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Original Research Article

Strategic Planning for Reducing Greenhouse Gas Emissions (CO_2, CH_4, and N_2O) from The Transportation, Industry, and Household Sectors in The City of Ungaran, Semarang Regency

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Abstract

Ungaran City, part of the SWP-1 area, is experiencing growth in transportation, industrial, and household sectors, which may increase greenhouse gas (GHG) emissions from energy use. Indonesia has committed to reducing GHG emissions by 29% by 2030 independently, requiring cooperation from regional governments, including Ungaran City. To support this commitment, mitigation actions are needed. This study aims to analyze development programs that potentially increase emissions, conduct an emission inventory, and plan strategies for emission reduction, focusing on transportation, industrial, and household sectors. The methodology applies the 2006 IPCC approach for energy use, using the average Vehicle Kilometer Traveled (VKT) for transportation, fuel consumption estimates for households, and the Industrial Pollution Projection System (IPPS) with worker numbers for the industrial sector. Data analysis was aligned with Indonesia's reduction targets. The results indicate that Ungaran City's development programs will increase GHG emissions, with projections reaching 156.46 Gg CO_2e in 2030. To meet the target, a reduction of 17.21 Gg CO_2e is required. However, current strategies can only reduce 12.35 Gg CO_2e. Therefore, additional programs, such as mandatory substitution of transportation fuels in Semarang Regency, are recommended to bridge the gap and support the 2030 reduction target.

Keywords: energy use sector; greenhouse gases; ungaran city; reduction strategy;

1. Introduction

Urban areas are increasingly recognized as major contributors to greenhouse gas (GHG) emissions due to the concentration of population, transportation activity, and industrial growth. In Indonesia, cities play a critical role in determining the success of national emission reduction targets, as urban energy use sectors particularly transportation, industry, and households account for a substantial share of total emissions (KLH, 2012). Ungaran City, located in Central Java, is one such urban area where rapid development in mobility and economic activities has led to a steady rise in energy consumption and associated emissions. The city functions as a key transit hub in the Semarang Metropolitan Area (SWP-1), making its transportation sector especially dominant in terms of energy use and emission output (Huboyo, Handayani, & Samadikun, 2013).

The challenge facing Ungaran City is how to reconcile the growing demand for energy with the urgent need to reduce GHG emissions in line with Indonesia's national climate commitment. Under the Paris Agreement, Indonesia has pledged to reduce its GHG emissions by 29% below business-as-usual (BAU) levels by 2030 through domestic efforts, and up to 41% with international support (Government of Indonesia, 2016). To achieve this target, cities such as Ungaran must implement effective local mitigation measures, particularly in the energy sector, which remains the largest source of emissions (IPCC, 2006). However, baseline assessments of current emission levels and sectoral contributions are still limited, posing a barrier to formulating evidence-based strategies (BPLHD DKI Jakarta, 2009).

Global warming is a major international concern caused primarily by greenhouse gases (GHGs) such as CO_2, CH_4, and N_2O, which result from the combustion of fossil fuels for human activities. In response, countries have undertaken mitigation efforts under agreements such as the Kyoto Protocol and the Paris Agreement, to which Indonesia is a signatory through Law No. 17 of 2004 and Law No. 16 of 2016. Based on the Greenhouse Gas Inventory Report for Semarang Regency (2013–2017), the energy sector was the largest GHG emitter in 2017, contributing 857,977.62 tons CO_2e (57.26% of total emissions), with transportation accounting for 96.027% of this sector's emissions, followed by manufacturing industries (3.970%) and other uses (0.003%). While CO_2 is the most abundant emission from energy combustion, CH_4 and N_2O exhibit much higher warming potentials and can substantially influence total emissions when expressed in CO_2-equivalent terms (IPCC, 2006). Accurate quantification of these gases is therefore essential to avoid underestimating the climate impact of urban energy use systems. The Intergovernmental Panel on Climate Change (IPCC) has developed standardized methodologies to support consistent and transparent emission inventories, which have been widely adopted in national and regional assessments (IPCC, 2000; IPCC, 2006). As the administrative center, Ungaran City has high emission potential from transportation, industry, and household energy use, making it essential to develop strategic emission reduction plans targeting these sectors.

At the regional level, emission reduction planning requires not only an understanding of current emission levels but also projections based on Business As Usual (BAU) scenarios and an evaluation of feasible mitigation strategies. Studies have shown that urban mitigation efforts are most effective when they target high-emission sectors, such as transportation, promote energy efficiency, encourage fuel switching, and integrate renewable energy technologies (Wilson et al., 2015). However, the absence of local emissions inventories and quantified reduction potentials often limits the effectiveness of policy interventions, especially in medium-sized cities such as Ungaran. Therefore, this study aims to fill this gap by conducting a comprehensive greenhouse gas emission inventory for Ungaran City, focusing on the transportation, industrial, and household sectors within the energy use category. This study was therefore conducted to analyze GHG emissions from the energy use sector in Ungaran City, focusing on transportation, industry, and household activities. Specifically, the objectives were: (1) to quantify baseline emissions from each sector for the period 2016–2020, (2) to project future emissions under a BAU scenario for 2021–2030, and (3) to evaluate potential mitigation strategies and their contribution to meeting national emission reduction targets. The findings are expected to provide scientific evidence that can inform policy interventions at the local level while supporting Indonesia's broader commitment to global climate change mitigation.

2. Methods

2.1 Study Area, Data Collection, and Research Design

This study was conducted in Ungaran City, Semarang Regency, Indonesia, which is included in the SWP-1 development zone and characterized by significant transportation, industrial, and household activities. Data collection was carried out from January to November 2020. The research employed a quantitative approach using both primary and secondary data sources. Primary data were obtained through traffic counts, odometer readings for selected vehicles, and field surveys to identify industrial facilities and household energy usage. Secondary data were collected from government agencies, statistical publications, and related institutions. Greenhouse gas (GHG) emissions were calculated following the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for the Energy sector and the Industrial Pollution Projection System (IPPS) for industrial emissions. For the transportation sector, the VKT method was applied, combining traffic volume data with average travel distances per vehicle type obtained from odometer surveys.

2.2 Greenhouse Gas Emission Inventory Methodology

In order to establish an accurate calculation of greenhouse gas (GHG) emissions originating from the road transport sector, it is crucial to begin with the determination of average fuel economy values for each type of vehicle. Fuel economy is a fundamental parameter because it directly links vehicle activity data, such as the number of vehicles on the road and the average distance traveled, to the amount of fuel consumed. Without this step, estimations of total energy use would remain uncertain and potentially misleading, since each type of vehicle from motorcycles to large trucks has very different energy requirements. Therefore, the selection of reliable fuel economy values ensures that the subsequent stages of emission estimation are both scientifically valid and contextually relevant for conditions in Ungaran City. Fuel consumption was estimated based on VKT values and average fuel economy (*Table 1*).

Table 1. Average Fuel Economy by Vehicle Type

Vechicle Type	Fuel Consumption (L/km)
Motorcycle	0.04
Car	0.06
Small Bus	0.05
Medium Bus	0.13
Large Bus	0.075
Small/Medium Truck	0.125
Large Truck	0.14

Source : Huboyo, Handayani & Samadikun, 2013

Table 1 summarizes the assumed average fuel economy for motorcycles, cars, buses, and trucks, expressed in liters of fuel per kilometer of travel. Motorcycles, which make up the majority of vehicles in Ungaran City, exhibit the lowest per-kilometer fuel consumption, while larger transport modes such as medium and large trucks have significantly higher fuel use per unit distance. These values were adopted from existing studies and surveys and then applied in the calculation of total fuel demand from the transport sector. By multiplying vehicle kilometers traveled (VKT) with the fuel economy values presented in this table, the study was able to estimate the amount of fuel consumed by each category, which in turn served as the input for emission calculations.

Once the amount of fuel consumption was established, the next essential stage in the emission inventory process involved applying standardized emission factors to translate fuel use into carbon dioxide (CO_2) emissions. Emission factors provide a scientifically validated measure of how much CO_2 is released for each unit of fuel combusted, and they differ according to fuel type because of variations in chemical composition and carbon content. By integrating these factors, the study ensures that the resulting CO_2 estimates are comparable with national and international inventories, and it also allows for uncertainty analysis by incorporating upper and lower bound values. This step is especially important in Ungaran City, where multiple fuel types are used, including gasoline, diesel, LPG, kerosene, and natural gas, each contributing differently to overall emissions. Table 2 shows CO_2 emission factors for road transport.

Table 2 presents the CO_2 emission factors that were used to calculate emissions from the transport sector, covering a range of commonly consumed fuels in the city. For each fuel type, three values are reported: the default factor, as well as the lower and upper bounds, which help capture the variability that may arise due to different combustion conditions or measurement uncertainties. For example, gasoline and diesel oil have relatively high CO_2 emission factors, reflecting their carbon intensity, while fuels such as natural gas and LPG generally emit less CO_2 per unit of energy consumed. By applying these factors to the previously estimated fuel consumption data, this study was able to determine total CO_2 emissions from road transport, forming the foundation for a more comprehensive GHG assessment.

Table 2. CO_2 Emission Factors for Road Transport

Fuel Type	Default (kg/TJ)	Lower	Upper
Motor Gasoline	69.300	67.500	73.000
Gas/Diesel Oil	74.100	72.600	74.800
Liquefied Petroleum Gases	63.100	61.600	65.600
Kerosene	71.900	70.800	73.700
Compressed Natural Gas	56.100	54.300	58.300
Liquefied Natural Gas	56.100	54.300	58.300

Source : KLH, 2012

While carbon dioxide is the most abundant greenhouse gas emitted from transportation, it is not the only contributor to climate change. Road vehicles also release smaller amounts of methane (CH_4) and nitrous oxide (N_2O), both of which possess far greater global warming potentials compared to CO_2. CH_4 is often associated with incomplete combustion processes, while N_2O tends to be produced from high-temperature combustion conditions, particularly in engines without advanced emission controls. Even though the absolute quantities of these gases are lower than CO_2, their contribution to overall warming can be disproportionately significant. Therefore, including CH_4 and N_2O in the emission inventory is critical to avoid underestimating the climate impact of the transportation sector in Ungaran City. Table 3 shows CH_4 and N_2O emission factors for road transport sourced from IPCC defaults.

Table 3. CH_4 and N_2O Emission Factors for Road Transport

Fuel Type	CH4 (kg/TJ)			N2O (kg/TJ)		
	Default	Lower	Upper	Default	Lower	Upper
Premium-Uncontrolled (b)	33	9.6	110	3.2	0.96	11
Premium-with Catalyst	25	7.5	86	8.0	2.6	24
Solar/ADO	3.9	1.6	9.5	3.9	1.3	12
Gas Bumi (CNG)	92	50	1540	3	1	77
LPG	62	na	na	0.2	na	na
Ethanol, truck, USA	260	77	880	41	13	123
Ethanol, sedan, Brazil	18	13	84	na	na	na

Source : KLH, 2012

Table 3 provides the emission factors for CH_4 and N_2O associated with different types of fuel used in road transport, expressed in kilograms per terajoule (kg/TJ). These values were taken from the Ministry of Environment (KLH, 2012) and serve as the official references for GHG inventory preparation in Indonesia. The table shows that the emission factors vary depending on the type of fuel, with some fuels producing relatively higher methane or nitrous oxide emissions than others. By integrating these values alongside the CO_2 emission factors, this study was able to calculate total emissions in CO_2-equivalent terms, thereby producing a more complete and scientifically robust picture of the greenhouse gas profile from Ungaran's transport sector.

The industrial sector emissions were estimated using IPPS by multiplying the number of employees in each industrial category with corresponding emission coefficients (*Table 4*). For the household sector, emissions were calculated from fuel consumption for cooking activities, using statistical data on LPG and kerosene distribution and applying stationary combustion emission factors (*Table 5*).

Table 4. Industrial sector IPPS emission factors

SO2	NO2	CO	HC	PM	CO2
18.28	15.64	1.59	1.18	47.56	1.00

Source : BPLH Daerah Provinsi DKI Jakarta, 2009

Table 4 presents the emission factors used for the industrial sector, which were sourced from the Industrial Pollution Projection System (IPPS) developed for Indonesia. These factors provide estimates of pollutant emissions—such as SO_2, NO_2, CO, HC, PM, and CO_2—per unit of industrial activity. The values are essential because they allow the conversion of industrial production data or employment statistics into emission estimates, particularly when direct measurement of emissions is not available. In this study, these emission factors were applied by combining them with statistical data on the number of workers across different industrial categories in Ungaran City, enabling the calculation of sectoral contributions to air pollution and greenhouse gas emissions.

Table 5. Stationary Combustion Emission Factors for Households

Fuel	CO2			CH4			N2O		
	Default FE	Lower	Upper	Default FE	Lower	Upper	Default FE	Lower	Upper
NGL	64.200	58.300	70.400	10	3	30	0.6	0.2	2
Solar/ADO/ HSD	74.100	72.600	74.800	10	3	30	0.6	0.2	2
MFO	77.400	75.500	78.800	10	3	30	0.6	0.2	2
M Tanah	71.900	70.800	73.700	10	3	30	0.6	0.2	2
LPG	63.100	61.600	65.600	5	1.5	15	0.1	0.03	0.3
Natural Gas	56.100	54.300	58.300	5	1.5	15	0.1	0.03	0.3

NGL = Natural Gas Liquids
ADO = Automotive Diesel Oil (Solar)
HSD = High Speed Diesel (Solar)
MFO = Marine Fuel Oil

Source : KLH, 2012

Table 5 shows the stationary combustion emission factors for household energy use, covering CO_2, CH_4, and N_2O emissions from different types of fuels commonly used in residential activities. These include diesel oil (ADO/HSD), marine fuel oil (MFO), kerosene (minyak tanah), LPG, and natural gas, with each factor presented in default, lower, and upper ranges. The inclusion of different bounds reflects the variability in combustion efficiency and technology, which may affect actual emission levels. In the context of this study, these factors were specifically applied to estimate emissions from household cooking activities, since cooking remains the dominant source of household energy use in Ungaran City. By multiplying statistical fuel consumption data with the factors provided in Table 5, the study was able to estimate the contribution of household activities to overall city-wide greenhouse gas emissions.

All emission values were converted into carbon dioxide equivalents (CO_2e) using Global Warming Potential (GWP) factors of 1 for CO_2, 25 for CH_4, and 298 for N_2O (*Table 6*). Data analysis included baseline emission projections for 2021–2030 and the assessment of potential reduction strategies.

Table 6 outlines the Global Warming Potential (GWP) values used to convert non-CO_2 gases into carbon dioxide equivalents (CO_2e), thereby enabling a standardized comparison of their climate impacts. The values adopted in this study follow the KLH (2012) guidelines and assign CO_2 a reference value of 1, while CH_4 is given a GWP of 25 and N_2O a GWP of 298, reflecting their significantly higher warming potential over a 100-year timeframe. These conversion factors are crucial in greenhouse gas inventories because they allow the aggregation of different gases into a single metric—CO_2e—which simplifies reporting and supports policy analysis. In this research, the GWP values from Table 6 were applied after calculating the emissions of CO_2, CH_4, and N_2O separately, ensuring that the final results represent the comprehensive climate impact of Ungaran City's energy use sector.

Table 6. Global Warming Potential (GWP) Factors for CO_2, CH_4, and N_2O

Greenhouse Gases	Emission	GWP
Carbon Dioxide	CO2	1
Methane	CH4	25
Nitrogen Oxides	N2O	298

Source : KLH, 2012

3. Result and Discussion

3.1 Baseline Emissions by Sector

The inventory results show that in 2020, the total greenhouse gas (GHG) emissions from the energy use sector in Ungaran City reached 137.44 Gg CO_2e, dominated by the transportation sector (92.5%), followed by the household sector (4.2%) and the industrial sector (3.3%). The predominance of transportation emissions is attributed to the high vehicle density and the role of Ungaran City as a transit hub in the SWP-1 zone. Figure 1 presents the proportional contributions of each sector to total emissions.

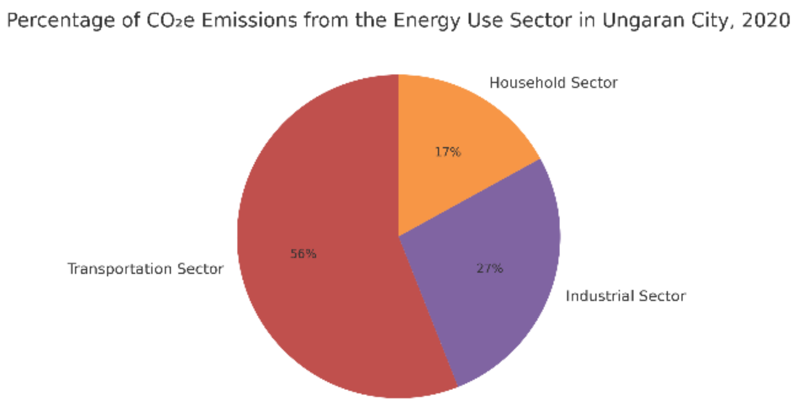

Figure 1. CO2e Emissions by Energy Sector in 2020

To understand the dynamics of greenhouse gas (GHG) emissions in Ungaran City, it is essential to examine the contribution of different energy use sectors over time. Table 7 presents a detailed breakdown of emissions from transportation, industry, and household activities between 2016 and 2020, as well as the total energy-related emissions. This tabulation provides a baseline overview of how sectoral energy consumption has translated into carbon dioxide equivalent (CO_2e) emissions, highlighting changes in emission magnitudes during the five-year period. By disaggregating the data into key economic sectors, the table serves as a critical foundation for analyzing sectoral trends, identifying the dominant contributors, and assessing how urban development patterns have influenced the overall emission trajectory of Ungaran City.

Table 7 provides a summary of the greenhouse gas (GHG) emissions from the energy use sector in Ungaran City over the period 2016 to 2020, disaggregated into transportation, industry, and household categories. The data clearly show an increasing trend in emissions across all sectors, with total energy-related GHG emissions rising from 77.36 Gg CO_2e in 2016 to 102.76 Gg CO_2e in 2020. The dominance of transportation-related emissions reflects the role of Ungaran City as a regional transit hub in the Semarang

Metropolitan Area. Similar patterns have been reported in medium-sized cities in developing countries, where urban expansion and increased demand for mobility have significantly increased fossil fuel consumption (IPCC, 2006; Wilson et al., 2015). The relatively small contribution from the industrial sector is due to the limited availability of large-scale manufacturing facilities within the city limits, whereas household emissions are mainly influenced by cooking fuel consumption, particularly liquefied petroleum gas (LPG).

Table 7. GHG Emissions From the Energy Sector in Ungaran City, 2016–2020

Years	CO2e Emission Prediction (Gg/year)			
	Transportation	Industry	Household	Energy Use
2016	44.15	17.48	15.73	77.36
2017	47.98	21.92	16.16	86.06
2018	51.71	19.62	16.50	87.83
2019	55.37	24.16	17.03	96.55
2020	57.58	27.66	17.53	102.76

3.2 Transportation Sector

Using the Vehicle Kilometers Traveled (VKT) method, transportation emissions in 2020 were calculated at 127.18 Gg CO_2e. Motorcycles contributed the largest share due to their high population and frequency of use, followed by passenger cars and freight vehicles. Historical data from 2016–2020 indicate a steady increase in transport-related emissions, reflecting vehicle population growth. Figure 2 illustrates the growth trend, which aligns with national patterns reported by the Ministry of Environment and Forestry, where road transport remains the single largest GHG contributor within the energy sector.

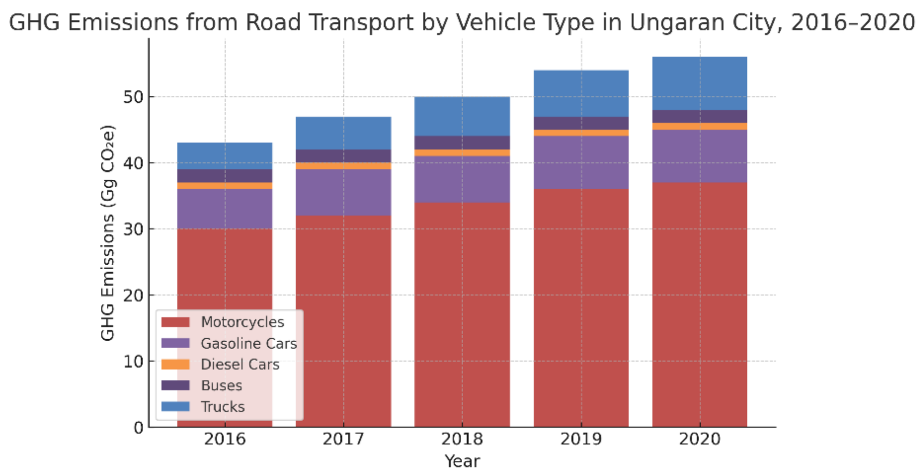

Figure 2. Total Source CO2e Emissions in Ungaran City 2016-2020

Figure 2 illustrates the distribution of greenhouse gas emissions from road transport in Ungaran City between 2016 and 2020, disaggregated by vehicle type. The data clearly show that motorcycles consistently dominate emissions across the five-year period, reflecting their very high population share and frequency of daily use in the city. Passenger vehicles, particularly gasoline cars, represent the second largest contributor, followed by freight vehicles such as trucks and buses. Diesel-powered cars, although fewer in number, also add a steady share to the total emissions. The overall trend displayed in the figure highlights a continuous increase in transport-related emissions during the study period, rising in line with vehicle population growth and intensifying urban mobility demands. This confirms the critical role of the transportation sector as the single largest source of greenhouse gas emissions in Ungaran City's energy sector and underscores the urgency of implementing targeted mitigation strategies such as promoting public transportation, reducing motorcycle dependence, and encouraging cleaner vehicle technologies.

3.3 Industrial Sector

Industrial emissions, estimated using the Industrial Pollution Projection System (IPPS) method, amounted to 4.56 Gg CO_2e in 2020. The food processing and textile industries were the main contributors, reflecting their prevalence in Ungaran's economic profile. The relatively small share compared to transportation is due to the limited number of large-scale facilities within the city. Nevertheless, projected industrial expansion could significantly increase this share by 2030 if no mitigation actions are implemented. Figure 3 shows the breakdown by industrial classification.

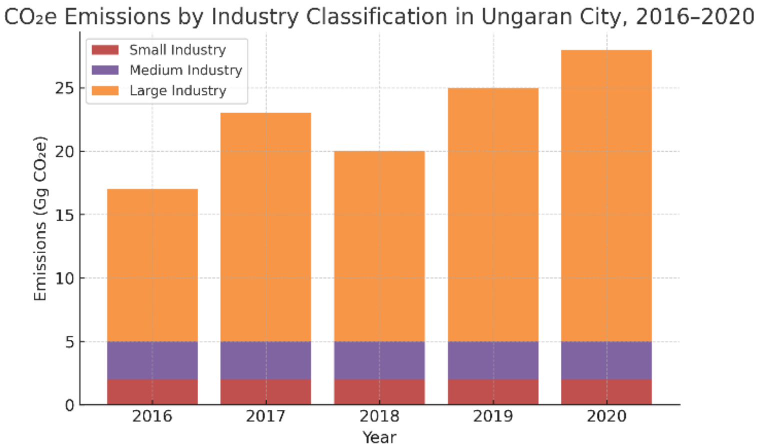

Figure 3. CO2 Emissions Based on Industrial Classification 2016-2020

Figure 3 shows the distribution of greenhouse gas emissions from the industrial sector in Ungaran City over the 2016–2020 period, categorized into small, medium, and large industries. The figure highlights that large industries consistently dominate total industrial emissions, reflecting their higher energy consumption and production capacity compared to smaller enterprises. Medium industries contribute a smaller but steady share, while emissions from small industries remain relatively minor throughout the study period. The overall trend indicates a gradual increase in emissions from 2016 to 2020, with the most notable rise observed in large industries, suggesting the impact of ongoing industrial activity expansion in the city. These results align with Ungaran's economic profile, where food processing and textile industries are prevalent, and demonstrate that while industrial emissions are relatively modest compared to transportation, they represent a growing source of CO_2e that could become more significant in the future if industrial growth continues without mitigation efforts.

3.4 Household Sector

Household emissions, calculated from cooking fuel consumption, were estimated at 5.70 Gg CO_2e in 2020. Liquefied petroleum gas (LPG) dominated fuel use, with minor contributions from kerosene. The emissions profile mirrors urban household energy patterns across Central Java, where LPG subsidies and infrastructure availability have led to widespread adoption. Figure 4 shows the household emissions by sub-district.

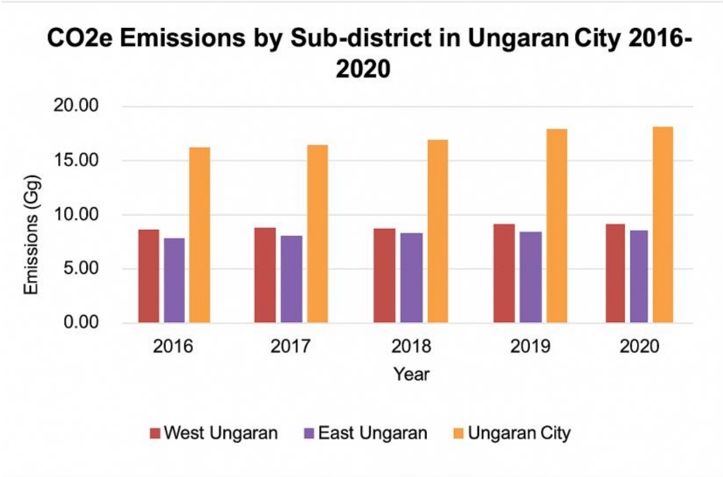

Figure 4. CO2 Emissions by District 2016-2020

Figure 4 illustrates the household sector's CO_2 emissions in Ungaran City from 2016 to 2020, disaggregated by sub-districts: West Ungaran, East Ungaran, and Ungaran City. The chart shows that Ungaran City consistently recorded the highest household emissions during the study period, reflecting its larger population density and greater reliance on liquefied petroleum gas (LPG) as the dominant cooking fuel. West Ungaran and East Ungaran contributed smaller but relatively stable shares of emissions, with only slight variations across the years. The overall trend across all three sub-districts indicates a gradual increase in household emissions, rising from about 14.9 Gg CO_2e in 2016 to around 17.5 Gg CO_2e in 2020. This pattern mirrors broader household energy use in Central Java, where government subsidies and the wide availability of LPG infrastructure have led to its widespread adoption, while kerosene continues to play only a minor role. These findings emphasize that while household emissions are smaller compared to transportation and industry, they remain a steady and growing component of Ungaran's total GHG profile.

3.5 Projection to 2030 and Target Gaps

Business-as-usual (BAU) projections indicate that total energy sector emissions in Ungaran City will reach 156.46 Gg CO_2e by 2030. To meet Indonesia's national target of a 29% reduction relative to BAU, Ungaran must reduce 17.21 Gg CO_2e by 2030. The current planned local mitigation measures are estimated to reduce only 12.34 Gg CO_2e, leaving a gap of 4.87 Gg CO_2e. Table 8 shows the baseline emission projection, and Table 9 summarizes the estimated reduction potential from each sector, showing that total planned measures can reduce 12.34 Gg CO_2e by 2030 equivalent to 72% of the reduction needed to meet the national target, leaving a gap of 4.87 Gg CO_2e.

Table 8 illustrates the projected greenhouse gas emissions from Ungaran City's energy use sector under a business-as-usual (BAU) scenario for the period 2021–2030. The data reveal a consistent upward trend in emissions across transportation, industrial, and household sectors, with the total energy-related emissions expected to rise from 107.12 Gg CO_2e in 2021 to 156.46 Gg CO_2e by 2030. Transportation remains the dominant contributor throughout the projection period, reflecting continued motorization and population growth in the city, while industrial emissions also grow steadily in line with increasing economic activities. Household emissions show a relatively smaller but still notable increase, primarily due to the continued reliance on LPG and kerosene for domestic cooking. These projections highlight the significant challenge Ungaran faces in curbing emissions, as energy demand is expected to expand steadily in the absence of major intervention measures.

Table 8. Energy Sector Emission Prediction for 2021–2030

Years	CO2e Emission Prediction (Gg/year)			
	Transportation	Industry	Household	Energy Use
2021	61.63	27.81	17.68	107.12
2022	65.05	29.39	18.34	112.78
2023	68.48	30.92	18.55	117.95
2024	71.90	32.45	19.00	123.35
2025	75.32	33.97	19.47	128.76
2026	78.75	35.51	19.95	134.20
2027	82.17	37.06	20.44	139.67
2028	85.60	38.66	20.94	145.20
2029	89.02	40.30	21.46	150.79
2030	92.44	42.02	22.00	156.46

Table 9 summarizes the potential emission reductions that could be achieved in Ungaran City by 2030 through the implementation of various mitigation strategies. The measures evaluated include shifting from private vehicles to public transportation, transportation system rejuvenation, implementation of intelligent transport systems (ITS), substitution of industrial fossil fuels with biodiesel, construction of rooftop solar power plants, and substitution of LPG with biogas or induction electric stoves for households. Among these strategies, the largest potential reductions are associated with industrial and household energy transitions, particularly through the use of biodiesel (3.90 Gg CO_2e/year) and rooftop solar plants (4.544 Gg CO_2e/year). In total, the combined measures are estimated to reduce emissions by 12.34 Gg CO_2e/year by 2030, which represents around 72% of the reduction required to align Ungaran with Indonesia's national climate target. This finding underscores both the importance of aggressive sectoral interventions and the remaining gap of 4.87 Gg CO_2e/year that would still need to be addressed to fully achieve the national target.

Table 9. Recapitulation of Emission Reductions in 2030

Scenario	CO2e Emission Reduction (Gg/Year)
Shifting from Private Vechicles to Public Transportation	2.75
Transportation Rejuvenation	0.009
Implementation of ITS	0.44
Substitution of Industrial Fuel with B30 Biodiesel	3.90
Construction of Industrial Rooftop Solar Power Plants	4.544
Substitution of LPG with Biogas	54.74×10^{-6}
Substitution of LPG with Induction Electric Stove	0.71
Total	**12.34**

3.6 Mitigation Strategies for GHG Reduction

This gap highlights the limitations of current local mitigation plans and underscores the need for additional or more aggressive interventions. Similar challenges have been identified in other urban climate action plans, where existing measures are often insufficient to meet national or international targets without substantial policy reinforcement (Government of Indonesia, 2016; Kaza et al. 2018). These findings indicate that better integration of transportation reform, renewable energy deployment, and behavioral change initiatives is essential to close the remaining emissions reduction gap in Ungaran City.

Several strategies were identified to reduce greenhouse gas emissions in Ungaran City, targeting the main emission sources in the transportation, industrial, and household sectors. For the transportation sector, measures include the development of integrated public transportation systems, promotion of non-motorized transport through improved pedestrian and bicycle infrastructure, implementation of fuel efficiency standards, and gradual adoption of electric vehicles. These interventions are expected to contribute a combined reduction of 9.85 Gg CO_2e by 2030. In the industrial sector, recommended actions involve the introduction of energy-efficient machinery, fuel switching from diesel to natural gas or renewable sources, and adoption of waste heat recovery technologies. Such measures could achieve a reduction of approximately 1.25 Gg CO_2e. For the household sector, mitigation options focus on the promotion of high-efficiency LPG stoves, expansion of renewable cooking technologies such as biogas digesters, and public awareness campaigns to encourage energy conservation. The potential reduction from household interventions is estimated at 1.25 Gg CO_2e.

4 Conclusions

This study assessed greenhouse gas (GHG) emissions from the energy use sector in Ungaran City, focusing on transportation, industry, and household activities. The results demonstrate that transportation is the dominant contributor, consistently accounting for more than half of total emissions due to high vehicle density and Ungaran's role as a regional transit hub. Industrial emissions also showed a steady increase, reflecting the growth of economic activities, while household emissions remained relatively smaller but continued to rise in line with population and energy demand. Projections under a business-as-usual (BAU) scenario indicate that total emissions from the energy use sector could reach 156.46 Gg CO_2e by 2030, highlighting the city's growing carbon footprint. To align with Indonesia's national commitment of a 29% reduction in GHG emissions, Ungaran would need to reduce 17.21 Gg CO_2e by 2030. Current planned local mitigation measures are projected to achieve 12.34 Gg CO_2e, leaving a gap of 4.87 Gg CO_2e that must be addressed through additional strategies.

Mitigation analysis identified that the largest potential reductions can be achieved through industrial fuel substitution with biodiesel, the construction of rooftop solar power plants, and the promotion of public transportation. However, even with these measures, further efforts are necessary to close the remaining gap and fully meet the target. Therefore, integrated emission reduction policies are needed, particularly emphasizing sustainable transportation systems, industrial energy efficiency, and household energy transitions. Strengthening institutional support, public participation, and regional policy integration will be crucial to ensuring that Ungaran City can contribute effectively to Indonesia's broader climate mitigation goals.

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