Residential energy and transport coupling for neighborhood decarbonization in transit-oriented development

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Abstract. Urban energy transitions are most meaningful when operational energy use in buildings and everyday mobility is assessed together rather than in isolation. This study examines how residential and transport energy jointly shape neighbourhood-level carbon footprints in a transit-oriented context by coupling Building Energy Use and Transport Energy Use for 700 households located within a 500 m buffer of Bus Rapid Transit (BRT) stations in a rapidly growing metropolitan setting. Monthly electricity and natural gas bills are used to derive household energy use, while self-reported travel diaries (modes, distances and trip frequencies) provide transport energy use; both are converted to CO_2e using standardized energy-to-carbon factors. Building and transport results for the sample are synthesised to construct household's total energy use and CO_2 footprint and to compare station-level patterns along the corridor. Results indicate that an average household's transport energy use is roughly twice its residential operational energy use, and that buildings and transport make broadly comparable contributions to direct operational CO_2 emissions. Central, well-serviced station areas generally exhibit lower combined (building and transport) energy consumption than more peripheral locations, suggesting that compact, transit adjacent residential environments moderate mobility energy demand while accommodating diverse building operational intensities. The study concludes that integrating residential efficiency measures with mobility planning and transit-oriented development can provide more effective and scalable carbon reductions than treating building and transport policies separately.

Keywords. Building Energy Use Intensity, Transport Energy Use Intensity, Transit-Oriented Development, Carbon Efficiency, Bus Rapid Transit

1 Introduction

Urban climate policy increasingly hinges on what happens inside households, where energy use in buildings and transport together drives much of final energy demand. The buildings sector alone accounts for roughly one-third of global final energy consumption and a similar share of energy related CO_2 emissions when operational and embodied impacts are combined [1]. Global transport energy use is rising steeply, with petroleum fuels still dominant, and the movement of people and freight simultaneously underpinning economic development while worsening climate change, air quality, health, and safety outcomes [2, 3]. Yet research and policy still tend to treat these sectors in isolation, through separate building codes, appliance standards, and transport or fuel policies, even though the same households are simultaneously lighting and cooling dwellings and generating daily travel demand.

A substantial literature estimates household carbon footprints from residential energy use, housing characteristics or expenditure surveys, showing that household consumption is responsible for well over half of global greenhouse gas emissions, with housing and mobility among the dominant components [4, 5]. Detailed country studies such as Goldstein et al. [6] for the United States and Druckman & Jackson [7] for the United Kingdom show how these footprints vary with income, dwelling type and lifestyle. In parallel, transport research has examined emissions and the mitigation potential of compact urban form, active modes and high-capacity public transport, for example in Creutzig et al. [8] and related urban mitigation assessments [9].

A smaller set of studies begins to integrate housing and transport within common frameworks, often by defining representative household types or combining spatially aggregated building and mobility data, but these contributions usually operate at metropolitan or neighborhood scale and draw on data rich contexts in the Global North [10-12]. A clear empirical gap remains: very few studies assemble matched estimates of building and transport energy use for the same households and use these to describe a whole of household operational energy and direct CO_2 footprint, particularly in rapidly urbanizing

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regions of the Global South where rising incomes, motorization and air conditioning ownership are reshaping both residential and mobility demand [13, 14].

This paper addresses that gap by treating the household as a single energy using unit spanning residential buildings and everyday transport. Using detailed survey and energy information for households located along a high-density transit corridor, the study synthesizes previously completed sectoral analyses of residential and transport energy into a unified picture. Rather than proposing new models, it reframes existing results around a single guiding question: how do residential buildings and everyday transport jointly contribute to total operational energy use and direct CO2 emissions of urban households in this transit corridor, and what does this combined footprint imply for integrated housing and mobility decarbonization strategies?

2 Literature Review

The literature on urban energy and climate spans three partly connected strands: household carbon footprints, residential (building) energy demand, and transport related emissions. First, a large body of work uses consumption based accounting and multi-regional input output (MRIO) models to attribute emissions to household demand [15-17]. According to recent consumption-based analysis, household consumption is responsible for around 72% of global greenhouse gas emissions once upstream supply chain impacts are allocated to final demand [18]. Country level analyses in high income settings such as the United States and the United Kingdom show that household carbon footprints increase strongly with income and are largely driven by housing and transport demand, with differences in dwelling characteristics and lifestyle explaining much of the variation across households [19, 20].

Within this broader footprint literature, a second strand focuses specifically on residential energy use and building related emissions. Large national datasets reveal how climate, building stock and energy infrastructure combine with socio-economic factors to shape household energy demand. For example, an analysis of 93 million US homes shows that residential energy accounts for roughly one-fifth of national greenhouse gas emissions, and that building age, size, heating fuel and neighborhood affluence are key drivers [6].

Neighborhood-scale life cycle assessments shows the importance of built form: case studies for suburban Melbourne and European housing stocks show that shifting from large, detached dwellings toward smaller, denser typologies such as townhouses and apartments can substantially reduce combined embodied and operational energy use and associated emissions [10, 21, 22]. This work underlines that residential energy demand is about appliance efficiency but also of morphology and location.

A third body of research examines transport energy and emissions, with a strong emphasis on the built environment and modal shift. Meta-analysis of empirical studies finds that higher density, mixed land use and better regional accessibility are systematically associated with shorter trip lengths, lower car dependence and reduced vehicle-kilometres travelled [23]. Global typologies of urban energy use show that compact, transit-oriented cities can substantially reduce per-capita transport and building energy use relative to sprawling, car-oriented patterns [24]. At a more applied level, studies of public transport and active travel policies document the potential for mode shift towards buses, rail, walking and cycling to cut urban transport emissions when combined with supportive land-use and street-design changes [25, 26].

Growing set of studies attempts to bridge buildings and transport within integrated frameworks. Multi-scale life-cycle analyses for neighbourhoods or city districts calculate embodied and operational energy of both buildings and mobility infrastructure, showing how changes in density, dwelling type and vehicle technology jointly affect long-term emissions [21, 27]. Urban systems research argues that climate solutions should be structured around infrastructures such as buildings, transport and energy networks, rather than isolated sectors, and estimates the mitigation potential of coordinated interventions across these domains [8, 28]. Household level carbon mapping for US cities goes one step closer to the present study by combining direct household energy, transport and consumption-related emissions in a single footprint for each location, revealing systematically higher footprints in car dependent suburbs [20, 29].

Recent work on transitional urban mobility systems further reinforces the need to treat transport, land use and equity as an integrated whole, with analyses of mode choice and socio-spatial equity in contrasting new town contexts showing how income, transit accessibility and built form jointly shape car dependence and public transport use in ways that can either entrench or ease spatial inequities [30]. Complementary studies in rapidly urbanizing settings highlight that integrating land use and transport planning can improve energy efficiency and reduce pollution, with coordinated densification around transit, mixed land use and strengthened public transport emerging as key levers for urban energy transitions [31].

Despite these advances, a specific gap remains. Existing integrated assessments typically operate at national, metropolitan or neighborhood scales, or rely on synthetic representative households. Very few studies assemble matched estimates of operational building energy and everyday transport energy for the same real households in rapidly urbanizing, data-constrained contexts. As a result, we still know relatively little about how residential and transport energy jointly shape the total operational energy and direct CO_2 footprint of individual urban households in transit-served corridors in the Global South, and about which household types or locations emerge as priorities when both sectors are considered together.

3 Materials and Methods

3.1 Study Area and Sampling Framework

The study is set in Lahore, Pakistan, the capital of Punjab province and one of South Asia's fastest-growing metropolitan regions. Lahore combines dense inner-city neighborhoods and rapidly expanding peripheral suburbs, with marked contrasts in income, housing form and access to services. The city's main north–south spine is served by a 27-km Bus Rapid Transit (BRT) corridor, the Lahore Metrobus, which provides high-capacity bus service along Ferozepur Road and across the River Ravi (**Figure 1**).

The analysis is based on 700 households located within the influence area of this 27-km BRT corridor, running from Gajjumata in the south to Shahdara in the north. The corridor traverses' neighbourhoods that differ in density, income, housing type and access to services, and was divided into seven station areas: Gajjumata, Yohanabad, Ghazi Chowk, Ichhra, Kalma Chowk, Azadi Chowk and Shahdara. For each station, a 500m buffer was delineated and 100 households were selected at each station, through door-to-door surveying, yielding a balanced sample of 700 observations across the corridor. This spatially stratified design captures variation in socio-economic profiles, dwelling characteristics and mobility patterns between inner-city and peripheral locations, while keeping all households broadly comparable in terms of formal access to the BRT system.

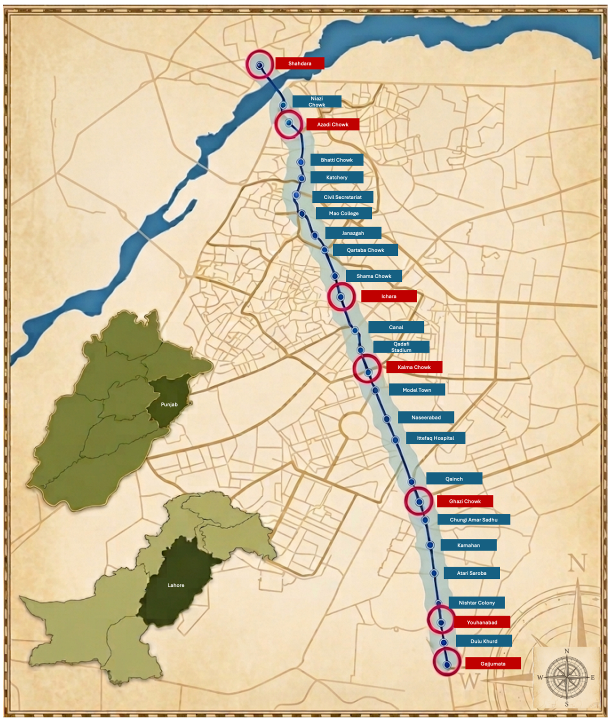

Fig. 1. BRT Route and Selected Station Points

3.2 Household survey and data collection

Fieldwork was conducted during June and July, representing peak summer conditions and thus high residential cooling demand. Trained surveyors administered a structured questionnaire at respondents' homes. The instrument combined closed and open-ended questions organized into four blocks:

- Socio-economic attributes: household size, income, tenure, education and occupation.
- Building characteristics: age, construction type, wall and roof materials, number of floors, covered area, ventilation, and presence of retrofits or insulation
- Appliances and energy use: electricity and natural gas bills, ownership and use of major appliances, space cooling and heating practices, and use of back-up systems such as UPS or generators.
- Mobility patterns: daily trip frequency and distance, trip purposes, vehicle ownership (car, motorcycle), preferred modes, BRT use, and reasons for mode choice.

Completed questionnaires were entered and cleaned in SPSS; observations with missing or inconsistent core variables were removed prior to analysis.

3.3 Building Operational Energy Use and Emissions

Building operational energy use is defined as the sum of annual electricity and natural gas consumption at household level. Metered quantities were taken from verified utility bills and converted into kilowatt-hours per year (kWh/yr) for each household.

Total annual building operational energy use for household h is given by:

$$E^h_{build} = E^h_{elec} + E^h_{gas} \quad (1)$$

where E^h_{elec} and E^h_{gas} denote yearly electricity and gas use (kWh). Emissions are computed using Pakistan-specific emission factors of 0.615 kg CO_2/kWh for grid electricity and 0.202 kg CO_2/kWh for natural gas, yielding household operational emissions in tonnes CO_2e per year.

For descriptive benchmarking and to link with the transport results, the paper draws on previously calculated indicators of mean building energy use, energy intensity (kWh/m²/yr) and associated CO_2e, as reported in the original building-energy analysis

3.4 Transport Energy Use and Emissions

Transport energy use is derived from self-reported daily trips by mode, trip distance and frequency for the same surveyed households. For each household, total annual passenger-kilometres (pkm) are calculated as:

$$\text{Passenger-km} = \sum_m^M (distance_m * trips_m) \quad (2)$$

where m indexes modes (car, motorcycle, rickshaw, BRT). Standard benchmark energy intensities (kWh/pkm) are then applied: 0.40 for cars, 0.18 for motorcycles, 0.15 for rickshaws, and 0.08 for BRT. Total annual transport energy use (E_{trans}) is the sum of mode-specific passenger-km multiplied by the relevant intensity. Transport-related emissions (C_{trans}) are calculated using fuel-based emission factors of 0.246 kg CO_2/kWh for petrol and 0.257 kg CO_2/kWh for diesel. BRT is diesel-based, while all other motorized trips are petrol-based. The present paper relies on previously derived distributional statistics, station-wise patterns, and regression results for transport energy and CO_2e from the dedicated transport chapter.

3.5 Whole-of-household Metrics

To construct a whole-of-household view, building and transport metrics for each surveyed household are conceptually combined. Total operational energy use is defined as:

$$E_{tot}^{h} = E_{build}^{h} + E_{trans}^{h} \quad (3)$$

and total direct CO_2e emissions as:

$$C_{tot}^{h} = C_{build}^{h} + C_{trans}^{h} \quad (4)$$

Although the original micro-data are no longer accessible for re-estimation, the paper uses reported means, ranges, and station-wise distributions of (E_{build}^{h}), (E_{trans}^{h}) , (C_{build}^{h}) , and (C_{trans}^{h}) to approximate the composition of (E_{tot}^{h}) and (C_{tot}^{h}) for the “average” household and for contrasting station areas.

The analytical strategy therefore explains existing sectoral findings are re-framed around the household as a single energy-using unit. Building and transport results are first summarised separately and then interpreted jointly to: (i) characterise the typical split between residential and transport energy in total household demand; and (ii) infer which stations and household profiles are likely to occupy the upper end of the whole-of-household energy and CO_2 distribution along the BRT corridor.

4 Results

4.1 Patterns of Residential Building Energy Use along the BRT corridor

Total residential energy use along the corridor is high but strongly clustered in a moderate band. For the 700 surveyed households, annual building energy consumption (electricity and gas) ranges from about 2,000 to 17,999 kWh/yr, with a mean of 8,796 kWh/yr and a standard deviation of 2,938 kWh/yr **(Figure 2)**.

Almost half of all households fall between 6,000 and 9,999 kWh/yr, with the single most common band being 8,000–9,999 kWh/yr (26.4% of the sample), followed by 6,000–7,999 kWh/yr (21.9%). Only a small minority (1.6%) exceeds 16,000 kWh/yr, while 3.9% consume less than 4,000 kWh/yr, corresponding to smaller or lower-income dwellings. Based on the socio-economic data, average floor area is 109 m², this translates into an average operational intensity of roughly 80 kWh/m²/yr, which lies toward the upper end of reported ranges for South Asian residential buildings and above domestic survey benchmarks for Punjab [32].

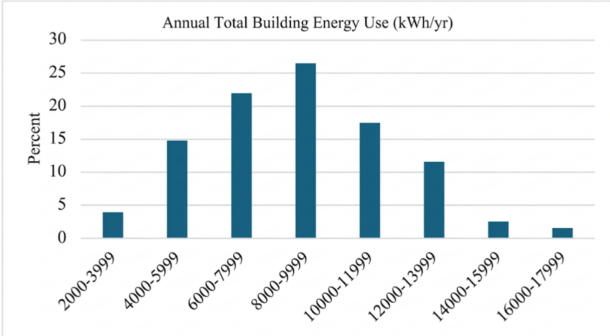

Fig. 2. Annual Total Building Energy Use (kWh/yr)

Spatially, household building energy use varies meaningfully by station. Kalma Chowk and Ghazi Chowk show the highest concentration of households in the 10,000–13,999 kWh/yr band, consistent with larger dwellings and higher appliance ownership in more central, affluent locations. In contrast, Shahdara and Gajjumata have more households in the 8,000–9,999 kWh/yr range, indicating mid-income, moderate-use profiles, while Ichhra and Yohanabad display a wider spread across 4,000–9,999 kWh/yr, reflecting mixed socio-economic conditions (**Figure 3**).

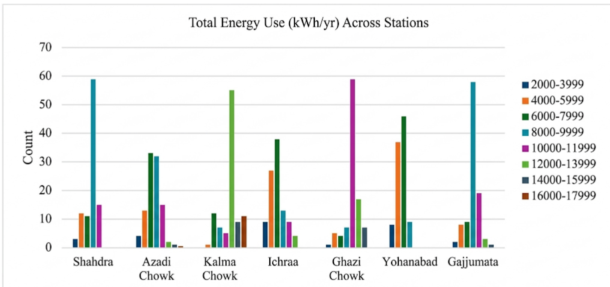

Fig. 3. Total Energy Use (kWh/yr) across BRT Stations

The corresponding building-related CO_2 emissions reinforce these patterns. Average operational emissions from buildings are 3.6 tCO_2e/yr per household (SD 1.59), equivalent to roughly 0.69 tCO_2e per capita for an average household size of 5.25 persons. Station-wise, Yohanabad, Shahdara and Kalma Chowk have the highest shares of households in the upper emission band (above 4.68 tCO_2e/yr), whereas Ichhra and Gajjumata show lower proportions of high-emission households, consistent with smaller homes and lower overall demand **(Figure 4)**.

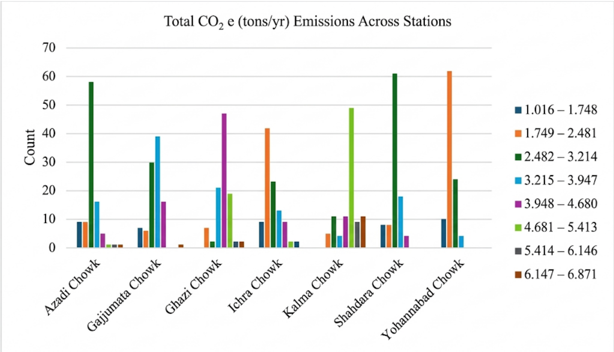

Fig. 4. Total CO2 e (tons/yr) across BRT Stations

Collectively, the building side of the corridor is characterised by a moderately high average energy intensity, a right-skewed distribution driven by a minority of high-consumption and clear spatial differentiation between more energy-intensive central/peripheral stations and lower-intensity middle-corridor areas.

4.2 Transport Energy Demand and Modal Effects on Household Footprints

Household transport energy use is, on average, substantially larger than residential building energy use and exhibits an even more pronounced right skew. Annual transport energy demand averages about 17,200 kWh/yr per household, with most households falling between 1,000–10,000 kWh and 10,001–20,000 kWh **(Figure 5)**. A small share extends into 20,001–30,000 kWh/yr, and only a very small fraction exceeds 50,000 kWh/yr, representing long commutes or heavy reliance on private motorised modes. These values are higher than national benchmarks for transport energy, underlining the intensity of urban travel along the corridor [33].

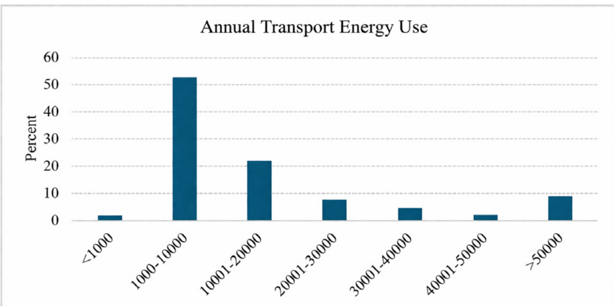

Fig. 5. Total Annual Transport Energy Use (kWh/yr)

Station-wise distributions show distinct mobility signatures **(Figure 6)**. Kalma Chowk and Shahdara have the highest concentrations of households in the 10,001–20,000 and 20,001–30,000 kWh/yr bands, signalling greater travel demand and/or longer routine distances. In contrast, Gajjumata and Azadi Chowk have more households in the lower energy ranges, suggesting shorter, localised travel. High-energy categories above 50,000 kWh/yr are rare but are most visible in Ghazi Chowk and Yohanabad, pointing to a small group of extreme commuters.

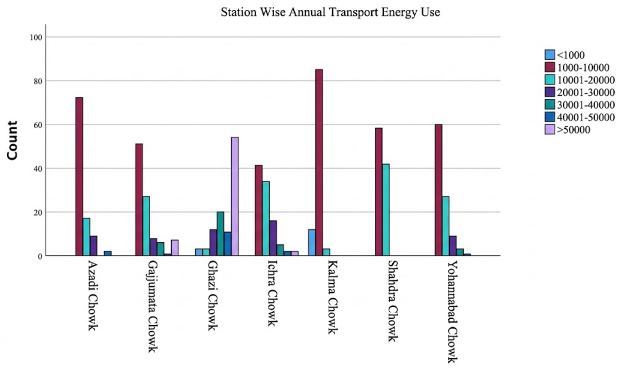

Fig. 6. Total Annual Transport Energy Use (kWh/yr) across BRT Stations

Transport-related CO_2 emissions show a similar skew. The vast majority of households emit less than 5 tCO_2/yr from transport, with a smaller cluster between 5–10 tCO_2/yr and very few in higher brackets above 15–20 tCO_2/yr. Average annual transport emissions are about 4.23 tCO_2/yr per household, which is above Pakistan's per-capita transport emissions once adjusted for household size, reflecting the energy intensity of urban motorised travel (**Figure 7**).

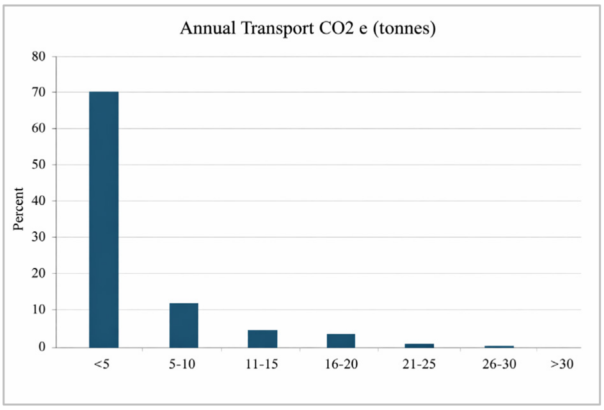

Fig. 7. Total Annual Transport CO2 e (tons/yr)

Descriptive indicators underline the behavioural basis of this demand. Most households report 4–6 trips per day, dominated by work and education travel, with daily distances clustered in the short-to-medium range. Motorcycles are by far the most common owned and preferred mode, followed by households owning both car and motorcycle, and a smaller group relying only on cars. BRT appears as a secondary mode despite being present along the corridor.

Correlation analysis confirms that average daily distance travelled is the dominant determinant of transport energy use ($r = 0.769$, $p < .001$), with daily trip frequency playing a secondary role ($r = 0.378$, $p < .001$). An independent-samples t-test shows very large and statistically significant differences between BRT users and non-users: BRT-using households consume on average 9,378 kWh/yr, compared with 21,994 kWh/yr for non-users, a gap of roughly 12.6 MWh/yr ($t = -8.527$, $p < .001$; Hedges' g –0.60).

Regression analysis further highlights car dependence as a key driver. Relative to households without vehicles, car owners use around 15,481 kWh/yr more transport energy, while motorcycle ownership alone does not significantly increase demand. Using BRT users as reference, car users consume about 13,840 kWh/yr more, whereas motorcycle and rickshaw users consume 4,113 kWh/yr and 3,822 kWh/yr less, respectively. Mode-choice motives also matter respondents choosing modes for accessibility or comfort/convenience have significantly lower transport energy use than those prioritising time savings, and work/education-oriented households consume about 6,205 kWh/yr more than recreation-oriented ones. These results explain that longer daily distance, car ownership and car use, and routine commuting emerges as the strongest transport-side drivers of high household energy demand.

4.3 Integrated Household Energy Footprint: Coupling Buildings and Transport

Taken together, the building and transport results reveal a strongly unbalanced whole-of-household energy profile. To see how building and transport energy are coupled across contexts, we interpret corridor patterns using two measurable proxies: dwelling scale (floor area/size) and mobility dependence (distance and mode choice). In our sample, average residential energy use is 8,796 kWh/yr with mean floor area 109 m² **(**≈ 80 kWh/m²/yr**)**, suggesting that larger or higher-amenity units, often more common in central station areas, can elevate building energy demand. Meanwhile, transport energy is higher (~17,200 kWh/yr) and strongly shaped by context: distance travelled correlates with transport energy ($r = 0.769$, $p < .001$)**,** and BRT users consume ~9,378 kWh/yr versus ~21,994 kWh/yr for non-users. Hence, these results indicate that central areas may exhibit higher building loads but lower mobility energy (shorter trips, better access), while peripheral areas may show the opposite, making outcomes jointly dependent on housing form/size and mobility condition. Using the reported means, an average corridor household consumes about 8,800 kWh/yr in buildings and 17,200 kWh/yr in transport. This implies a combined operational energy use of 26,000–27,000 kWh/yr, of which roughly two-thirds (66%) is associated with everyday mobility and one-third (34%) with running the dwelling (**Table 1**).

Based on average emissions, the combined whole-of-household CO_2 footprint is about 7.8 tCO_2e/yr, with transport contributing slightly more than half (54%) and buildings the remainder (46%). From a mitigation perspective, this means that, along this transit corridor, transport energy slightly dominates total household demand, while building and transport emissions are of comparable magnitude. In other words, focusing only on buildings would overlook about half of the direct operational CO_2 footprint; focusing only on transport would miss a similar share.

Table 1. Whole-of-household operational energy use and direct CO_2 emissions for the average corridor household

Component	Annual energy use (kWh/yr/ household)	Share of total energy (%)	Annual direct CO_2e (tCO_2e/y/ household)	Share of total CO_2e (%)
Buildings	8,800	34	3.6	46
Transport	17,200	66	4.2	54
Total	26,000	100	7.8	100

The station-wise patterns indicate that on the building side, Yohanabad, Shahdara and Kalma Chowk have the largest shares of households in the highest CO_2e band and higher fractions of high-use (10,000–13,999 kWh/yr) homes. On the transport side, Kalma Chowk and Shahdara stand out with greater concentrations in the 10,001–30,000 kWh/yr bands, while high-energy outliers above 50,000 kWh/yr are most visible in Ghazi Chowk and Yohanabad. Interpreted jointly, these distributions indicate that Kalma Chowk, Shahdara and Yohanabad are the most plausible whole-of-household hotspots, where both residential and mobility energy are elevated for a significant minority of households, whereas Gajjumata and Ichhra are more likely to host lower-intensity profiles on at least one side.

Even without re-estimating models on the combined dataset, the sectoral determinants point to household types that are likely to sit at the top of the whole-of-household energy distribution. On the building side, higher floor area, more appliances (especially air conditioning), and higher incomes are associated with increased total energy demand. On the transport side, car ownership and car use, long daily distances, and commuting for work and education sharply raise energy use, while BRT use and two-wheeler modes significantly moderate it. Taken together, this implies that high-income, larger, car-owning households in central or peripheral station areas with long commuting distances are the most likely to be "double-high" in both building and transport energy. Conversely, smaller, middle-income, motorcycle-reliant or BRT-using households in more compact station areas are more likely to occupy the lower end of the combined energy spectrum.

5 Discussion and Policy Implications

The results show that, along this transit corridor, transport energy dominates total household demand in kWh terms, while building and transport emissions are of comparable magnitude. For the "average" household, roughly two-thirds of operational energy is associated with everyday mobility and one-third with running the dwelling, yet buildings still contribute nearly half of direct

CO_2e. This confirms that neither sector can be treated as marginal: a meaningful decarbonisation strategy must address both housing and mobility together, rather than sequentially or in isolation.

A first implication is that transport policy cannot be an afterthought in household energy debates. Urban energy discussions in many low- and middle-income countries still gravitate toward electricity shortages, appliance efficiency and building codes. The corridor evidence suggests that even substantial gains in residential efficiency would, on their own, leave a very large transport-related component untouched. At the same time, a purely mobility-focused strategy that reduces car dependence but leaves high cooling loads and leaky envelopes in larger dwellings unchanged would only partially cut the whole-of-household footprint. Policy needs to be framed explicitly around the sum of building and transport energy, not just the performance of each silo.

Second, the spatial concentration of "double-high" households, particularly in Kalma Chowk, Shahdara and Yohanabad, points to the value of geographically targeted interventions. These stations combine relatively high dwelling energy use and higher transport energy bands, suggesting a subset of households with large homes, higher appliance ownership, car access and long commutes. In such hotspots, an integrated package could be prioritised:

- On the housing side: incentives for envelope retrofits, shading, efficient air-conditioning and appliance upgrades, potentially linked to utility on-bill financing or targeted subsidies.
- On the mobility side: improved BRT service quality and reliability, feeder connections, safer walking and cycling access, and demand-management measures that make private car use less attractive for routine commuting.

Conversely, in stations such as Gajjumata and Ichhra, where at least one side of the energy profile tends to be lower, lighter-touch or more incremental measures may suffice, focusing on preserving compact form, supporting two-wheeler and BRT use, and avoiding the lock-in of more energy-intensive dwelling.

Third, the analysis highlights household types that should be prioritised for whole-of-household interventions. High-income, larger, car-owning households with long work and education commutes are the most likely to sit at the top of the combined energy distribution. They are also typically better placed to respond to pricing signals and investment incentives. Policy instruments such as progressive electricity and fuel tariffs, targeted grants or low-interest loans for retrofits and EVs, and parking and congestion measures near employment centres could be explicitly designed with this group in mind, while ensuring that basic mobility and thermal comfort remain affordable for lower-income households.

Fourth, the findings reinforce arguments for transit-oriented development (TOD) as an energy policy, not just a transport or land-use strategy. When higher-density, mixed-use housing around BRT stations is combined with strict parking standards, good non-motorised access and minimum efficiency requirements for new buildings, households can simultaneously reduce both their transport and residential energy needs. In the corridor context, this suggests that future growth around stations like Shahdara and Kalma Chowk should be steered toward compact, energy-efficient forms rather than larger, car-oriented developments.

Finally, the study's synthetic approach limits joint household-level modelling and the analysis of rebound effects and temporal change. Future work using panel billing and GPS-based travel data could examine how shocks, such as fuel price shifts, BRT improvements, or heatwaves, reallocate energy use between buildings and transport within households. Even so, the results clearly argue for urban energy and climate policy that treats the household as an integrated system encompassing both the dwelling and daily mobility.

6 Conclusion

This paper set out to treat the urban household as a single energy-using unit, spanning residential buildings and everyday transport, rather than as two separate sectors. Using detailed, sectoral analyses for 700 households along a high-capacity transit corridor, it synthesised building and transport results into a whole-of-household picture of operational energy use and direct CO2 emissions. The central finding is that, in this context, transport energy dominates total household demand in kWh terms, accounting for roughly two-thirds of average operational energy, while buildings contribute about one-third. Yet in emissions terms, the two sectors are of comparable magnitude, with buildings responsible for nearly half of direct CO2e.

This combined view matters. It shows that single-sector interventions are structurally insufficient: a strategy focused only on appliance efficiency and building envelopes will leave a large transport-related footprint untouched, while a strategy centred solely on modal shift and transit improvements will leave a substantial residential baseline in place. Station-wise patterns further reveal "hotspots" where high dwelling and transport energy use coincide, and sectoral determinants point to specific household types, larger, higher-income, car-owning, long-distance commuters, as most likely to sit at the top of the combined distribution.

Conceptually, the study reframes sectoral evidence around whole-household energy, showing what can be learned without new model estimation. Practically, it supports urban policies that target combined building and transport energy through place-based packages linking retrofits, transit-oriented development, and demand management. Future research using household-level and longitudinal data could examine how shocks and policies shift energy use between housing and mobility over time.

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