Estimation of greenhouse gas emission from household activities during the COVID-19 pandemic in Binjai City, North Sumatera

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Abstract. Household activities have the potential to produce greenhouse gas emissions. The government’s policy to work and study from home during the COVID-19 pandemic affects greenhouse gas emissions produced by household activities, starting from energy and waste and liquid waste produced, so it is necessary to carry out an emission inventory. The purpose of this study is to calculate greenhouse gas emissions (CO₂ and CH₄) from household activities in Binjai City during the COVID-19 pandemic and determine emission reduction scenarios that can be carried out in Binjai City. The calculation method used is based on the 2006 IPCC (Intergovernmental Panel on Climate Change) guidelines. CO₂ emissions resulting from the use of LPG are 2025.80 tons CO₂e/month, the use of fuel for daily transportation activities is 3484.84 tons CO₂e/month, and electricity usage is 14956.66 Ton CO₂e/month. CH₄ emissions produced from domestic liquid waste are 417.14 tons CO₂e/month, and household waste is 27.54 tons CO₂e/month. The COVID-19 pandemic increases GHG emissions from household electricity consumption in Binjai City by ± 7% and reduces GHG emissions from fuel consumption by 3.5%.

1. Introduction

WHO declares that Coronavirus Disease (COVID-19) is a pandemic [1] with one of the transmissions of this virus through the air in specific spaces. With the massive spread of COVID-19 with virus variants that continue to grow and have a fatal impact on humans, one of the policies taken by several countries, including Indonesia, is to limit activities indoors so that most activities are carried out from home.

Community activities, mostly carried out at home, such as studying from home and working from home, certainly influence energy consumption and waste generated during the COVID-19 pandemic. Changes in the use of household-scale energy consumption will have an impact on the greenhouse gases produced. Several research results related to greenhouse gas emissions during the COVID-19 pandemic, such as in China by Qingqing et al. [2], showed a decrease in CO₂ emissions in the industrial sector (1.6 – 9.8%); transportation sector (down 62%), and construction sector (down 23.9%).

Meanwhile, research results from Zhiu L et al. [3] stated that the effect of the COVID-19 pandemic on global CO₂ emissions based on satellite observations decreased by 1.6 Gt. Some sectors do experience a decrease in GHG emissions, but all activities in the home will increase GHG emissions...
from household consumption. It can be seen from the results of research by SEAI [4] in Ireland, emissions in housing have increased by 9% (0.6 Mt CO$_2$e) in Ireland. 2020 due to an increase in working and studying at home.

Greenhouse gas (GHG) is a phenomenon that has become an international issue and directly affects human life. GHG is produced from various human activities, one of which is household activities [5]. Presidential Regulation of the Republic of Indonesia Number 71 of 2001 concerning the Implementation of the National Greenhouse Gas Inventory states that the GHG inventory is an activity to obtain data and information regarding the level, status, and trend of periodic changes in GHG emissions from various emission sources [6].

Household activities are a source of GHG emissions from the energy sector in the form of the use of fossil fuels for cooking, daily transportation, and the use of electricity for electronic devices that have the potential to produce carbon dioxide (CO$_2$) emissions [7]. In addition to the use of energy in household activities, household waste such as domestic liquid waste and household waste is also a source of GHG emissions that can produce CH$_4$ gas emissions [8]. According to Ministry of the Environment 2012, carbon dioxide (CO$_2$) contributes 77% of the total GHG and is expected to increase 0.3-2% per year, while methane emissions are expected to increase 20% from 2005 to 2020 [9].

One of North Sumatra Province, which is close to the provincial capital, is Binjai City. By the mandate of the PP, the population density that continues to increase with various household activities will directly affect the GHG emissions produced. This research was conducted following PP No. 71 of 2011 concerning the Implementation of the National Greenhouse Gas Emission Inventory, which states that every district/city government is required to carry out GHG inventory activities where the research results can be used as a reference for calculating GHG emissions in Binjai City using the 2006 IPCC (Intergovernmental Panel on Climate Change) method [10]. The purpose of this study is to calculate greenhouse gas emissions (CO$_2$ and CH$_4$) generated from household activities during the COVID-19 pandemic in Binjai City.

2. Methodology
This research method uses quantitative methods. This study begins by determining the number of samples, testing the validity and reliability of the questionnaire, distributing questionnaires, analyzing questionnaire data, calculating GHG emissions from household energy consumption, domestic solid waste, and domestic wastewater using the IPCC Tier 1 and Tier 2 methods.

2.1. Location of study
The study was conducted during the COVID-19 pandemic, namely June - August 2020 in Binjai City. Binjai City is an urban area with an area of 90.23 km$^2$ with a population of 276,957 people. The population density reaches 3,065 people/km$^2$ [11]. Determination of the number of samples using the Slovin method to obtain a sample of 397 respondents with a sample distribution per district can be seen in Table 1.

| No. | Sub District | Number of Household | Number of Sample |
|-----|--------------|---------------------|-----------------|
| 1.  | Binjai Utara | 18.299              | 114             |
| 2.  | Binjai Timur| 13.980              | 88              |
| 3.  | Binjai Selatan | 12.381            | 77              |
| 4.  | Binjai Barat | 10.950              | 68              |
| 5.  | Binjai Kota | 7.869               | 50              |
| Total |              | 63.479              | 397             |

Source: [11]

2.2. Data collection
The primary data used in this research is a questionnaire. The questions asked in the questionnaire are general questions related to personal data such as gender, occupation, income, and the number of family
members. Specific questions related to GHG emissions are calculated, such as energy-related to the amount and cost of electricity usage per month by the respondent, the use of fuel for cooking, and vehicles by the respondent—Meanwhile, questions related to waste and wastewater, especially the waste and wastewater treatment in households.

The questionnaire distribution was carried out online through the google form and offline (direct observation) to the residents of Binjai City as respondents. The secondary data used in this study are data on the population of Binjai City from the Central Statistics Agency (BPS) of Binjai City in 2020 [11], data on waste generation and composition in Binjai City, BOD value data for Binjai City wastewater, and default data from the Intergovernmental Panel on Climate Change (IPCC) 2006.

2.3. Questionnaire validity and reliability test
A validity test is helpful to find out whether the questionnaire distributed is valid or valid from the correlation value obtained. A reliability test was conducted to determine the consistency of respondents' answers. To test the validity and reliability of the questionnaire distributed, 40 respondents are considered to have represented the number of respondents. Validity and reliability tests were carried out using a statistical approach using SPSS 25. Validity and reliability tests were carried out on 25 questions. The research questionnaire is declared valid if the total correlation value for each question is 0.3 and reliable if the value is 0.7.

2.4. CO₂ emission calculation
The calculation of CO₂ emissions in this study uses the IPCC method and is the same as the calculations carried out by researchers for the case study in Medan City [19]. The difference between this research and the research in Medan City is in addition to the difference in location and the condition of this research being carried out during the COVID-19 pandemic. The calculation of CO₂ emissions includes the use of LPG for cooking, the use of fuel for transportation, and the use of daily electricity. The data obtained from the respondents become input data for calculating CO₂ emissions with equation 2.1 to calculate CO₂ emissions from the use of LPG, equation 2.2 to calculate CO₂ emissions from the use of fuel for vehicles, and equation 2.3 to calculate secondary emissions from household-scale electricity use.

\[
\text{Emission CO}_2 \text{ primary (P}_\text{ey}) = EF \times F_{cy} \times NCV \times LPG \tag{2.1}
\]

Where \( \text{CO}_2 \) emission of LPG use in tons of \( \text{CO}_2 \) eq/month; \( F_{cy} \) is fuel consumed (Kg/month); \( EF \) is emission factor (63,100 Tj/Kg) and \( NCV \) is Net Calorific Volume (47.3 x 10⁻⁶ Tj/Kg).

Equation 2.2 is used to calculate \( \text{CO}_2 \) generated from the use of fuel for vehicles.

\[
\text{Emission of } \text{CO}_2 = \text{Number of vehicle} \times \text{Fuel Consumption} \times \text{FE} \times \frac{\text{CO}_2}{L} \tag{2.2}
\]

Where \( \text{CO}_2 \) emissions from fuel use are in units of Ton \( \text{CO}_2 \) eq/month; Fuel consumption in km/l and \( FE \) is the emission factor of 2.33 Kg \( \text{CO}_2 \)/liter. The fuel consumption used in this study is calculated based on the average fuel consumption per mileage, namely: motorcycles 21.5 km/liter gasoline and cars 7.8 km/liter gasoline.

Electricity consumption for household scale can be calculated by equation 2.3.

\[
\text{Emission CO}_2 \text{ secondary} = \text{EF} \times \text{Electricity Consumption (KWh)} \tag{2.3}
\]

Where \( \text{CO}_2 \) emissions from electricity use are in units of Ton \( \text{CO}_2 \) eq/month; \( EF \) is the emission factor of 0.89 Ton \( \text{CO}_2 \)/MWh.

2.5. \( \text{CH}_4 \) emission calculations
Calculation of \( \text{CH}_4 \) emissions in this study refers to the IPCC (2006). The scope of \( \text{CH}_4 \) calculated in this study comes from domestic wastewater and waste sources in Binjai City. The equation used for \( \text{CH}_4 \) emissions from domestic wastewater is in equation 2.4.

\[
\text{CH}_4 \text{ Emission} = \sum_{ij} \left( U_i \times T_{ij} \times EF_j \right) \times \left( TOW - S \right) - R \tag{2.4}
\]
Where are CH$_4$ emissions is CH$_4$ emissions generated in the inventory year (Kg CH$_4$/year); TOW is total organic wastewater in inventory year (Kg BOD/year); S is organic components taken as sludge in the inventory year (Kg BOD/year); $U_i$ is the fraction of the population in the income group $i$ in the inventory year; $T_{ij}$ is degree of utilization from drains or treatment/disposal system $j$ for each fraction of income group $i$ in the inventory year; $i$ is income group (rural, high-income urban, low-income urban); $j$ is each channel/processing system; $EF_j$ is emission factor Kg CH$_4$/Kg BOD and $R$ is amount of recovery of CH$_4$ in inventory year Kg CH$_4$/year.

The method for calculating the amount of CH$_4$ gas emissions in waste is the First Order Decay (FOD) method (IPCC, 2006). CH$_4$ emissions from household waste can be calculated using equation (2.5).

$$CH_4 \text{ Emission} = \sum_x \text{Waste generation CH}_4 \times \left(1 - OX_T\right)$$

Where the CH$_4$ is CH$_4$ emissions emitted in year $T$ (Gg); $T$ is inventory year; $x$ is waste category or type/material, $R_T = CH_4$ recovered in year $T$ (Gg) and $OX_T$ = oxidation factor in year $T$ (Fraction). In this study, the unit used is Ton CO$_2$e. The calculation results of CO$_2$ and CH$_4$ emissions are multiplied by the value of GWP (Global Warming Potential), where the GWP for CO$_2$ is 1 and the GWP for CH$_4$ is 25. The calculation results in units of Ton CO$_2$e/year.

3. Result and discussion

3.1. CO$_2$ emissions from household energy consumption

Based on the results of data processing from the questionnaire using the IPCC method, the obtained CO$_2$ emissions from energy consumption (primary energy from the use of LPG and fuel for transportation and secondary energy from electricity use) in Binjai City can be seen in Table 2.

Table 2. CO$_2$ emissions for household scale energy consumption in Binjai city.

| No | Sub District      | Number of Household | CO$_2$ Emission Primary (Ton CO$_2$eq/Month) | CO$_2$ Emission Secondary (Ton CO$_2$eq/Month) | Total Emission (Ton CO$_2$eq/Month) |
|----|-------------------|---------------------|---------------------------------------------|-----------------------------------------------|--------------------------------------|
|    |                   |                     | LPG                                        | Fuel Consumption                              |                                     |
| 1  | Binjai Utara     | 18299               | 604.95                                     | 769.80                                       | 4856.55                             |
| 2  | Binjai Timur     | 13980               | 459.49                                     | 790.87                                       | 3102.82                             |
| 3  | Binjai Selatan   | 12381               | 393.24                                     | 592.37                                       | 3039.60                             |
| 4  | Binjai Barat     | 10950               | 325.76                                     | 346.29                                       | 2076.12                             |
| 5  | Binjai Kota      | 7869                | 242.36                                     | 985.51                                       | 1881.57                             |
|    | Total            | 63479               | 2025.80                                    | 3484.84                                      | 14956.66                            |

Table 2 presents the calculation of CO$_2$ emissions from the use of LPG in Binjai City of 2025.80 tons CO$_2$e/month with an average emission produced by each household of 0.032 tons CO$_2$e/month. When compared to each sub-district, Binjai Utara District produces the most significant CO$_2$ emissions using LPG, 604.95 tons CO$_2$e/month. Factors that affect the amount of CO$_2$ emissions are fuel consumption, the number of households, and the area. Binjai Utara District produces the most significant CO$_2$ emissions because the average total LPG consumption reaches 11.03 Kg/month and has the most significant number of households and the largest area in Binjai City [12].

The calculation of CO$_2$ emissions from fuel use in Binjai City is 3484.84 tons CO$_2$e/month, with an average emission produced by each household of 0.062 tons CO$_2$e/month. Compared to each sub-district, Binjai Utara District produces CO$_2$ emissions from the most prominent use of fuel, which is 985.51 Ton CO$_2$e/month. The factor that affects CO$_2$ emissions is the average mileage, where the more significant the average mileage, the greater the fuel consumption. The average distance traveled by residents of Binjai Kota Sub-district is 13.78 km/day and has higher outdoor activities than other sub-districts in Binjai City [13].
Household electricity consumption in Binjai City produces CO\textsubscript{2} emissions of 14956.67 tons CO\textsubscript{2}e/month, with an average CO\textsubscript{2} emission produced by each household of 0.236 tons CO\textsubscript{2}/month. When compared to each sub-district, Binjai Utara District produces the most significant CO\textsubscript{2} emissions using electricity, 4856.55 tons CO\textsubscript{2}e/month. Factors that affect the value of electricity consumption are the length of use of electronic devices and the number of households in an area [14]. North Binjai District is the sub-district with the most significant number of households and the most prominent electricity usage in Binjai City.

From the calculation results, the total CO\textsubscript{2} emissions in Binjai City are 20467.30 tons CO\textsubscript{2}e/month. The activity that produces the most CO\textsubscript{2} emissions is household electricity consumption, 14956.66 tons CO\textsubscript{2}e/month. Binjai Utara sub-district is the sub-district that produces the most significant total emission of 6231.30 ton CO\textsubscript{2}e/month. The average CO\textsubscript{2} emission produced by each household in Binjai City is 0.322 ton CO\textsubscript{2}eq. The main factors that influence the most significant total CO\textsubscript{2} emissions are the total consumption of each energy and the number of households in the study area [15]. Binjai Utara District produces the most significant total CO\textsubscript{2} emissions compared to the other four sub-districts. The number of households and total energy consumption in Binjai Utara is the highest compared to other sub-districts.

3.2. CH\textsubscript{4} emissions from domestic wastewater

Domestic waste treatment in Binjai City is categorized as untreated and directly discharged into receiving water bodies. The most dominant type of greenhouse gas emissions generated from domestic waste on a household scale is CH\textsubscript{4}. The results of the calculation of CH\textsubscript{4} emissions from the domestic liquid waste of Binjai City can be seen in Table 3.

| No | Sub District   | Population (Household) | CH\textsubscript{4} Emission/ (kg CH\textsubscript{4}/month) | CH\textsubscript{4} Emission (Ton CO\textsubscript{2}eq) |
|----|----------------|------------------------|------------------------------------------------------------|-------------------------------------------------|
| 1  | Binjai Utara   | 18299                  | 4809.99                                                   | 120.25                                          |
| 2  | Binjai Timur   | 13980                  | 3674.72                                                   | 91.87                                           |
| 3  | Binjai Selatan | 12381                  | 3254.41                                                   | 81.36                                           |
| 4  | Binjai Barat   | 10950                  | 2878.26                                                   | 71.96                                           |
| 5  | Binjai Kota    | 7869                   | 2068.41                                                   | 51.71                                           |
| **Total** |                   | **63.479**            | **16685.78**                                               | **417.14**                                     |

Table 3 shows the calculation results of CH\textsubscript{4} emissions generated from domestic liquid waste in Binjai City of 417.14 Ton CO\textsubscript{2}eq. Based on the calculation of CH\textsubscript{4} emissions produced by each household from domestic liquid waste in Binjai City, it is 0.006 Ton CO\textsubscript{2}eq CH\textsubscript{4} emissions from the waste sector are related to population and human activities. North Binjai District is the sub-district with the largest population in Binjai City and produces CH\textsubscript{4} emissions from domestic liquid waste, which is 120.25 tons CO\textsubscript{2}eq/month or 29% of the total CH\textsubscript{4} emissions from domestic wastewater in Binjai City. The increase in population also increases CH\textsubscript{4} emissions resulting from domestic liquid waste, where an increase in population will also be followed by an increase in water use so that the waste produced is also more significant [16].

3.3. CH\textsubscript{4} emissions from household waste

To calculate the amount of GHG emissions generated from household waste in Binjai City, it is necessary to know the type of waste handling carried out in Binjai City. To calculate CH\textsubscript{4} emissions from each type, see Figure 1.
There are four ways to handle the waste carried out by respondents in Binjai City: transported by cleaners, disposed of at the Transport Processing Site (TPS), burned, and thrown into the river. Based on the questionnaire results, the percentage of respondents whose waste was transported by janitors was 54%, and 24% of those who disposed of their waste directly to the TPS. The waste transported and disposed of to the TPS will then be transported to the Final Processing Site (TPA) in Binjai City. In addition, 22% of respondents in Binjai City burn waste, and as many as 0% of respondents throw garbage directly into the river. The calculation of CH$_4$ emissions from household waste in this study was carried out based on the amount of waste generated in Binjai City and the handling of community waste in Binjai City, which was transported and disposed of to the TPS for further transportation to the TPA. Based on the questionnaire results, the percentage of Binjai City waste transported to the TPA is 77%, and the rest is burned. The amount of waste generated in Binjai City based on previous research [17] is 0.17 kg/p/day. The CH$_4$ emissions from household waste processing in Binjai City are 1,101 tons of CH4 or equivalent to 27,536 tons of CO$_2$eq, where the CH$_4$ emissions produced in Binjai City are relatively low. Factors that affect CH$_4$ emissions are composition, waste treatment system, and waste generation [18].

3.4. Total GHG emissions from household activities in Binjai City during the COVID-19 pandemic

Inventory of GHG emissions from household activities during the COVID-19 pandemic in Binjai City obtained the highest GHG emissions from the domestic liquid waste sector. It happened because, in Binjai City, there was no centralized wastewater treatment. The percentage contribution of each GHG emission source from household activities in Binjai City during the COVID-19 pandemic can be seen in Figure 2.
Based on Figure 2, household activities that contribute the most to GHG emissions in Binjai City from electricity consumption are 71.52% (14,956.67 Ton CO\textsubscript{2}eq/month). Meanwhile, a minuscule contribution came from the household waste of 0.13% (27.54 Ton CO\textsubscript{2}eq/month). The contribution of electricity use is more significant than from other sectors because the research was carried out during the COVID-19 pandemic where all dominant activities mainly were at home, such as using the Zoom meeting application, Google Meet to work, and study from home.

The results of this study are in line with research by Suryati [19], who found that the highest household-scale GHG emissions in Medan City were sourced from energy consumption in the form of LPG and electricity of 83.11%. Energy consumption from representative regions for Medan City is 0.39 million tons CO\textsubscript{2}eq/year with an average per household producing CO\textsubscript{2} emissions of 2.2 tons CO\textsubscript{2}/year/household while Binjai City produces CO\textsubscript{2} emissions from the average energy consumption per household is 2.8 tons CO\textsubscript{2}/year/household. The average figure produced by the City of Binjai is still relatively low compared to the City of Medan. It is because household-scale GHG emissions are strongly influenced by population, income, and consumption patterns.

3.5. The effect of the covid-19 pandemic on household GHG emissions in Binjai City

The COVID-19 pandemic impacts electricity costs because of the work from home and study from home policies that increase the consumption of electricity consumption in households ranging from 5-10%. The increase in electricity consumption will, of course, also increase the resulting GHG emissions. If the increase in electricity consumption ranges from 5-10% in Binjai City, it will increase GHG emissions by ±7%. The addition of GHG emissions is not too significant because emissions from electricity use include secondary emissions. Meanwhile, according to respondents, the sources of GHG emissions from household activities, such as the use of LPG, had not changed because cooking activities before and during the COVID-19 pandemic remained the same.

An influential source of GHG emissions is the decrease in fuel consumption for transportation considering the policies from the government during the COVID-19 pandemic, ranging from large-scale social restrictions to the imposition of restrictions on community activities. At the research time, the general policy was large-scale social restrictions to reduce fuel consumption for private vehicles, which was reduced by 20-25%. Reducing fuel consumption will undoubtedly reduce GHG emissions. In this study, the reduction of GHG emissions from private vehicle fuel consumption by 3.5%. It happens because the calculation of GHG emissions from vehicle fuel consumption considers the number of liters of fuel consumed and the distance traveled.
This research is like a previous study conducted by the Sustainable Energy Authority of Ireland and Environmental Protection Agency in 2021 [4], where residential sector emissions (mainly home heating) are estimated to have increased by 9% (0.6 Mt CO$_2$e) in 2020 as many people have been working extensively from home. Meanwhile, emissions from the transport sector are estimated to have reduced by over 2 Mt CO$_2$e compared to 2019, a fall of almost 17%.

Meanwhile, the results [20] stated that with the study at home policy, activities on campus were reduced to reduce GHG emissions by 751 tons/year potentially. However, the consequence will certainly be an increase in household energy consumption. According to research [2], China’s fossil fuel CO$_2$ emissions decreased by 18.7% compared to last year, including 12.2% reductions in the industrial sector, 61.9% in transportation, and 23.9% in construction. However, this research does not include the energy used for household activities.

This study indicates that sectors decrease in GHG emissions, such as the industrial sector, transportation. However, some sectors increase, primarily from household energy use.

4. Conclusion

Binjai City CO$_2$ emissions are resulting from household activities during the COVID-19 pandemic (June – August 2020) in the form of LPG use of 2,025.82 tons CO$_2$e/month, from the use of fuel for daily transportation activities of 3,484.85 tons CO$_2$e/month, and electricity usage of 14,956.67 ton CO$_2$e/month. The CH$_4$ emission of Binjai City produced from domestic wastewater is 417.14 tons CO$_2$e/month and from household waste in Binjai City is 27.54 tons CO$_2$e/month. The impact of the COVID-19 pandemic has contributed to increasing GHG emissions in the electricity consumption sector and reducing GHG emissions for fuel consumption due to government policies in reducing the spread of COVID-19.

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