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Assessment Of the Carbon Footprint of Household Activities in Kleak, Malalayang District, Manado City .

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Abstract. Household energy use and private mobility are important sources of greenhouse-gas emissions in urban residential areas. This study assessed the carbon footprint of household activities in Kelurahan Kleak, Malalayang District, Manado City, Indonesia. The study was conducted from January to March 2026 using a field-based survey approach with purposive sampling. A total of 354 households were selected from six neighbourhood units (lingkungan). Primary data were collected through direct observation and questionnaires covering LPG consumption, electricity use, vehicle ownership, fuel type, and fuel consumption. Carbon emissions were estimated for three major household-related sources, namely LPG use, electricity consumption, and private transportation fuel use, using IPCC-based emission calculation methods. The results showed that the total household carbon footprint of Kelurahan Kleak reached 6,599.65 ton CO_2eq year^{-1}. Transportation fuel was the largest contributor, accounting for 3,609.97 ton CO_2eq year^{-1}, followed by electricity consumption at 2,613.89 ton CO_2eq year^{-1}, while LPG use contributed 375.80 ton CO_2eq year^{-1}. Among the six neighbourhoods, Lingkungan 6 produced the highest total emissions at 2,123.05 ton CO_2eq year^{-1}, equivalent to 32.17% of the total carbon footprint. These findings indicate that household carbon emissions in Kelurahan Kleak were driven primarily by private mobility and electricity use rather than cooking fuel consumption. The study provides baseline evidence for neighbourhood-scale carbon management and highlights the importance of community-based mitigation strategies in urban residential environments.

Keywords: carbon footprint; electricity consumption; household activities; LPG use; transportation fuel

INTRODUCTION

Climate change remains one of the most pressing environmental challenges of the twenty-first century because it is closely linked to the accumulation of greenhouse gases (GHGs) from human activities. The IPCC emphasizes that effective mitigation requires not only supply-side decarbonization but also demand-side interventions targeting energy use, mobility, and household consumption patterns (IPCC, 2023). In this context, the carbon footprint has become a widely used indicator for quantifying the GHG emissions associated with human activities, products, and lifestyles (Du et al., 2024). Recent reviews further show that household carbon emission research has expanded rapidly, reflecting growing recognition that residential consumption is an important entry point for climate mitigation (Long et al., 2025; Wang et al., 2025).

At the household level, carbon footprints are generated through both direct and indirect forms of energy use. Direct emissions commonly arise from electricity consumption, cooking fuel use, and private transportation, while indirect emissions are embedded in goods and services consumed by households (Du et al., 2024). Urban household carbon accounting is therefore increasingly viewed as essential because it helps clarify emission sources at the scale where daily energy use actually occurs (Huang et al., 2023). Recent work also shows that household decarbonization is strongly shaped by behavioural routines, infrastructure access, and urban lifestyles, meaning that local context matters substantially when estimating residential emissions and designing mitigation strategies (Long et al., 2025; Wang et al., 2025).

The Indonesian context makes such analysis particularly important. Indonesia's Enhanced Nationally Determined Contribution raised its 2030 mitigation target to 31.89% unconditionally and 43.20% conditionally, indicating stronger national commitment to emission reduction (UNFCC, 2022). At the same time, the country remains highly dependent on fossil fuels, and the IEA notes that Indonesia's energy-sector CO_2 emissions had reached around 600 Mt CO_2 in 2021, more than double the level of two decades earlier (IEA, 2022). More recent energy assessments also report that fossil fuels still dominated 81% of Indonesia's electricity generation in 2023, showing that residential electricity use remains structurally linked to carbon-intensive power supply(IESR, 2024). These trends confirm that local studies of household energy use are highly relevant to the broader national decarbonization agenda.

Household-related emissions in Indonesia are not limited to electricity use. A recent province-level study found that 63.5% of Indonesia's national GHG emissions are related to household consumption, while utilities and transportation services remain important contributors to carbon intensity across provinces(Rum et al., 2024). In addition, household electricity consumption in Indonesia has been explicitly identified as a significant source of carbon emissions, and experimental evidence suggests that even simple informational interventions can influence electricity-saving behaviour at the household scale (Massagony et al., 2026). These findings indicate that residential lifestyles, appliance use, and mobility choices are central to understanding emissions in Indonesian urban communities.

Transportation is another critical component of urban carbon footprints in Indonesia. The Asian Transport Observatory reported that Indonesia's transport sector emitted 149,538 thousand tonnes of CO_2 in 2023, while road transport accounted for 90% of transport emissions and 19% of economy-wide emissions in 2022 (Asian Transport Outlook (ATO), 2024). Likewise, Zahari et al. (2024) showed that the transportation sector has become Indonesia's largest energy-demand sector, consuming more than 2.4 million TJ in 2022, with most of that demand still supplied by fossil fuels. Because household mobility in urban areas is still dominated by motorcycles and private cars, transport-related emissions must be considered alongside electricity and cooking fuels when assessing the carbon footprint of community activities (Zahari & McLellan, 2024).

These issues are highly relevant to Kelurahan Kleak, an urban residential area directly adjacent to Sam Ratulangi University in Manado. The study draft indicates that Kleak is composed of six neighbourhood units and has experienced increasing residential density, commercial activity, and daily mobility due to its proximity to the university area, which in turn likely intensifies the use of LPG, electricity, and motorized transport in everyday life. Local statistical reporting also confirms that Kelurahan Kleak is part of Malalayang District, whose geographical and socio-economic characteristics continue to evolve alongside urban development in Manado (BPK Kota Manado, 2024). In such a setting, household carbon-footprint assessment is important not only for quantifying emissions, but also for identifying which routine activities contribute most strongly to local environmental pressure.

Recent scholarship increasingly calls for context-specific and smaller-scale household carbon assessments that can support local mitigation planning more directly than national or provincial averages (Du et al., 2024; Huang et al., 2023; Wang et al., 2025). In the Indonesian case, broader

consumption-based and sectoral studies have already highlighted the importance of household activities, but such macro-scale analyses do not replace neighbourhood-level inventories needed for practical intervention in specific urban communities (Rum et al., 2024). Based on this gap, an assessment of the carbon footprint generated by community activities in Kelurahan Kleak is scientifically and practically relevant. Therefore, this study was conducted to analyze the carbon footprint associated with household activities in Kelurahan Kleak, Malalayang District, Manado City, with emphasis on emissions derived from LPG use, electricity consumption, and motorized transportation.

MATERIALS AND METHODS

Study area and period

The study was conducted from January to March 2026 in Kelurahan Kleak, Malalayang District, Manado City, North Sulawesi, Indonesia. The study area comprises six administrative neighbourhood units (*lingkungan*). This urban settlement was selected because of its proximity to Sam Ratulangi University and its relatively dense residential and mobility activities, which are relevant for household carbon-footprint assessment.

Research design and sampling

This study employed a field-based survey approach using purposive sampling. The purposive sampling technique was applied to ensure that the selected respondents represented households whose activities were relevant to the objectives of the study, namely the estimation of carbon emissions from domestic energy use and private transportation. The target population consisted of residential households in Kelurahan Kleak. Houses used primarily for ordinary family residence were included, whereas stand-alone boarding houses and houses with home-industry activities were excluded from the sampling frame in order to avoid bias from non-household energy consumption patterns.

The number of respondents was determined using the Slovin formula with an error tolerance of 10%, as stated in the original study design. Based on the household distribution in the six neighbourhoods, the final sample allocation consisted of 60 households in Lingkungan 1, 62 households in Lingkungan 2, 53 households in Lingkungan 3, 57 households in Lingkungan 4, 57 households in Lingkungan 5, and 65 households in Lingkungan 6. Thus, the study covered a total of 354 sampled households distributed proportionally across the study area.

Data collection

Both primary and secondary data were used in this study. Primary data were collected through direct observation and household questionnaires. Observation was conducted to identify neighbourhood boundaries and confirm the spatial coverage of the study area. The questionnaire survey was used to obtain household-level information on LPG consumption, electricity use, vehicle ownership, vehicle fuel type, and fuel consumption. Information on installed household electricity capacity was also recorded, including 450 VA, 900 VA, 1300 VA, 2200 VA, 3500 VA, 4400 VA, and 5500 VA service classes.

Secondary data were obtained from official publications and technical references relevant to carbon-emission estimation. These included administrative and household data from local statistics, as well as emission factors, net calorific values, and global warming potential values derived from IPCC-based guidelines and Indonesian technical references used in the study.

Emission sources and system boundary

The carbon-footprint assessment focused on three major household-related emission sources: LPG use for cooking,

electricity consumption, and fuel use in private motorized transport. The system boundary was limited to emissions associated with community activities at the household level within Kelurahan Kleak. For transport, the calculation was based on household-reported fuel consumption for privately used vehicles. The study estimated annual carbon emissions expressed as CO_2 equivalent (CO_2eq) for each neighbourhood and for the kelurahan as a whole.

Carbon-emission calculation

Emissions from LPG consumption

Carbon emissions from LPG use were calculated based on annual fuel consumption multiplied by the corresponding net calorific value, emission factor, and global warming potential. The general equation used in the study followed the IPCC-based approach:

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

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

Emissions from transportation fuel use

Emissions from motorized transport were estimated from annual fuel consumption of private vehicles reported by respondents. The same IPCC-based framework was applied:

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

where KBB is fuel consumption in litres. The analysis considered the fuels reported in the survey, namely Pertamax, Pertalite, and Solar. The emission factors and net calorific values applied in the study 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.

Emissions from electricity consumption

Carbon emissions from electricity use were calculated based on annual electricity consumption and the grid emission factor using the following equation:

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

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 study applied a grid emission factor of 0.78 kg CO_2 kWh^{-1}.

Total household carbon footprint

The total carbon footprint for each neighbourhood was obtained by summing the emissions from LPG use, electricity consumption, and transportation fuel use:

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

where TE_{GHG} is total greenhouse-gas emissions (ton CO_2eq), TE_{LPG} is emissions from LPG consumption (ton CO_2eq), TE_{fuel} is emissions from transportation fuel use (ton CO_2eq), and $TE_{electricity}$ is emissions from electricity consumption (ton CO_2eq). The results were then aggregated to estimate the annual carbon footprint of Kelurahan Kleak.

Data analysis

All survey data were tabulated and converted into annual consumption values for each emission source. Emissions were then calculated separately for each neighbourhood and each activity category using the relevant conversion parameters and emission factors. The results were presented descriptively in terms of total consumption, total carbon emissions, and percentage contribution of each neighbourhood and activity source to the overall carbon footprint of Kelurahan Kleak.

RESULTS AND DISCUSSION

Household energy-use profile in Kelurahan Kleak

Kelurahan Kleak consisted of six neighbourhood units (*lingkungan*) with a total of 873 households. Based on the sampling design described in the study, 354 households were surveyed across the six neighbourhoods. The survey showed that household activities in Kelurahan Kleak were closely associated with three main energy sources, namely LPG for cooking, electricity for domestic use, and fuel for private motorized transport. These three sources formed the basis of the household carbon-footprint inventory in the study area.

The survey results indicated that LPG and electricity were used by virtually all sampled households, confirming that both energy sources are integral to daily domestic activities in the area. In addition, household mobility was dominated by the use of private vehicles, with Pertalite being the most commonly used fuel. This pattern suggests that the urban lifestyle of the community, combined with the strategic location of Kelurahan Kleak adjacent to Sam Ratulangi University, has contributed to relatively high dependence on modern household energy and private transport.

Carbon emissions from LPG use

Annual LPG consumption in Kelurahan Kleak reached 125,915.04 kg year^{-1}, resulting in total emissions of 375.80 ton CO_2eq year^{-1}. Among the six neighbourhoods, the highest LPG-related emissions were recorded in Lingkungan 6, whereas the lowest were observed in Lingkungan 4. This pattern indicates that household cooking activities and related LPG demand were not evenly distributed across the study area.

Table 1. Annual LPG consumption and carbon emissions in Kelurahan Kleak

Neighbourhood	Total LPG consumption (kg year^{-1})	Total LPG emissions (ton CO_2eq year^{-1})
1	20,010.00	59.72
2	20,454.12	61.05
3	16,604.52	49.55
4	14,778.84	44.1
5	18,445.20	55.05
6	35,622.36	106.32
Total	125,915.04	375.8

Lingkungan 6 contributed the largest share of LPG-related emissions, accounting for approximately 28.3% of total LPG consumption and 106.32 ton CO_2eq year^{-1}. This result is consistent with the profile of the area as a more densely occupied and highly active residential zone. The manuscript also indicates that this neighbourhood is directly adjacent to the university area and includes a greater number of households and food-related activities, which may increase cooking intensity and LPG use. In contrast, Lingkungan 4 showed the lowest LPG emissions at 44.10 ton CO_2eq year^{-1}, suggesting lower overall household gas consumption.

Although LPG contributed the smallest share of total carbon emissions among the three sources evaluated, it still represented an important component of household energy demand. The relatively lower emission contribution of LPG compared with transport fuel and electricity is largely attributable to its lower total annual energy consumption and lower carbon intensity per unit of activity than motorized transport.

Carbon emissions from electricity consumption

Electricity use represented the second-largest source of household carbon emissions in Kelurahan Kleak. Total annual electricity consumption reached 3,351,138.24 kWh year^{-1}, generating 2,613.89 ton CO_2eq year^{-1}. The highest electricity-related emissions occurred in Lingkungan 6, followed by Lingkungan 2,

while the lowest were found in Lingkungan . 4.

Table 2. Annual electricity consumption and carbon emissions in Kelurahan Kleak

Neighbourhood	Total electricity consumption (kWh year^{-1})	Total electricity emissions (ton CO_2eq year^{-1})
1	489,061.20	381.47
2	670,329.84	522.86
3	507,817.32	396.1
4	454,556.28	354.55
5	539,627.64	420.91
6	689,745.96	538
Total	3,351,138.24	2,613.89

The large contribution of electricity to the household carbon footprint reflects the central role of electrical energy in domestic life, including lighting, cooling, cooking support appliances, and other household electronics. The concentration of households in the 900 VA and 1300 VA categories further suggests that medium-level electricity use is common in the study area. However, when multiplied by the annual consumption volume and the grid emission factor, the resulting emissions become substantial.

Lingkungan 6 produced the highest electricity emissions at 538.00 ton CO_2eq year^{-1}, while Lingkungan 2 followed closely with 522.86 ton CO_2eq year^{-1}. This result indicates that neighbourhoods with more concentrated settlement patterns and greater residential intensity also tend to generate larger indirect emissions from electricity use. Because grid electricity is still largely linked to fossil-fuel-based power generation, high household electricity demand translates directly into higher carbon emissions. By contrast, Lingkungan 4 had the lowest electricity-related emissions, which corresponds to its lower total annual consumption.

Carbon emissions from transportation fuel use

Transportation fuel use was the dominant contributor to the total household carbon footprint in Kelurahan Kleak. The total annual fuel consumption for private transport reached 1,502,854.08 L year^{-1}, producing 3,609.97 ton CO_2eq year^{-1}. This was substantially higher than the emissions generated by either LPG or electricity use.

Table 3. Annual transportation fuel consumption and carbon emissions in Kelurahan Kleak.

Neighbourhood	Total fuel consumption (L year^{-1})	Total transport emissions (ton CO_2eq year^{-1})
1	105,133.32	253.15
2	145,748.52	350.95
3	248,392.44	596.82
4	135,101.88	325.31
5	251,910.00	605.01
6	616,567.92	1,478.73
Total	1,502,854.08	3,609.97

The dominance of transport emissions indicates that daily mobility patterns in Kelurahan Kleak are highly dependent on fossil-fuel-based vehicles. Pertalite was the most widely used fuel among respondents, whereas diesel use was not recorded in the surveyed households. This result is important because it shows that, at the household level, routine travel behaviour may exceed the carbon impact of domestic cooking and electricity use.

Lingkungan 6 was by far the largest transport-related emitter, contributing 1,478.73 ton CO_2eq year^{-1}, or about 41.0% of total transport emissions. This very high contribution suggests that the area experiences more intense private-vehicle activity than the other neighbourhoods. This may be related to higher household density, greater mobility demand, and stronger interaction with the surrounding university and urban service areas. In contrast, Lingkungan 1 had the lowest transport emissions, at 253.15 ton CO_2eq year^{-1}.

The predominance of transport emissions also highlights the importance of household mobility in local carbon-footprint assessments. Unlike LPG and electricity, which are mainly linked to domestic activities within the home, vehicle fuel consumption reflects a broader pattern of daily movement. Therefore, the transport sector appears to be the most critical target for carbon mitigation in Kelurahan Kleak.

Total household carbon footprint in Kelurahan Kleak

The total household carbon footprint in Kelurahan Kleak, calculated from LPG use, electricity consumption, and transportation fuel use, reached 6,599.65 ton CO_2eq year^{-1}. Among the six neighbourhoods, Lingkungan 6 contributed the highest total emissions, while Lingkungan 1 contributed the lowest. The distribution of total emissions clearly shows spatial variation in household energy use and transport behaviour across the kelurahan.

Table 4. Total household carbon footprint in Kelurahan Kleak

Neighbourhood	LPG (ton CO_2eq year^{-1})	Electricity (ton CO_2eq year^{-1})	Transport fuel (ton CO_2eq year^{-1})	Total (ton CO_2eq year^{-1})	Share (%)
1	59.72	381.47	253.15	694.34	10.52
2	61.05	522.86	350.95	934.85	14.17
3	49.55	396.1	596.82	1,042.47	15.8
4	44.1	354.55	325.31	723.97	10.97
5	55.05	420.91	605.01	1,080.96	16.38
6	106.32	538	1,478.73	2,123.05	32.17
Total	375.8	2,613.89	3,609.97	6,599.65	100

When aggregated by source, transportation fuel accounted for the largest proportion of total emissions, contributing 54.70% of the total carbon footprint. Electricity followed with 39.61%, while LPG contributed only 5.69%. These results indicate that transport and electricity are the two dominant drivers of household carbon emissions in Kelurahan Kleak, with transport representing the principal source of local carbon pressure.

The very high contribution of Lingkungan 6 is notable, as it alone accounted for 32.17% of the total household carbon footprint of the kelurahan. This suggests that this neighbourhood has the most intensive combination of household energy use and mobility demand. The result is consistent with the local context described in the manuscript, namely that Kelurahan Kleak has experienced growing residential and economic activity associated with its proximity to Sam Ratulangi University. Such development tends to increase electricity demand, cooking energy use, and especially private-vehicle dependence.

From an environmental perspective, the findings demonstrate that emissions from everyday residential activities can accumulate to a considerable level even at the neighbourhood scale. The total carbon footprint identified in this study confirms that local communities contribute meaningfully to greenhouse-gas emissions through routine household behaviour. Consequently, mitigation efforts at the kelurahan level should focus primarily on

the most emission-intensive sources, particularly transportation and electricity use. Measures such as improving energy efficiency, promoting low-emission household practices, encouraging the use of public or shared transport, and strengthening awareness of energy-saving behaviour may help reduce the local carbon burden.

Overall, the results show that the household carbon footprint in Kelurahan Kleak is shaped more strongly by mobility and electricity consumption than by cooking fuel use. This finding is important for local environmental planning because it suggests that emission-reduction strategies should not focus solely on household energy within the dwelling, but also on the broader lifestyle and transport patterns of urban residents.

CONCLUSION

This study showed that household activities in Kelurahan Kleak generated a substantial carbon footprint derived from three main sources, namely LPG use, electricity consumption, and transportation fuel use. The total household carbon footprint of the study area reached 6,599.65 ton CO_2eq year^{-1}, indicating that routine residential energy use and private mobility contribute significantly to local greenhouse-gas emissions. Among the assessed sources, transportation fuel was the largest contributor, followed by electricity consumption, whereas LPG use contributed the smallest share of total emissions.At the neighbourhood level, Lingkungan 6 was identified as the highest emitter, contributing 2,123.05 ton CO_2eq year^{-1}, or 32.17% of the total carbon footprint of Kelurahan Kleak. This result suggests that differences in household density, energy demand, and transport intensity strongly influenced the spatial distribution of emissions across the study area. By contrast, the lowest total emissions were recorded in Lingkungan 1, indicating that household carbon footprints varied considerably among neighbourhoods. Overall, the findings confirm that household carbon emissions in Kelurahan Kleak were driven more strongly by mobility patterns and electricity use than by cooking-fuel consumption. This implies that local mitigation efforts should prioritize measures aimed at reducing transport-related fuel use and improving household electricity efficiency. Therefore, the present study provides an empirical basis for neighbourhood-scale carbon management and may serve as a reference for community-based climate-mitigation strategies in urban residential areas.

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