Assessing Greenhouse Gas Emissions from Urban Dairy Farming in Jakarta as an Indicator of Environmental

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ABSTRAK

Tessa M, Yusman S, Faroby F, Suprehatin. 2025. Pengukuran emisi gas rumah kaca peternakan sapi perah di perkotaan Jakarta sebagai indikator keberlanjutan lingkungan. JITV 39(3):170-177. DOI:http://dx.doi.org/10.14334/jitv.v30i3.3536.

Penelitian ini bertujuan untuk mengevaluasi potensi emisi gas rumah kaca (GRK) dari peternakan sapi perah sebagai salah satu indikator keberlanjutan lingkungan di wilayah perkotaan DKI Jakarta. Kajian dilakukan terhadap 59 peternak aktif yang tersebar di Jakarta Timur, Selatan, dan Pusat, dengan pendekatan Tier 2 the Intergovernmental Panel on Climate Change (IPCC). Hasil menunjukkan bahwa emisi rata-rata per ekor sapi per tahun berada pada kisaran 1,67 ton CO2-eq yang sebanding dengan standar negara berkembang. Jakarta Timur menyumbang emisi total terbesar, sementara Jakarta Pusat mencatat emisi per ekor tertinggi meski jumlah ternaknya paling sedikit. Variabilitas emisi antar wilayah mencerminkan pengaruh faktor manajerial, spasial, serta ketersediaan infrastruktur pengelolaan limbah. Temuan ini menyoroti perlunya kebijakan terpadu yang tidak hanya meningkatkan produksi susu, tetapi juga menekan dampak lingkungan melalui pengelolaan peternakan yang adaptif dan berkelanjutan.

Kata Kunci: Sapi Perah, Keberlanjutan Lingkungan, Emisi Gas Rumah Kaca, Peternakan Urban, Jakarta

ABSTRACT

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This study assesses greenhouse gas (GHG) emissions from urban dairy farming as a key indicator of environmental sustainability in Jakarta, Indonesia. Using the IPCC Tier 2 methodology, data were collected from 59 dairy farmers across East, South, and Central Jakarta. The findings reveal an average annual emission of 1.67 tons CO_2-eq per cow, aligning with estimates for developing countries. East Jakarta accounted for the highest total emissions, while Central Jakarta recorded the highest per-cow emission despite having the fewest animals. Emission disparities reflect variations in manure management, spatial conditions, and resource access. These results highlight the need for integrated policies that balance nutritional demands with sustainable farming practices in urban settings.

Key Words: Dairy Farming, Environmental Sustainability, Greenhouse Gas Emissions, Jakarta, Urban Agriculture

INTRODUCTION

Dairy farming is a significant contributor to greenhouse gas (GHG) emissions within the agricultural sector, primarily through enteric fermentation, manure management, and feed production (Rotz 2018; Congio et al. 2022; Knapp et al. 2014). The two main GHGs emitted by this sector—methane (CH_4) and nitrous oxide (N_2O)—have global warming potentials approximately 28 and 265 times greater than carbon dioxide (CO_2) over a 100-year time horizon (IPCC 2006; Baceninaite et al. 2022; Díaz de Otálora et al. 2024).

Emission levels from dairy farms are influenced by a range of factors, including production systems, feed types, manure handling practices, animal health, and local climatic conditions (Munidasa et al. 2023; González-Quintero et al. 2025). Pasture-based and confined-housing systems exhibit varying emission intensities, as demonstrated by several studies (Ouatahar et al. 2025; Arndt et al. 2020). Feed composition, particularly fiber and protein content, plays a crucial role in determining methane emissions from enteric fermentation (Holtshausen et al. 2021; Shetty et al. 2017).

To improve the accuracy of GHG assessments, the Intergovernmental Panel on Climate Change (IPCC) has developed a tiered methodology. The Tier 1 method uses generalized emission factors and yields broad estimates that may overlook local farm characteristics (Penman et al. 2006; EMEP/EEA 2019). In contrast, the Tier 2 approach incorporates farm-specific data, such as milk production, live weight, and feed intake, resulting in more precise, context-relevant estimates (Opio et al. 2013; Arndt et al. 2020). As such, Tier 2 methods are increasingly adopted in North America, South America, and Europe (Aguirre-Villegas et al. 2024; Cashman et al. 2025; Ferraz et al. 2024). In Indonesia, Tier 2 has also been applied in several regions (Ishak et al. 2019; Widiawati et al. 2016; Amriana et al. 2024), but its use remains limited, particularly in urban areas.

Dairy farming in urban areas like Jakarta faces distinct challenges, mainly due to land scarcity, which necessitates intensive or semi-intensive housing systems. These systems influence feed strategies and manure management practices (Kumar et al. 2019; Herawati 2012). Nevertheless, the use of Tier 2 methodologies in urban livestock systems, particularly in developing countries such as Indonesia, remains limited. In Jakarta and similar urban areas, GHG emission estimates from dairy farms are typically based on Tier 1 methods, which do not fully capture the complexity of local farming conditions (Sukmono et al. 2024; Ishak et al. 2019).

Several GHG mitigation strategies have been proposed for the dairy sector, including improving feed quality, enhancing manure management, and implementing genetic selection (Pelton et al. 2024; Ni et al. 2025; Guðmannsdóttir et al. 2024). However, the effectiveness of such strategies in Jakarta remains poorly understood due to constraints on infrastructure, access to technology, and policy frameworks that differ from those in high-income countries.

Evaluating GHG emissions from urban dairy farming in Jakarta is essential to support Indonesia's Nationally Determined Contribution (NDC) under the Paris Agreement and to provide a foundation for sustainable urban agriculture policies (FAO 2018; Pramono 2016). Moreover, this study aims to inform broader discussions on sustainable livestock production in Southeast Asian cities and contribute to the global discourse on sustainable food systems (Dillon et al. 2021; Olthof et al. 2025; Horrillo et al. 2024).

This study, therefore, seeks to evaluate the potential GHG emissions from small-scale urban dairy farms in Jakarta using the IPCC Tier 2 method and primary data collected from local farmers. The findings are expected to offer more accurate emission estimates and guide the development of policy and mitigation strategies to promote environmentally sustainable dairy farming in urban Indonesia.

MATERIAL AND METHODS

Material

This study involved 59 smallholder dairy farmers representing the entire population of small-scale dairy farms in the Province of DKI Jakarta. The farmers were located across three administrative regions: 32 in East Jakarta, 26 in South Jakarta, and only 1 in Central Jakarta. The data indicate that currently, only one active smallholder dairy farmer remains in Central Jakarta. DKI Jakarta was selected as a representative urban area where dairy farming is still practiced by residents, despite the city's highly urbanized characteristics.

Methods

The study was conducted from October to November 2024. A survey method was employed to collect comprehensive data on dairy farming practices, including herd physiological structure, management systems, and feed types. To estimate greenhouse gas (GHG) emissions—specifically methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2)—this research adopted the Tier 2 approach as recommended by the 2006 IPCC Guidelines.

The analysis focused on quantifying emissions from two primary sources: enteric fermentation and manure management. The Tier 2 method was selected for its ability to provide more accurate estimates by incorporating detailed animal-specific data, such as body weight, feed intake, and milk production. This approach enables a more representative assessment of GHG emissions from smallholder dairy farming activities in urban settings.

Greenhouse gas (GHG) emissions were calculated using the Tier 2 methodology as recommended by the IPCC (2006). The equations used in this study are presented below:

$$\text{Enteric CH4 emission} = \left(\frac{FE_{enteric(T)}\ x\ N_T}{10^6}\right)$$

$$\text{Enteric CH4 emission from manure management} = \left(\frac{FE_{manure(T)}\ x\ N_T}{10^6}\right)$$

$$N_2O_{D(mm)} = \left[\sum_s\left[\sum_T\left(N_T \cdot Fex_{(h)} \cdot BB_{(t)}\right]FE_{t(s)}\right]\frac{44}{28} \cdot 365c$$

where $FE_{enteric(T)}$ is enteric CH_4 emission factor for livestock type *T* based on IPCC 2006 default values (kg CH_4/head/year), $FE_{manure(T)}$ is manure CH_4 emission factor for livestock type *T* based on IPCC 2006 default values (kg CH_4/head/year), $N_{(T)}$ is livestock population of type *T* (head/year), 10^6 is conversion factor from kilograms to gigagrams, $N_2O_{D(mm)}$ is direct N_2O emissions from manure management (kg N_2O/year), $Fex_{(h)}$ is nitrogen excretion factor per 1000 kg of live animal weight per day (kg N/1000 kg live weight/day); value used: 0.47 (IPCC 2006 default), $BB_{(t)}$ is average live weight of the animal (kg/head), $FE_{t(s)}$ is N_2O emission factor for manure under intensive management systems (kg N_2O-N/kg N); value used: 96 (IPCC 2006 default), 365 is Number of days in a year, and 44/28 is molecular weight ratio of N_2O to N_2.

RESULT AND DISCUSSION

This study estimates the magnitude of greenhouse gas (GHG) emissions from dairy farming in the urban area of Jakarta, focusing on key sources: enteric methane (CH_4), methane from manure management, and nitrous oxide (N_2O). The following figure presents boxplots for each GHG emission component: enteric CH_4, manure CH_4, N_2O, and total emissions. These visualizations illustrate the distribution of data, variability among farmers, and the presence of outliers in the emission values.

The distribution of greenhouse gas (GHG) emissions from enteric methane (CH_4) produced by 59 small-scale dairy farmers in DKI Jakarta is presented in a boxplot (Figure 1). Emissions are expressed in gigagrams of CO_2-equivalent (Gg CO_2-eq), based on the Global Warming Potential (GWP) of methane as outlined by the IPCC methodology. The visualization shows substantial variation in emission levels among farmers, which is directly linked to the environmental sustainability performance of each farming system.

Enteric CH_4 emissions

The boxplot of enteric methane shows a skewed distribution with a long right tail and several outliers, suggesting that some farms have significantly higher emissions than the majority. The mean emission was 0.0275 Gg CO_2-eq, exceeding the median of 0.0199 Gg CO_2-eq, suggesting that a small number of farms disproportionately contribute to the total emissions. The interquartile range (IQR) spanned from 0.0086 to 0.0338 Gg CO_2-eq, with the maximum value reaching 0.1452 Gg CO_2-eq—more than five times the third quartile (Q3). Such a distribution underlines that the variability in emissions is primarily driven by a few farms with extreme values well above the average.

Further analysis revealed that the three farms with the highest emission levels accounted for approximately 22.5% of the total enteric methane emissions, despite representing only a small fraction of the sample. These outliers consistently originate from farms with larger herd sizes, particularly those dominated by lactating cows and breeding cows.

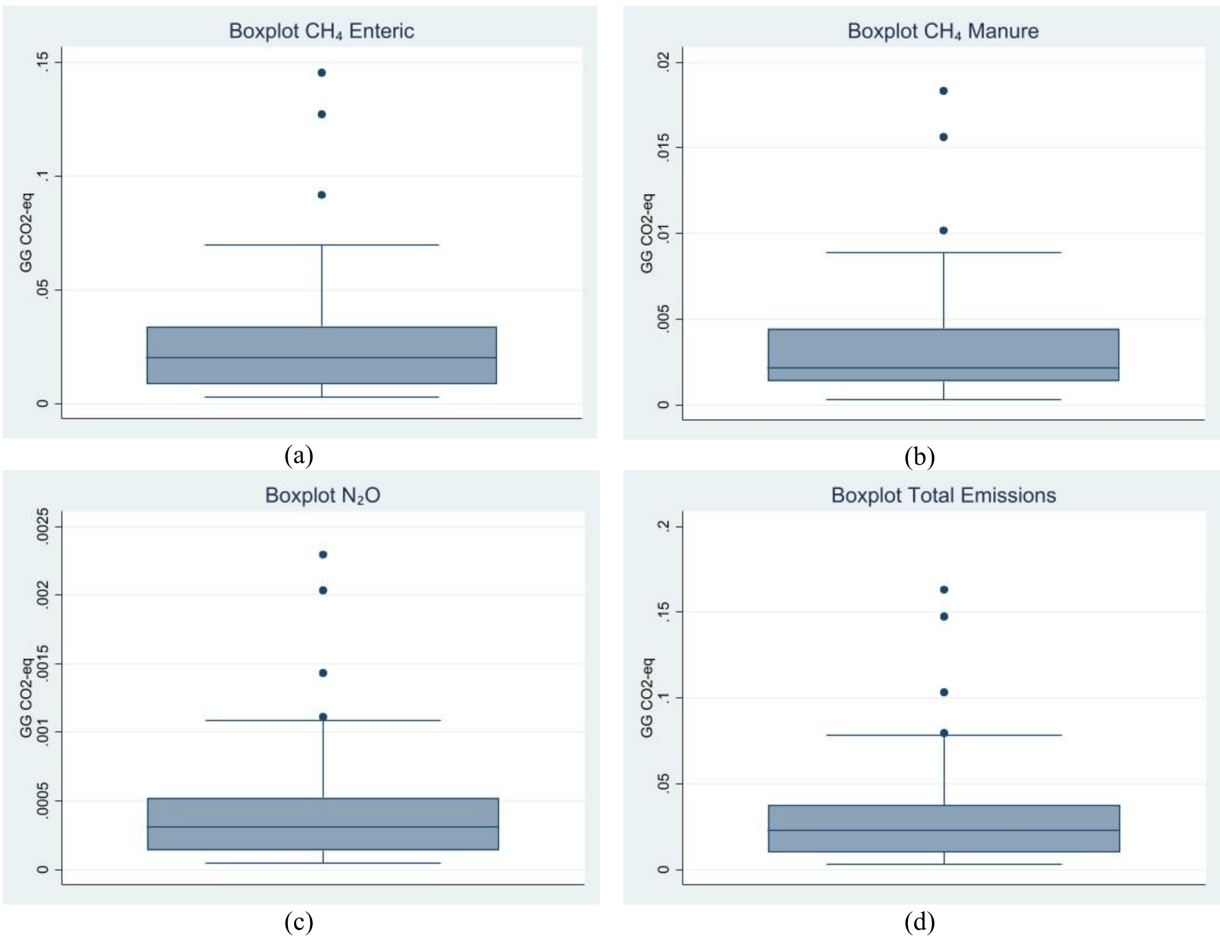

Figure 1. GHG emissions results (in CO_2 equivalents) from livestock sources: (a) CH_4 emissions from enteric fermentation, (b) CH_4 emissions from manure management, (c) N_2O emissions, and (d) total GHG emissions. The plots indicate the median, interquartile range, and the presence of extreme values (outliers) across sampled production units.

The proportion of CH4 emissions from enteric fermentation generated by dairy cows also showed a relatively consistent pattern compared with the total cattle population (Marklein et al., 2021), reinforcing the evidence that lactating and breeding groups account for a substantial share of overall emissions. These categories of cattle require higher feed intake and exhibit more intensive rumen fermentation, thereby producing greater methane emissions. These findings align with those of Ibidhi et al. (2021), who emphasized that herd size and structure are critical determinants of emission variability across dairy farms.

The result carries important implications for emission mitigation strategies in smallholder dairy systems in Jakarta. Mitigation efforts should not rely solely on reducing average emissions, as farms with larger numbers of lactating and breeding cows make the most substantial contribution to aggregate enteric methane output. Targeted interventions focusing on these high-intensity farms are therefore more likely to yield significant reductions in total emissions, while simultaneously enhancing the environmental benefits of urban dairy production systems.

Manure-derived CH_4 emissions

Methane emissions from manure showed a narrower distribution, with a median of approximately 0.005 Gg CO_2-eq. Although smaller than enteric emissions, some outliers were still observed, particularly in farms with larger or more productive animals. These differences are primarily shaped by herd structure—such as age, physiological status, and body weight—that influences excretion rates. Widiawati et al. (2016) found that manure emission factors for beef cattle in Indonesia differ across animal categories. Similarly, Amriana et al. (2024) stressed the importance of including animal age and body weight data to explain category-specific variability better. Consistent with this, the IPCC Tier-2 guidelines also derive manure emission factors from animal categories rather than manure management practices.

N_2O emissions

The boxplot of N_2O emissions shows a median of approximately 0.0005 Gg CO_2-eq, which is substantially lower than 0.002 Gg CO_2-eq and represents the smallest contribution among the three emission sources analyzed: enteric CH_4, manure CH_4, and N_2O. The relatively narrow distribution indicates that most farms consistently generated low emissions. Nevertheless, a few outliers above 0.001 Gg CO_2-eq were observed, suggesting variation among farmers.

According to the IPCC Tier 2 guidelines, this variability is primarily due to differences in nitrogen excretion, which are calculated based on body weight, milk productivity, feeding practices, and environmental factors influencing the transformation of nitrogen into N2O(IPCC 2006; Bougouin et al. 2022; Reed et al. 2015). With the Tier 2 approach, nitrogen excretion is estimated individually for each animal, so differences in animal characteristics and feed management are directly reflected in the N_2O emission estimates, including the appearance of outliers in the boxplot.

Total GHG emissions

The boxplot for total GHG emissions reflects the cumulative contribution of all three sources (enteric CH_4, manure CH_4, and N_2O). The median total emission was approximately 0.03 Gg CO_2-eq, though outliers approached 0.20 Gg CO_2-eq. This wide distribution underscores the disparity in emissions across farms and highlights the potential for targeted mitigation strategies. These findings support the prioritization approach advocated by Ouatahar et al. (2025) and González-Quintero et al. (2025), who recommend focusing mitigation efforts on high-emission farms through incentive schemes and environmental education.

Among the four emission types analyzed, the environmental sustainability of small-scale dairy systems in DKI Jakarta appears highly dependent on feed and waste management practices. The uneven emission patterns reflect structural challenges in standardizing farming practices across urban settings. GHG emissions not only indicate climate impacts but also serve as proxies for system efficiency.

In the Indonesian context, Sukmono et al. (2024) stressed the importance of location-specific and socio-economic considerations in evaluating and reducing the livestock sector's carbon footprint. Strategies such as improved feeding management, the introduction of micro-scale waste-treatment technologies, and farmer training in low-carbon practices are critical steps toward a more sustainable dairy sector.

Understanding the potential contribution of GHG emissions from dairy farms also requires analysis by livestock age group and administrative region; this is important because physiological characteristics influence emission levels and feed consumption, both of which vary with age. For instance, adult cows typically emit more greenhouse gases than calves due to higher metabolic activity and milk production. Furthermore, differences in farm management practices across Jakarta's administrative regions—such as herd density, feeding routines, and waste handling systems—also affect the magnitude of emissions.

Greenhouse gas (GHG) emissions from the dairy farming sector are a crucial indicator for evaluating environmental sustainability, particularly in urban areas such as DKI Jakarta, where land pressure, spatial conflict,

Table 1. Estimated emissions by age group and administrative region in Jakarta

Area	East Jakarta		South Jakarta		Central Jakarta		Total		Estimated Emissions Average ($GG\ CO_2$-eq / year/head)
Range Age of Cattle	Total (head)	Estimated Emissions ($GG\ CO_2$-eq /year)	Total (head)	Estimated Emissions ($GG\ CO_2$-eq /year)	Total (head)	Estimated Emissions ($GG\ CO_2$-eq /year)	Total (head)	Estimated Emissions ($GG\ CO_2$-eq /year)	
Calves (<1 year)	122	0.0588	57	0.0275	1	0.0005	180	0.0867	0.0005
Growers (1–2 years)	158	0.1689	53	0.0567	0	0	211	0.2256	0.0011
Young Adults (2–4 years)	177	0.2891	136	0.2221	0	0	313	0.5112	0.0016
Mature Adults (>4 years)	298	0.7556	98	0.2485	9	0.0233	405	1.0274	0.0025
Total	755	1.2724	344	0.5548	10	0.023	1109	1.8509	

and resource constraints present significant challenges. Based on estimations from 59 dairy farmers across three administrative regions (East Jakarta, South Jakarta, and Central Jakarta), the total annual emissions were calculated at 1.8509 GG CO_2-equivalent (CO_2-eq), with an average emission of 1.67 tons CO_2-eq per cow per year.

East Jakarta contributed the highest emissions, totaling 1.2724 GG CO_2-eq, followed by South Jakarta (0.5548 GG CO_2-eq) and Central Jakarta (0.023 GG CO_2-eq). When normalized by livestock population, regional variations in average emissions per cow were observed: 1.69 tons CO_2-eq in East Jakarta (755 head), 1.61 tons CO_2-eq in South Jakarta (344 head), and 2.30 tons CO_2-eq in Central Jakarta (10 head). The relatively high per-animal emissions in Central Jakarta likely reflect the small sample size, where statistical variation per individual becomes more pronounced.

These findings fall within the emission range reported by FAO (2018), which estimated 1.6–2.5 tons CO_2-eq per dairy cow annually in developing countries, depending on production systems, feed management, and manure handling. In Jakarta, most dairy farms operate at small, household scales, with heterogeneous management practices. According to Opio, C. et al. (2013), such systems tend to produce higher emissions when inputs are inefficient and manure management is suboptimal, particularly due to dominant methane emissions from enteric fermentation and nitrous oxide emissions from untreated manure.

An age-based analysis of the livestock showed that the largest share of emissions originated from adult cows (>4 years old), contributing 1.0274 tons CO_2-eq, or more than 55% of the total emissions. Cattle in this age group are generally in lactation and have higher feed intake, resulting in more intensive enteric fermentation. In contrast, calves (<1 year) contributed only 0.0867 tons CO_2-eq, consistent with lower metabolic activity and reduced feed consumption.

Spatial differences also revealed important dynamics. In East Jakarta, dairy farms are more clustered and benefit from government-supported collective manure management systems. These facilities process manure into liquid and solid fertilizers, reducing GHG emissions from waste and promoting circular economy practices in urban agriculture. Conversely, in South Jakarta, farms are scattered within densely populated residential areas and are often located near riverbanks, increasing the risk of pollution, social conflict, and poor waste management. As noted by Kumar et al. (2019), such conditions require adaptive policy approaches that address spatial planning challenges and the complex socio-human-animal interactions in urban contexts.

Meanwhile, the high per-cow emissions in Central Jakarta—reaching 2.30 tons CO_2-eq—may indicate managerial inefficiencies. Despite the tiny livestock population, this highlights that small scale does not guarantee low emissions; every farm unit, regardless of its size, must be supported with environmentally sound management practices.

Food policy contexts must also be taken into account. Government programs promoting free nutritious meals for school-aged children are expected to increase the demand for fresh milk. Without corresponding improvements in production systems and environmental management, the increased demand could lead to higher GHG emissions from urban dairy farms. Therefore, food and environmental policies must be developed in an integrated manner. As emphasized by Yuhendra et al. (2022), a sustainable food systems approach must balance environmental, social, and economic dimensions.

As a practical implication, GHG mitigation strategies for dairy farming in urban areas like Jakarta must be tailored to local conditions. These include providing technical training for farmers, offering incentives for using organic fertilizers derived from livestock waste, and implementing zoning policies that support the sustainability of small-scale farms. This study underscores the importance of integrating quantitative emission data with socio-economic understanding of local contexts as the foundation for evidence-based policymaking.

CONCLUSION

Dairy farming in the DKI Jakarta area has been shown to contribute significantly to greenhouse gas (GHG) emissions, with an average emission of 1.67 tons CO_2-equivalent (CO_2-eq) per cow per year. Variations in emissions across farms and regions indicate that managerial practices, business capacity, and institutional support play a critical role in determining emission levels. The highest emissions were recorded from adult cows, highlighting a strong correlation between animal age and emission potential.

These findings underscore the importance of environmental management in urban livestock systems. Without implementing technology-based interventions and adaptive policy frameworks, increased milk production to meet urban food demand may exacerbate environmental pressures. Therefore, GHG emissions from dairy farming should be considered a key indicator of environmental sustainability in the planning of more integrated urban food systems.

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