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Neighbourhood-Scale Carbon Footprint of Community Activities in Batu Kota, Malalayang District, Manado City.

Jehezkiel K. Claudhio[1], Sofia Wantasen[1]*, Adeleyda M. W. Lumingkewas[1], Frangky J. Paat[1], Wiske C. Rotinsulu[1], Jeanne M. Paulus[2], Sandra E. Pakasi[1], Diane D. Pioh[1], Tommy B. Ogie[1], Jelie Viekson Porong[1].

[1]*Department of Agrotechnology, Faculty of Agriculture, Sam Ratulangi University-Manado, 95115 Indonesia*
[2]*Department of Agronomy, Faculty of Agriculture, Sam Ratulangi University-Manado, 95115 Indonesia*

*Corresponding author:
s_wantasen@unsrat.ac.id

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Abstract. Neighbourhood-scale carbon-footprint assessment is increasingly important for understanding how everyday urban activities contribute to greenhouse-gas emissions. This study evaluated the carbon footprint generated by community activities in Kelurahan Batu Kota, Malalayang District, Manado City, Indonesia. The research was conducted from January to February 2026 using a quantitative survey approach with purposive sampling. A total of 335 households were selected from five neighbourhood units. Primary data were collected through field observation and questionnaires covering LPG use, household electricity consumption, motor-vehicle ownership, fuel type, and transport-fuel consumption. Carbon emissions were estimated for three activity categories, namely LPG use, electricity consumption, and motorized transportation, using IPCC-based calculation procedures. The results showed that the total carbon footprint of community activities in Kelurahan Batu Kota reached 7,410.98 ton CO_2eq $year^{-1}$. Transportation was the dominant emission source, contributing 4,546.12 ton CO_2eq $year^{-1}$ or 61.34% of the total, followed by electricity consumption at 2,432.12 ton CO_2eq $year^{-1}$ and LPG use at 432.74 ton CO_2eq $year^{-1}$. Spatially, the carbon footprint was unevenly distributed across neighbourhoods. Lingkungan 5 produced the highest total emissions at 2,646.89 ton CO_2eq $year^{-1}$ or 35.72% of the total, whereas Lingkungan 4 contributed the lowest share. These findings indicate that the carbon profile of Batu Kota was driven primarily by daily mobility and electricity use rather than by cooking-fuel consumption. The study provides baseline evidence for neighbourhood-based emission management and highlights the importance of place-specific mitigation strategies in urban residential environments.

Keywords: carbon footprint; electricity consumption; household emissions; neighbourhood-scale assessment; urban transportation

INTRODUCTION

Climate change is no longer best understood as a distant global risk; it is now a measurable and rapidly intensifying condition that is increasingly expressed through local energy use, mobility, and settlement patterns. The World Meteorological Organization reported that 2024 was the warmest year in the 175-year observational record, underscoring the urgency of mitigation across all scales of society (World Meteorological Organization, 2025). Recent energy-climate research further shows that demand-side strategies can reduce emissions by 51–85% in buildings and 37–91% in transport by 2050, indicating that everyday household and mobility behaviour are central to meaningful mitigation (van Heerden et al., 2025). At the same time, neighbourhood-scale carbon accounting is gaining importance because urban areas generate most greenhouse-gas emissions, while city-wide averages often conceal strong internal disparities in how emissions are produced and distributed (Roncero-Tarazona et al., 2025).

Within this context, the carbon footprint has become an important analytical tool for translating routine human activities into quantifiable greenhouse-gas emissions. A recent review of household carbon-footprint research notes that this approach is widely used to capture direct and indirect emissions associated with domestic energy use and consumption behaviour (Du et al., 2024). A broader analytical review published in 2025 also shows that household carbon-emission research has expanded substantially, particularly in relation to assessment methods, influencing factors, and mitigation pathways (Wang et al., 2025). However, household emissions are not socially or spatially uniform. Yologlu et al. (2024) demonstrated that social determinants significantly affect household carbon-emission levels, while Yan et al. (2024) highlighted strong spatial heterogeneity in household greenhouse-gas emissions across urban areas (Yan et al., 2024; Yologlu & Halisdemir, 2024). In a similar direction, Dawkins et al. (2024) showed that downscaling household carbon footprints from the national level to municipalities and postcode areas can reveal local patterns that remain invisible in aggregated assessments (Dawkins et al., 2024).

For Indonesia, this perspective is particularly important because the country's Second Nationally Determined Contribution reaffirms an emission-reduction commitment of 31.89% unconditionally and 43.20% conditionally, while also positioning the energy sector as a major focus of mitigation. The same official document reports that, in the First Biennial Transparency Report, the energy sector accounted for 69.01% of Indonesia's total emissions in 2022, indicating the growing centrality of energy-related activities in the national emissions profile (UNFCCC, 2025). This challenge is reinforced by the structure of the electricity system. The U.S. Energy Information Administration reported in 2025 that fossil fuels accounted for 81% of Indonesia's installed electricity generation capacity in 2023. The same source also states that the residential sector consumed more than 30% of electricity generation in 2023, confirming that household electricity demand remains closely tied to a still carbon-intensive power system (U.S. Energy Information Administration, 2025).

Transport presents an equally important challenge, but with a somewhat different structure. WRI Indonesia has emphasized that road-transport emission accounting in Indonesia still requires stronger standardization and baseline development, which makes local transport-emission inventories especially valuable for policy and planning (Rum et al., 2024). The International Council on Clean Transportation likewise identifies transport as the second-largest emissions contributor in Indonesia, highlighting its strategic relevance to the country's net-zero pathway (Tong et al., 2025). The same ICCT assessment notes that 60% of fossil fuels used in road transport were imported in 2023, illustrating the continued dependence of Indonesian mobility on petroleum-based energy. In parallel, ITDP Indonesia reported that the country had more than 112 million motorcycles, equivalent to 84.4% of registered motor vehicles, and that motorcycles accounted for 64.2% of trips in Greater Jakarta in 2019 (Chen et al., 2025). Although those figures come from a different metropolitan context, they are highly relevant for understanding the household carbon footprint of Indonesian urban settlements, where private motorized mobility often dominates daily movement patterns.

The relevance of neighbourhood-scale assessment becomes even clearer when viewed from the perspective of household consumption. Rum et al. (2024) estimated that 63.5% of Indonesia's national greenhouse-gas emissions are related to household consumption, with substantial variation across provinces (Rum et al., 2024). This indicates that mitigation in Indonesia cannot rely solely on supply-side reform or sector-wide targets, but must also engage the carbon consequences of how households consume energy and organize daily life. More recent work by Massagony et al. (2026) further suggests that household electricity use in Indonesia is a meaningful source of carbon emissions and that even relatively simple informational interventions can influence residential electricity-saving behaviour (Massagony et al., 2026).

In this regard, Kelurahan Batu Kota offers a relevant case for localized carbon-footprint assessment. The study area is one of the urban settlements surrounding Sam Ratulangi University and is shaped by the interaction of residence, local services, and daily mobility. The study file indicates that Kelurahan Batu Kota covers 0.94 km², is divided into five administrative neighbourhoods, and has experienced a transition toward more energy-dependent and modernized living patterns. Official district statistics also identify Malalayang as an urban area with dynamic geographical and socio-economic conditions, reinforcing the need for localized assessment of household and community emissions.

Taken together, recent literature shows that carbon-footprint analysis is moving toward finer spatial scales because local social structure, neighbourhood form, and daily activity systems strongly shape emission outcomes (Yologlu & Halisdemir, 2024). Yet broader municipal or national assessments cannot fully explain how emissions are distributed within specific urban communities or which activity sources dominate in a given neighbourhood setting. Therefore, this study was conducted to assess the carbon footprint generated by community activities in Kelurahan Batu Kota, Malalayang District, Manado City, with particular focus on emissions from LPG use, household electricity consumption, and motorized transportation. By identifying the relative contribution of these sources across neighbourhood units, the study is expected to provide a more place-sensitive basis for community-level mitigation planning in urban residential environments.

MATERIALS AND METHODS

Study location

The research was carried out in Kelurahan Batu Kota, Malalayang District, Manado City, North Sulawesi, Indonesia, from January to February 2026. Batu Kota consists of five administrative neighbourhood units (*lingkungan*) and represents a densely inhabited urban settlement influenced by residential expansion and daily socio-economic activities in the surrounding Malalayang area.

Study approach

This study applied a quantitative survey approach to estimate the carbon footprint generated by community activities at the household level. The assessment focused on three principal emission sources associated with daily household activities, namely LPG consumption, electricity use, and fuel consumption from motorized transportation. The analysis was intended to quantify annual CO_2-equivalent emissions for each neighbourhood and for Kelurahan Batu Kota as a whole.

Population and sample

The study population consisted of households located in Kelurahan Batu Kota. Respondents were selected using purposive sampling, in which households were chosen based on criteria considered relevant to the objectives of the study. In contrast to the previous study setting, the sampling frame in Batu Kota included not only conventional residential houses but also houses with home-industry activities, because mixed-use dwellings were part of the actual settlement structure in the study area.

The sample size was determined using the Slovin formula with a 10% error tolerance. Based on the number of households in each neighbourhood, the planned sample distribution was 63 households in Lingkungan 1, 66 in Lingkungan 2, 78 in Lingkungan 3, 57 in Lingkungan 4, and 71 in Lingkungan 5. Accordingly, the total number of surveyed households was 335.

Types and sources of data

The study used both primary and secondary data. Primary data were collected through field observation and questionnaire-based interviews. Observation was conducted to identify the spatial boundaries of each neighbourhood and to confirm the settlement coverage of the study area. The questionnaire was designed to obtain household-level information on LPG use, electricity consumption, motor-vehicle ownership, fuel type, and monthly fuel consumption.

Secondary data were obtained from statistical reports, published references, and technical documents related to greenhouse-gas accounting. These data included the number of households in each neighbourhood and emission parameters such as emission factors, net calorific values, and global warming potential coefficients used in the calculation procedure.

Carbon-footprint boundary

The carbon-footprint calculation was limited to energy-related emissions generated from community activities within the study area. Three activity categories were included: household LPG use for cooking and related domestic activities, household electricity consumption, and transportation fuel use from privately operated motor vehicles. Emissions were expressed in CO_2 equivalent (CO_2eq) on an annual basis.

Calculation of emissions

LPG emissions

Emissions from LPG consumption were estimated using the IPCC-based approach by combining fuel consumption data with the corresponding energy-conversion and emission parameters:

$$E = KBB \times NCV \times FE \times GWP$$

where E is total emissions (kg CO_2eq), KBB is fuel consumption (kg), NCV is net calorific value (TJ kg^{-1}), FE is emission factor (kg CO_2 TJ^{-1}), and GWP is global warming potential. The LPG parameters used in the study were an emission factor of 63,100 kg CO_2 TJ^{-1} and an NCV of 47.3×10^{-6} TJ kg^{-1}.

Transportation emissions

Carbon emissions from transportation were calculated from annual household fuel consumption of private vehicles. The same general equation was applied:

$$E = KBB \times NCV \times FE \times GWP$$

where KBB is fuel consumption in litres. The fuels included in the analysis were Pertamax, Pertalite, and Solar. The emission factors and calorific values used were 72,600 kg CO_2 TJ^{-1} and 0.000033 TJ L^{-1} for Pertamax, 72,967 kg CO_2 TJ^{-1} and 0.000033 TJ L^{-1} for Pertalite, and 74,433 kg CO_2 TJ^{-1} and 0.000036 TJ L^{-1} for Solar.

Electricity emissions

Emissions from household electricity consumption were estimated using annual electricity use and the applicable grid emission factor:

$$E = KE \times FE \times GWP$$

where E is total emissions (kg CO_2eq), KE is electricity consumption (kWh), FE is the electricity emission factor (kg CO_2 kWh^{-1}), and GWP is the global warming potential. The emission factor used for grid electricity in this study was 0.78 kg CO_2 kWh^{-1}.

Total carbon footprint

The total annual carbon footprint was obtained by summing the emissions from LPG, electricity, and transportation fuel use:

$$TE_{GHG} = TE_{LPG} + TE_{electricity} + TE_{transport}$$

where TE_{GHG} is total greenhouse-gas emissions (ton CO_2eq year^{-1}), TE_{LPG} is emissions from LPG use, $TE_{electricity}$ is emissions from electricity consumption, and $TE_{transport}$ is emissions from motorized transportation. The calculations were performed for each neighbourhood and then aggregated for Kelurahan Batu Kota.

Data analysis

The collected data were processed in Microsoft Excel. Monthly activity data were converted into annual consumption values and then multiplied by the relevant conversion and emission factors to obtain annual CO_2-equivalent emissions. The results were analyzed descriptively to compare the relative contribution of each emission source and each neighbourhood to the total carbon footprint of Kelurahan Batu Kota.

RESULTS AND DISCUSSION

Overall carbon-emission profile of Batu Kota

The carbon-footprint assessment showed that community activities in Kelurahan Batu Kota generated a total of 7,410.98 ton CO_2eq year^{-1}. This total was derived from three major activity groups, namely LPG use, household electricity consumption, and motorized transportation. Among these, transportation was the dominant source, contributing 4,546.12 ton CO_2eq year^{-1}, followed by electricity at 2,432.12 ton CO_2eq year^{-1}, whereas LPG contributed only 432.74 ton CO_2eq year^{-1}. These results indicate that the carbon profile of Batu Kota was shaped more strongly by mobility and daily transport dependence than by cooking-related household energy use.

This pattern is particularly important because it suggests that Batu Kota should not be interpreted merely as a residential settlement with conventional domestic energy demand. Rather, it appears to function as an active urban neighbourhood in which household life, local business activity, and movement across the city are closely connected. As a result, the largest share of emissions originated from activities that extend beyond the interior of the house, especially the use of private vehicles.

Table 1. Carbon emissions by source in Kelurahan Batu Kota

Source of emission	Total emissions (ton CO_2eq year^{-1})	Contribution (%)
LPG	432.74	5.84
Electricity	2,432.12	32.82
Transportation	4,546.12	61.34
Total	7,410.98	100

Table 1 shows a highly uneven source structure. Transport alone contributed more than three-fifths of total emissions, meaning that any effort to reduce the carbon footprint of Batu Kota will be far less effective if it focuses only on cooking fuel or household electricity. The dominance of transport emissions also distinguishes Batu Kota as a settlement where carbon intensity is driven primarily by movement patterns rather than by static domestic consumption alone.

Neighbourhood contrasts in carbon footprint

Although Batu Kota forms one administrative kelurahan, the emission burden was not distributed evenly among its five neighbourhoods. The results revealed strong spatial contrasts, with one neighbourhood contributing disproportionately to the total carbon footprint. Lingkungan 5 produced the highest emissions, reaching 2,646.89 ton CO_2eq year^{-1}, while Lingkungan 4 showed the lowest value at 705.21 ton CO_2eq year^{-1}. This difference indicates that the internal structure of Batu Kota is heterogeneous in terms of household activity intensity, energy use, and mobility behaviour.

A striking feature of Table 2 is the concentration of emissions in Lingkungan 5. This neighbourhood alone accounted for **35.72%** of the entire carbon footprint of Batu Kota, meaning that more than one-third of all emissions assessed in the study area were generated from a single neighbourhood. Such concentration suggests that neighbourhood-scale analysis is essential, because kelurahan-level averages alone would obscure this internal imbalance.

By contrast, Lingkungan 4 contributed less than one-tenth of total emissions. This lower value reflects a smaller scale of activity in general, including lower electricity use and lower transportation emissions. The contrast between Lingkungan 5 and Lingkungan 4 demonstrates that the carbon footprint of Batu Kota was not simply a function of administrative area, but rather of the intensity and composition of activities taking place within each neighbourhood

Table 2. Total carbon footprint by neighbourhood in Kelurahan Batu Kota.

Neighbourhood	LPG (ton CO_2eq year^{-1})	Electricity (ton CO_2eq year^{-1})	Transportation (ton CO_2eq year^{-1})	Total (ton CO_2eq year^{-1})	Share (%)
1	58.83	326.81	509.23	894.87	12.07
2	75.31	558.44	791.81	1,425.56	19.24
3	136.5	724.28	877.67	1,738.45	23.46
4	66.76	274.26	364.19	705.21	9.52
5	95.34	548.33	2,003.22	2,646.89	35.72
Total	432.74	2,432.12	4,546.12	7,410.98	100

What actually drove emissions in each neighbourhood?

A closer examination of the data shows that the dominant source of emissions was not the same in magnitude, even though transportation remained the largest contributor overall. In Lingkungan 5, transportation emissions reached 2,003.22 ton CO_2eq year^{-1}, far above the contributions of LPG and electricity in the same neighbourhood. This indicates a highly transport-intensive activity pattern, likely associated with greater private-vehicle use, more frequent travel, or stronger household dependence on fossil-fuel mobility.

Lingkungan 3 presented a somewhat different profile. Although transportation still dominated, the neighbourhood also recorded the highest LPG emissions (136.50 ton CO_2eq year^{-1}) and the highest electricity emissions (724.28 ton CO_2eq year^{-1}) among all neighbourhoods. This suggests that Lingkungan 3 was characterized by a broader intensity of household activity overall, rather than by transport dependence alone. In other words, Lingkungan 3 combined high domestic energy use with high mobility demand, which made it the second-largest contributor to the total Batu Kota carbon footprint.

Lingkungan 1 and Lingkungan 4 showed relatively lower values for all three sources, especially LPG and electricity. Their lower totals suggest less intensive overall household activity, lower consumption, or lower mobility volume compared with the other neighbourhoods. Meanwhile, Lingkungan 2 occupied an intermediate position, with substantial contributions from both electricity and transport but without the extreme concentration observed in Lingkungan 5. These contrasts confirm that each neighbourhood had a distinct carbon-emission signature.

Reading Batu Kota as an urban energy–mobility system

The Batu Kota results can be interpreted as evidence of an urban settlement whose carbon emissions are produced through the interaction of domestic energy consumption and external daily movement. LPG remained almost universal as a cooking fuel, which shows that conventional household energy demand persisted across the area. Electricity also contributed significantly, indicating that residential life in Batu Kota depended strongly on modern electrical services. However, neither of these sources exceeded the impact of transportation. This makes transport the key factor distinguishing Batu Kota's carbon profile.

The presence of mixed residential and semi-productive activities in the study area may partly explain this profile. Because the sampling frame included houses with home-industry activities, energy use in Batu Kota cannot be treated as purely domestic in the narrow sense. Some household energy and transport demand likely supported not only residence, but also small-scale productive and service-related functions. This gives the Batu Kota carbon footprint a more complex character than a purely residential inventory.

In this respect, the results suggest that the neighbourhood operates as an integrated energy–mobility system. Household emissions were shaped by what residents used at home, but also by how they moved, how often they travelled, and how strongly their daily activities depended on private vehicles. Therefore, the carbon footprint of Batu Kota should be interpreted not simply as an inventory of household utilities, but as an expression of everyday urban metabolism at the community scale.

Implications for local mitigation

The findings point to a clear mitigation priority. Since transportation contributed **61.34%** of total emissions, efforts to reduce the Batu Kota carbon footprint should focus first on lowering fossil-fuel use in mobility. Measures aimed only at LPG substitution or minor household electricity savings would likely produce more limited emission reductions unless accompanied by transport-related interventions.

Nevertheless, electricity should remain a secondary priority because it contributed nearly one-third of total emissions. In practical terms, a dual strategy would be more appropriate for Batu Kota: mobility-related emission reduction in the short term, combined with greater household electricity efficiency and energy-saving practices at the domestic level. Since the spatial distribution of emissions was highly uneven, such interventions should be targeted geographically. Lingkungan 5 should receive particular attention because of its exceptionally high transport emissions, while Lingkungan 3 should be prioritized for integrated measures because of its high emissions across all three source categories.

Overall, the Batu Kota case demonstrates that neighbourhood-scale carbon accounting can reveal both source dominance and spatial concentration of emissions in ways that broader urban averages cannot. The study therefore provides a useful baseline for designing place-specific mitigation strategies that are more responsive to how energy and mobility are actually organized in an urban community.

CONCLUSION

The present study shows that the carbon footprint of community activities in Kelurahan Batu Kota was strongly shaped by the interaction between household energy use and daily motorized mobility. The total annual carbon footprint reached 7,410.98 ton CO_2eq year^{-1}, indicating that routine activities at the neighbourhood level can generate a substantial local emission burden. However, this burden was not distributed evenly across emission sources. Transportation was the principal driver of emissions, contributing 4,546.12 ton CO_2eq year^{-1} or 61.34% of the total, followed by electricity consumption at 2,432.12 ton CO_2eq year^{-1} and LPG use at 432.74 ton CO_2eq year^{-1}. These results indicate that

Batu Kota's carbon profile was dominated more by mobility-related fuel use than by indoor household energy demand. The analysis also revealed marked spatial variation within the study area. Among the five neighbourhoods, Lingkungan 5 was the largest contributor, generating 2,646.89 ton CO_2eq year^{-1}, equivalent to 35.72% of the total Batu Kota carbon footprint. By contrast, Lingkungan 4 showed the lowest total emissions at 705.21 ton CO_2eq year^{-1}. This uneven distribution demonstrates that the carbon intensity of Batu Kota was concentrated in specific neighbourhoods rather than spread uniformly across the kelurahan. Such a pattern confirms the importance of neighbourhood-scale carbon accounting for identifying where emissions are most heavily concentrated and where mitigation efforts may be most effective. Overall, the findings suggest that Batu Kota should be understood as an urban energy–mobility system in which domestic life, local activity, and private transport are closely interconnected. In practical terms, this means that carbon-reduction efforts in the area should not focus solely on household cooking fuel or electricity efficiency, but should give primary attention to reducing transport-related fossil-fuel use. The study therefore provides an empirical basis for more targeted, place-specific mitigation strategies in urban residential areas, particularly those characterized by mixed residential and activity-intensive settlement patterns.

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