                 | 1.33                          |
| Food waste                  | 1.9                           |
| Polystyrene                 | 0.02                          |
| Mixed plastics              | 0.02                          |
| Mixed metals                | 0.02                          |
| Glass                       | 0.02                          |
| Tires                       | 0.02                          |
| Mixed municipal solid waste | 1.27                          |

Source: US Environmental Protection Agency (US EPA) 2019[18]

Table 2. BOD per capita in black water and gray water

|                  | Black water | Gray water |
|------------------|-------------|------------|
| BOD (g/person/day) |             |            |
| 13[19]           | 27[19]      |
| 10.5 [20]        | 4.24 [21]   |
| 31.1 [22]        | 8.7 [22]    |

\[
EF_j = B_o \cdot MCF_j
\] (3)

Where, \( EF_j \) denotes an emission factor (kg CH₄/kg BOD), \( B_o \) is the maximum CH₄-producing capacity (kg CH₄/kg BOD), and \( MCF_j \) represents the methane correction factor (fraction).

\[
CH_4 \text{ Emissions} = \left[ \sum_{i,j} \left( U_i \cdot T_{i,j} \cdot EF_j \right) \right] (TOW - S) - R
\] (4)

Where, \( S \) refers to the organic component removed as sludge in an inventory year (kg BOD/year), \( U_i \) is the fraction of a population by income group in an inventory year, \( T_{i,j} \) indicates the degree to which a process/flowchart or system \( j \) is used for fraction \( i \), \( i \) represents the income groups to which residents belong, \( j \) is each process/system, \( EF_j \) pertains to an emission factor (kg CH₄/kg BOD), and \( R \) is the amount of CH₄ recovered in annual inventory (kg CH₄/year).

\[
N_{EFFLUENT} = (P \cdot Protein \cdot F_{NPR} \cdot F_{NON-CON} \cdot F_{IND-COM}) - N_{SLUDGE}
\] (5)

Where, \( N_{EFFLUENT} \) is the total annual amount of nitrogen in effluent wastewater (kg N/year), \( P \) denotes the total population, \( Protein \) refers to the total annual protein consumption per capita (kg/person/year), \( F_{NPR} \) represents the nitrogen fraction in protein (default = 0.16, kg N/kg protein), \( F_{NON-CON} \) is the factor for non-consumed protein added to wastewater, \( F_{IND-COM} \) stands for the factor for industrial and commercial co-discharge protein in a sewer system (default value = 1.25), and \( N_{SLUDGE} \) is the nitrogen removed from sludge (default = 0, kg N/year).

\[
N_2O \text{ emissions} = N_{EFFLUENT} \cdot EF_{EFFLUENT} \cdot 44/28
\] (6)
Where, $N_{\text{EFFLUENT}}$ is the nitrogen in effluent disposed to aquatic environments (kg N/year), $EF_{\text{EFFLUENT}}$ is the emission factor for N$_2$O (kg N$_2$O-N/kg), and 44/28 is the conversion factor from kgN$_2$O-N to kg N$_2$O.

The GHG emissions related to water were emissions from clean water consumption from PDAMs and those from groundwater. Emissions based on groundwater consumption for daily activities were derived from the consumption of electricity that powers water pumps. The estimation of GHG emissions from groundwater consumption was combined with that of emissions from electricity consumption for the pumps. The GHG emissions produced by the consumption of PDAM water were estimated using an emission factor method with the emission factor of 0.49 kg CO$_2$/m$^3$ water [23].

$$E_w = \text{Water consumption} \times \text{emission factor}$$ (7)

The GHG emissions from electricity consumption were estimated using equation (8) with the emission factor of 0.862 kg CO$_2$/kWh).

$$E_e = C_e \times EF_e$$ (8)

Where, $E_e$ represents the GHG emissions from electricity consumption (kg CO$_2$/month), $C_e$ is the total electricity consumption (kWh/month), and $EF_e$ is the electricity emission factor (kg CO$_2$/kWh).

3. Results and discussion

3.1. Household solid waste and wastewater generation, water and electricity consumption

The organic waste accounted for an average of 72.44% out of the total solid waste generated (Figure 1) which was mostly food waste. The second-largest category was paper, which accounted for 7.71% of the total and weighed an average of 4.91 kg. Paper/card waste was composed mostly of packaging materials, such as duplex and cardboard. The third-largest waste category was plastic which accounted for 5.93% of the total waste generated and weighed an average of 4.11 kg. This type of waste was composed primarily of transparent and colored plastic shopping bags. The cost of PDAM water and electricity consumptions per month was converted into monthly PDAM cubic meter and electricity usage in Table 3.

| Category                | Household category |
|-------------------------|--------------------|
|                         | Min   | Average | Max   |
| Electricity consumption | 12.3  | 52.3    | 76.4  |
| (kWh/person/month)      |       |         |       |
| PDAM water consumption  | 5.1   | 14.7    | 28.3  |
| (m$^3$/person/month)    |       |         |       |
3.2. GHG emissions

The GHG emissions in the study site are summarized in Table 4. The results on electricity-induced GHG emissions were in line with previous study that among all the energy sectors in the country, the electrical power sector had been the most significant contributor to emissions hence managing the electricity consumption can become a priority for reducing the GHG emissions [6].

Table 4. Summary of GHG emissions in Bintang Alam

| Description                          | Total emissions (ton CO₂e/year) | Total emissions (kg CO₂e/person/year) | Percentage (%) |
|--------------------------------------|-------------------------------|--------------------------------------|----------------|
| Emissions from collected waste       | 1,552.74                      | 297.14                               | 26.2           |
| Emissions from uncollected waste     | 81.53                         |                                      |                |
| CH₄ emission from black water        | 7.58                          |                                      |                |
| CH₄ emission from gray water         | 5.69                          | 16.21                                | 1.4            |
| N₂O emission from wastewater         | 75.86                         |                                      |                |
| Drinking water                       | 381.24                        | 86.64                                | 6.1            |
| Electricity                          | 4,122.87                      | 749.61                               | 66.2           |
| Total                                | 6,227.50                      | 1,149.60                             |                |

A previous GHG study on waste management in Indonesia has been done in Surabaya, and Depok showed that emissions in a residential area amount to 219.83 and 58.64 kg CO₂e/person/year, respectively, than the levels found in the present study [10]. Compared with other cities in Indonesia, Surabaya and Depok have more advanced solid waste management, including composting and anaerobic digester. Another study found that GHG emissions in India amount to 102.94 kg CO₂e/person/year [11], which is much lower than that found by the current research in Bintang Alam. This difference is ascribed to the fact that India generates less solid waste than does the housing complex investigated in the current work.

GHG emissions from domestic wastewater management throughout Indonesia reached 51.08 kg CO₂e/person/year, which is higher than the values measured in the present study [24]. Because the study
considered the entire domestic wastewater treatment system, it was able to determine that the GHG emissions from septic tanks and black and gray water management account for 31.7% of the total emissions from domestic wastewater management.

GHG emissions in Iran showed wastewater treatment-induced emissions of 61.7 kg CO$_2$/person/year, which exceeds the values determined in the present work [13]. This difference is attributed to the higher protein consumption level in the current study. A study related to GHG emissions from energy consumption in Pekanbaru, Indonesia at 550 kWh/month is 4.54 ton CO$_2$/household/year [12]. Under the assumption that one family consists of four members, the emissions generated from energy consumption in Bintang Alam would be 2.99 ton CO$_2$/family/year at an average electricity consumption of 290 kWh/family/month. An investigation similar to the current study has been done in the regency of Semarang, Indonesia and determined an emission of 0.117 ton CO$_2$/house/month, which is equivalent to 1.404 ton CO$_2$/house/year; the average electricity consumption in Semarang regency is 200 kWh/house/month [15]. The difference in emissions was due to average electricity consumption, among other factors.

4. Conclusion
The total GHG contribution of Bintang Alam in Karawang, Indonesia, was 6,227.50 ton CO$_2$/year. The most significant contributor to GHG emissions was the electricity/energy sector, followed by the solid waste management sector. GHG emissions should be reduced by saving on electricity consumption as well as managing waste through recycling and composting practices. If these two practices were exercised, GHG emissions would decline to 1,619.15 ton CO$_2$/year, which was equivalent to a 26% reduction in total current emissions. The targeted reduction of 26% was based on Indonesia’s pledge to decrease GHG emissions, as expressed in the Indonesia National Action Plan for GHG reduction.

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