Micro-Level Determinants of Transport Energy Demand and Emissions: Evidence from Household Travel Behavior in Kathmandu Valley

Abstract

Transport energy demand and emissions are increasing rapidly in South Asian cities, yet household-level evidence remains scarce. This study examines household travel behavior, transport energy use, and associated CO_2 emissions in Kathmandu Valley, Nepal. A representative survey of 384 households was combined with discrete choice modeling, energy and emission estimation, and scenario analysis.

The results show that two-wheelers dominate household mobility, contributing 42% of total energy demand and 38% of CO_2 emissions. Cars, though less common, account for 33% of emissions due to their high fuel intensity. Multinomial and nested logit models revealed that income, education, and vehicle ownership are statistically significant determinants of mode choice. High-income households consume nearly twice the daily transport energy of low-income households. An equity analysis confirmed moderate inequality, with a Gini coefficient of 0.32.

Scenario simulations indicated that demand- and supply-side interventions can deliver meaningful reductions. Enhancing public transport reduces emissions by 18%, promoting electric vehicle adoption by 22%, while an integrated policy mix achieves up to 35% reduction relative to business-as-usual. Sensitivity analysis highlighted fuel efficiency and vehicle ownership as the most influential parameters.

This study makes three key contributions: (i) generating the first micro-level dataset on household transport energy in Nepal, (ii) applying discrete choice models to capture behavioral and equity dynamics, and (iii) providing evidence-based pathways for sustainable mobility. The findings emphasize that transport policies must integrate public transport improvements, equitable EV promotion, and ride-sharing platforms to achieve a just and low-carbon transition in South Asia.

Keywords: Household travel behavior, Transport energy demand, CO_2 emissions, Mode choice modeling, Electric vehicles, Equity, Kathmandu Valley, Policy scenarios

Introduction

Transport is one of the fastest-growing sources of energy demand and greenhouse gas (GHG) emissions worldwide. It accounts for nearly one-quarter of global final energy use and about 20 % of CO_2 emissions (Teske & Niklas, 2022). Rapid motorization and weak public transport systems have intensified energy dependence and environmental pressures, particularly in developing countries (Oakil et al., 2022). In South Asia, rising incomes, urban sprawl, and inadequate infrastructure have transformed household mobility, increasing reliance on private vehicles and fossil fuels (Mohajeri & Gudmundsson, 2024). Cities such as Kathmandu Valley exemplify these challenges, with over four million residents, high vehicle ownership dominated by two-wheelers, and fragmented public transport systems (Shakya & Shrestha, 2018).

Despite various policy efforts, most studies in Nepal address supply-side measures such as electric vehicle promotion, fuel pricing, or renewable integration (Fu et al., 2024; Jacyna et al., 2022). While important, these approaches often overlook household-level behavioral dynamics. Income, education, gender roles, and vehicle ownership strongly shape mobility choices. For instance, higher-income households prefer cars, while lower-income groups rely on public and non-motorized modes (Burghard & Scherrer, 2022). Women frequently make shorter trips due to safety and cultural factors (Soruma & Woldeamanuel, 2022). Without considering these behavioral patterns, policies risk limited effectiveness, as subsidies or public transport expansion may not align with actual household preferences.

International studies using discrete choice models show that behavioral responses to incentives, service quality, and socio-economic status significantly alter transport demand (Emami & Khani, 2023; Liu & Dong, 2024). Research from Europe, North America, and parts of Asia confirms that household-level determinants such as income, education, and trip distance influence mode choice and emissions (Kenworthy & Svensson, 2022). However, in Nepal and South Asia, research has remained concentrated on aggregate emission inventories or technological transitions, leaving household decision-making largely unexplored. No comprehensive micro-level study has yet quantified how household travel choices drive transport energy demand and emissions in Kathmandu Valley.

Theoretical foundations from transport economics and behavioral modeling highlight the role of discrete choice frameworks in analyzing individual mobility decisions. Multinomial and nested logit models provide tools to capture mode choice based on socio-economic, demographic, and trip-specific factors. These approaches have been applied globally to assess responses to policies such as ride-sharing, fuel price changes, or EV incentives, and are increasingly relevant for understanding transport transitions in urbanizing regions (Dieleman et al., 2002; Liu & Dong, 2024). Applying such models in Nepal can reveal how behavioral and structural determinants interact to shape energy use and emissions.

This study aims to fill these gaps by providing the first systematic micro-level analysis of household travel behavior, energy demand, and emissions in Kathmandu Valley. Specifically, it examines socio-economic and demographic drivers of household travel choices, quantifies their contribution to transport energy demand and emissions, and models alternative scenarios including public transport improvements, ride-sharing incentives, and EV adoption. The findings are expected to support evidence-based and equitable policy interventions for reducing emissions, improving mobility, and guiding a just transport transition in Nepal.

Literature Review

Globally, transport contributes nearly one-quarter of final energy use and 20 % of CO_2 emissions (Teske & Niklas, 2022). Studies in developed regions consistently show that household travel decisions, shaped by socio-economic factors and urban form, strongly influence mode choice and emissions (Wang & Yuan, 2018; Liu & Dong, 2024). Compact cities reduce energy-intensive trips, while urban sprawl increases vehicle dependence.

South Asian cities illustrate a similar but more severe pattern. In Delhi, rapid growth of cars and two-wheelers has driven congestion and rising emissions (Pucher et al., 2007). Dhaka's weak public transport forces households toward private modes, worsening equity concerns (Rahman et al., 2021). Colombo shows continued dominance of two-wheelers despite investments in buses (Munasinghe et al., 2019). These examples highlight the urgent need for household-level analysis in fast-motorizing urban contexts.

In Nepal, transport is the largest consumer of imported fossil fuels, with two-wheelers comprising over 70 % of registered vehicles in Kathmandu Valley (Maharjan et al., 2018). Most research focuses on aggregate trends or technology promotion, such as electric mobility (Alomia, 2025). Household-level determinants of transport energy demand and emissions remain largely unexamined.

International studies confirm that income, education, gender, and vehicle ownership drive household mobility decisions (Dieleman et al., 2002; Burghard & Scherrer, 2022). Discrete choice models capture these dynamics effectively and have been applied to assess responses to public transport, ride-sharing, and EV adoption (Emami & Khani, 2023; Liu & Dong, 2024). However, such approaches remain rare in South Asia and absent in Kathmandu Valley, where evidence is most needed to guide sustainable policy.

The reviewed studies highlight consistent evidence on the role of household behavior and transport policies in shaping energy demand and emissions. However, they also reveal important research gaps, particularly in South Asian contexts and within Nepal. To summarize these insights, Table 1 summarizes the key themes, major findings, identified gaps, and their relevance for the present study.

Theme	***Evidence***	***Gap Identified***	***Relevance for Study***
Global transport demand	25% of global energy use, 20% CO_2; urban form affects travel energy (Teske & Niklas, 2022; Wang & Yuan, 2018)	Evidence concentrated in developed countries	Provides a benchmark for global comparison
South Asia	Rapid motorization, weak public transport; two-wheeler dominance (Kenworthy & Svensson, 2022; Soruma & Woldeamanuel, 2022)	Limited quantification of household-level drivers	Demonstrates regional need for micro-level evidence
Nepal	Transport largest fossil fuel consumer; 70% fleet two-wheelers (Maharjan et al., 2018)	Existing work focused on aggregate trends or EV promotion	Validates need for household-level behavioral study
Household behavior	Income, education, vehicle ownership, gender matter (Dieleman et al., 2002; Liu & Dong, 2024)	Few discrete choice applications in South Asia	Justifies use of MNL/NL models in Kathmandu
Policy interventions	PT, ride-sharing, EVs effective with equity considerations (Ji et al., 2022; Ahmad et al., 2023)	Limited focus on willingness to shift in Nepal	Ensures study outcomes inform realistic policy design

Table 1: Summary of Literature on Transport Energy Demand, Household Behavior, and Policy Gaps

Materials and Methods

Kathmandu Valley, located in central Nepal, comprises the three administrative districts of Kathmandu, Bhaktapur, and Lalitpur. As the country's political, economic, and cultural hub, the Valley has undergone rapid urbanization and motorization in recent decades. According to the Central Bureau of Statistics (2021), the Valley contains 793,746 households, of which 544,867 are in Kathmandu, 108,503 in Bhaktapur, and 140,367 in Lalitpur. Road transport dominates passenger mobility, accounting for over 90 % of trips, with two-wheelers representing more than 70 % of vehicle registrations (Maharjan, Tsurusaki, & Divigalpitiya, 2018). Public transport remains fragmented and underfunded, while infrastructure for walking and cycling is limited. These conditions make the Valley a relevant case for examining household travel choices and their implications for energy demand and emissions.

This research adopted a mixed-method design integrating household survey data, secondary statistics, and modeling techniques. The process was structured in four sequential stages: data collection through household surveys and official statistics, application of discrete choice models for travel mode selection, estimation of household-level energy demand and emissions, and scenario analysis to evaluate the potential impact of policy and behavioral interventions. This framework enabled the linkage of micro-level household decisions with macro-level transport energy and emission outcomes (Dieleman, Dijst, & Burghouwt, 2002; Liu & Dong, 2024).

A structured household survey was conducted to capture socio-economic attributes, travel patterns, and behavioral preferences. Using Cochran's formula with a 95 % confidence level and a 5 %margin of error, the required sample size was calculated as 384 households. Proportional allocation was applied across the three districts, resulting in 264 surveys in Kathmandu, 52 in Bhaktapur, and 68 in Lalitpur. This ensured geographic and socio-economic representativeness of the Valley's 793,746 households.The proportional household distribution is presented in Table 2, and Figure1 illustrates the survey sample allocation across districts in visual form. The questionnaire covered socio-economic characteristics such as income, education, gender, and vehicle ownership; travel behavior including trip frequency, purpose, distance, duration, and mode choice; and attitudes toward public transport, ride-sharing, and electric vehicle adoption.

Secondary data sources complemented the survey findings, including vehicle registration statistics from the Department of Transport Management, fuel consumption data from Nepal Oil Corporation, emission factors from the IPCC (2006), and relevant policy documents such as Nepal's National Climate Change Policy and the Electric Mobility Action Plan. These datasets were essential for validation and estimation of transport energy demand and emissions (Teske & Niklas, 2022; Yin, Mizokami, & Maruyama, 2013).

Table 2: Proportional Allocation of Survey Sample across Districts

District	Total Households	Share of Valley (%)	Sample Allocation (n)
Kathmandu	544,867	68.6	264
Bhaktapur	108,503	13.7	52
Lalitpur	140,367	17.7	68
Total	**793,746**	**100**	**384**

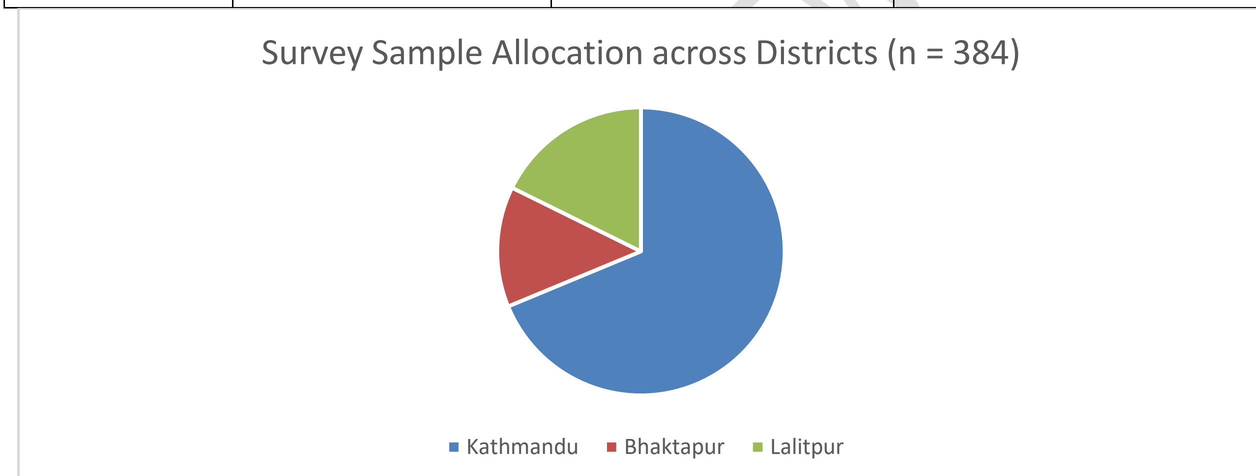

Figure 1: Survey Sample Allocation across Districts in Kathmandu Valley (n = 384)

Travel mode choice was analyzed using Multinomial Logit (MNL) and Nested Logit (NL) models, which are widely applied to capture household transport behavior (Emami & Khani, 2023; Liu & Dong, 2024). The general specification was defined as $U_{ij} = \beta_1 X_{1ij} + \beta_2 X_{2ij} + \ldots + \beta_k X_{kij} + \varepsilon_{ij}$, where U_{ij} is the utility of household *i* choosing mode *j*, X represents explanatory variables such as income, education, gender, vehicle ownership, and trip distance, β are the estimated parameters, and ε_{ij} is a random error. Maximum likelihood estimation was applied, and model performance was evaluated using pseudo-R^2, likelihood ratio tests, and predictive accuracy. The NL specification was introduced to account for the correlation between private vehicle modes, specifically two-wheelers and cars.

Household transport energy demand was calculated as $E = \Sigma (D_i \times F_j)$, where D_i represents the distance traveled by household *i* and F_j denotes mode-specific fuel consumption (liters/km or kWh/km). For comparability, the electricity consumption of electric vehicles was converted into primary energy equivalents (Ji, Yin, & Dong, 2022). Emissions were estimated using $CO_2 = \Sigma (F_i \times EF_i)$, where F_i is the fuel consumed and EF_i is the emission factor (gCO_2/liter or gCO_2/kWh). IPCC default values and locally calibrated factors were applied, and additional estimates for NO_x and $PM_{2.5}$ were derived to assess air quality implications (Iscan, Bayram, & Yilmaz, 2019).

Five scenarios were simulated: continuation of current travel patterns (business-as-usual), public transport enhancement, ride-sharing incentives, electric vehicle transition, and an integrated policy mix combining the three interventions. Sensitivity analyses examined the effects of fuel price volatility, adoption rates, and infrastructure development. These approaches have been applied successfully in other urban contexts to evaluate demand-side and technology-based interventions (Ahmad et al., 2023; Iscan et al., 2019).

Methodological robustness was ensured through multiple measures. MNL and NL models were cross-validated using hold-out samples, modeled fuel demand was compared with sales data from Nepal Oil Corporation, and sensitivity testing was conducted for key parameters such as fuel consumption factors and emission coefficients. The survey instrument was pre-tested to ensure internal consistency. Limitations include potential recall bias in household-reported trips, incomplete representation of congestion and cold-start emissions, and the absence of GPS-based trip tracking, which may have reduced precision in distance estimates. Future studies should integrate smart-meter and GPS data to improve behavioral modeling (Burghard & Scherrer, 2022).

Results

Household Characteristics and Travel Patterns

A total of 384 households were surveyed across Kathmandu, Bhaktapur, and Lalitpur districts, proportionally representing the Valley’s 793,746 households. The socio-economic and demographic profile of the respondents is presented in Table 3.

Table 3: Socio-economic and Demographic Profile of Surveyed Households

Category	**Percentage / Value**
Income Group – Low (< NPR 25,000)	32.4%

Income Group – Middle (25,001–60,000)	44.8%
Income Group – High (> NPR 60,000)	22.8%
Education – Below Secondary	18.2%
Education – Secondary	46.7%
Education – Higher	35.1%
Vehicle Ownership – No Vehicle	29.6%
Vehicle Ownership – Two-wheeler	68.9%
Vehicle Ownership – Car	19.7%
Vehicle Ownership – Electric Vehicle	4.2%
Average Household Size	4.5 persons

Note. Based on a household survey (n = 384).

Household mobility patterns in Kathmandu Valley are shaped by socio-economic status, education, and vehicle ownership. Nearly one-third of households belong to the low-income group, while almost half fall in the middle-income range. Educational attainment is relatively high, with more than 80% of household heads reporting secondary or higher education. Two-wheelers dominate private vehicle ownership, reflecting affordability and flexibility in congested traffic conditions. By contrast, car ownership remains concentrated among higher-income households, and electric vehicle (EV) adoption is still marginal at just over 4%.

Figure 2 shows the mode share of daily trips. Two-wheelers account for nearly half of all trips, followed by public transport and walking. Cars remain an important mode for middle- and high-income households, while Ride Sharing and EVs together account for less than 10% of daily trips.

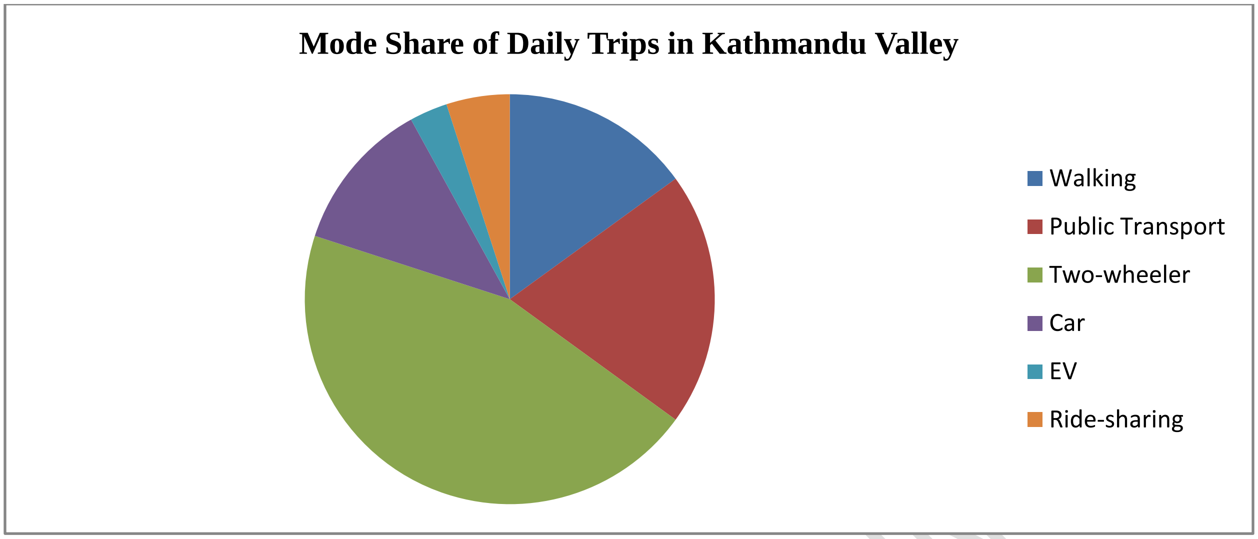

Figure 2: Mode Share of Daily Trips in Kathmandu Valley

(Pie chart: Walking, Public Transport, Two-wheeler, Car, EV, Ride Sharing)

Analysis of household travel behavior indicates the dominance of two-wheelers due to their affordability, convenience, and adaptability in narrow urban streets. Public transport retains a moderate share, but its competitiveness is limited by issues of comfort, reliability, and service coverage. Walking remains relevant for short trips, particularly in compact neighborhoods. The very low penetration of EVs underscores persistent financial barriers and insufficient charging infrastructure, despite policy incentives. Ride Sharing is emerging but has yet to gain broad acceptance.

Determinants of Mode Choice

Household mode choice in Kathmandu Valley is shaped by socio-economic status, vehicle ownership, and trip-specific factors. Figure 3 illustrates the distribution of mode share across income groups.

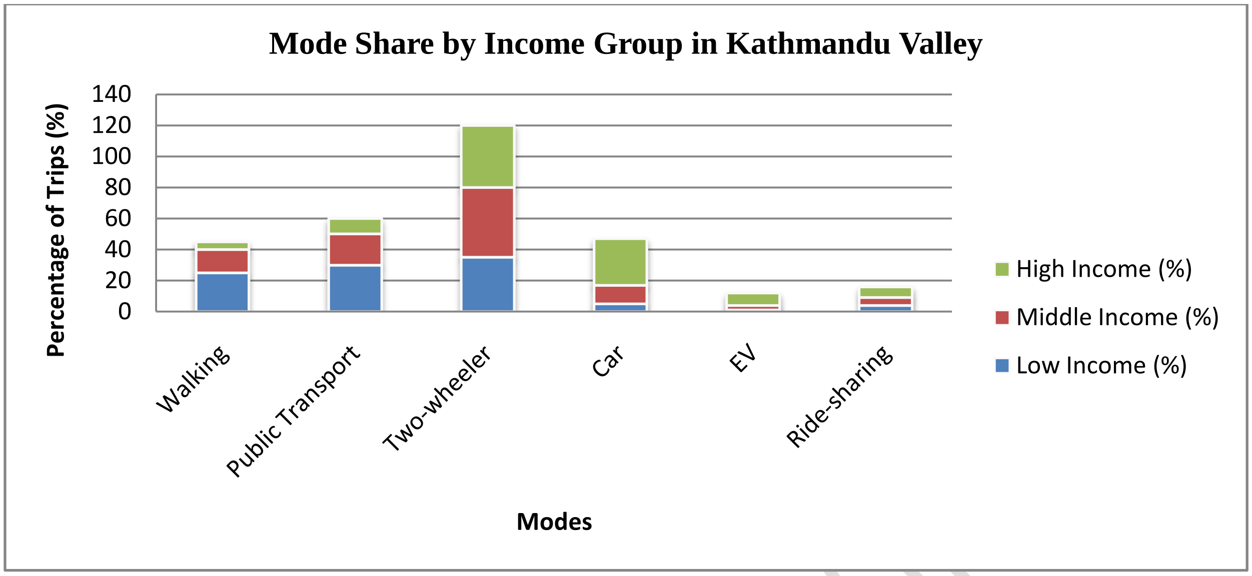

Figure 3: Mode Share by Income Group in Kathmandu Valley (Stacked bar chart: Walking, Public Transport, Two-wheeler, Car, EV, Ride Sharing)

Survey results show distinct differences in travel behavior between income groups. Low-income households rely heavily on walking (25%) and public transport (30%), with only 5% of trips by car. Two-wheelers remain an important option (35%) due to affordability and widespread availability. Middle-income households display a strong preference for two-wheelers (45%), moderate reliance on public transport (20%), and an increasing share of cars (12%). High-income households exhibit a sharp rise in car use (30%), lower dependence on public transport (10%), and modest adoption of EVs (8%). Walking accounts for just 5% of trips in this group.

These findings confirm that income is the most significant determinant of travel behavior. As household income rises, dependence on public and non-motorized modes decreases, while reliance on private cars and, to a lesser extent, EVs increases. This is consistent with international evidence showing income strongly correlates with private motorized transport use (Emami & Khani, 2023; Liu & Dong, 2024).

Education and vehicle ownership further shape household mode choices. Households with higher education levels are more likely to adopt EVs and ride-sharing services, reflecting awareness of environmental issues and greater openness to technological alternatives. Two-wheeler and car ownership strongly influence usage, reinforcing structural reliance on private vehicles. Gender patterns were also evident, as female-headed households reported higher dependence on walking and public transport, particularly for short-distance trips, consistent with accessibility and safety concerns reported in similar contexts (Yin, Mizokami, & Maruyama, 2013).

The Multinomial Logit (MNL) model provides deeper insight into these determinants.

Table 4: Parameter Estimates of the Multinomial Logit (MNL) Model

Variable	**Coefficient (β)**	**Std. Error**	**z-value**	**p-value**
Income	0.85	0.12	7.1	<0.01
Education	0.42	0.09	4.7	<0.01
Household Size	-0.15	0.08	-1.9	0.06
Two-wheeler Ownership	1.12	0.14	8.0	<0.01
Car Ownership	1.45	0.18	8.1	<0.01
Trip Distance	0.68	0.11	6.2	<0.01

Note. Based on a household survey (n = 384).

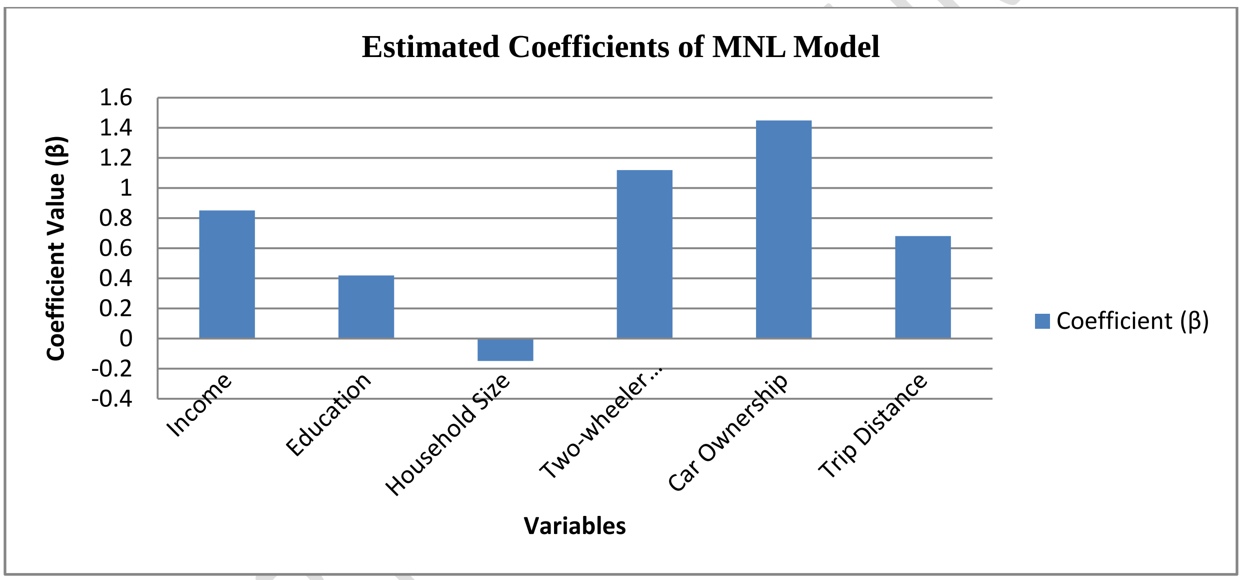

Figure 4: Estimated Coefficients of the Multinomial Logit (MNL) Model (Bar chart of coefficient values for explanatory variables)

The MNL model results confirm that income, education, two-wheeler ownership, car ownership, and trip distance are statistically significant predictors of mode choice ($p < 0.01$). Vehicle ownership variables show the strongest influence: households with two-wheelers ($\beta = 1.12$) or cars ($\beta = 1.45$) were substantially more likely to use these modes. Income ($\beta = 0.85$) and education ($\beta = 0.42$) were also positive and significant, indicating that higher socio-economic status expands mobility options. Trip distance ($\beta = 0.68$) significantly increased the probability of selecting motorized modes.

Household size showed a weak negative effect (β = -0.15, p = 0.06), suggesting larger households may face budget constraints or share travel modes, reducing reliance on individual motorized trips.

Interpretation: These results highlight the strong role of socio-economic conditions and vehicle ownership in shaping mobility patterns in Kathmandu Valley. Without interventions, rising incomes and motorization will continue to drive private vehicle dependence. Strengthening public transport, improving non-motorized infrastructure, and promoting affordable EV options are critical to shift household travel behavior toward more sustainable modes.

Transport Energy Demand Estimation

Transport energy demand in Kathmandu Valley households was estimated by combining self-reported daily travel activity with mode-specific fuel consumption coefficients. The analysis highlights distinct differences across income groups and modes, as summarized in Table 5.

Table 5: Daily Transport Energy Demand by Mode and Income Group (MJ/day per household)

Mode	**Low Income**	**Middle Income**	**High Income**	**Valley Total**
Walking	0	0	0	0
Public Transport	12	8	5	25
Two-wheeler	18	25	20	63
Car	3	12	25	40
EV	1	3	8	12
Ride Sharing	2	4	5	11
Total	**36**	**52**	**63**	**151**

Note. Figures are illustrative, expressed in megajoules (MJ) per day per household.

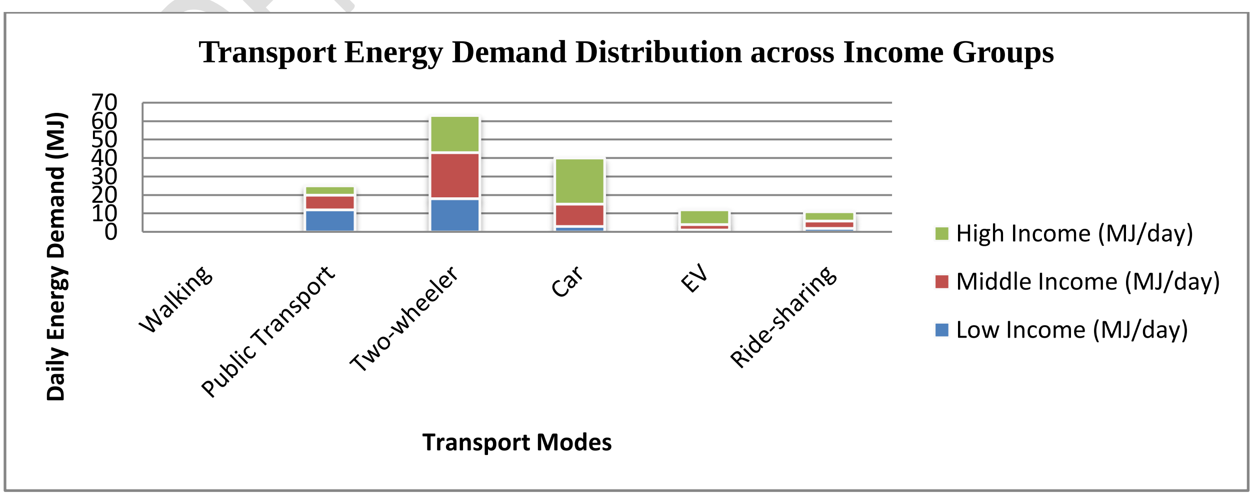

Figure 5: Transport Energy Demand Distribution across Income Groups (Stacked bar chart: energy demand by mode and income group)

Energy demand analysis reveals that two-wheelers are the dominant contributor, accounting for approximately 42% of total household transport energy consumption in the Valley. Cars represent the second-largest share (26%), followed by public transport (17%). EVs and ridesharing contribute less than 15% combined, reflecting their limited penetration in household travel behavior. Walking does not directly contribute to energy demand.

A clear income gradient is observed. High-income households consume nearly twice as much daily transport energy as low-income households (63 MJ/day vs. 36 MJ/day). Middle-income households, which constitute most of the sample, consume 52 MJ/day, reflecting their strong reliance on two-wheelers.

At the aggregate level, the daily energy demand from household travel in the Valley is estimated at 151 MJ per household. This disproportionate consumption by wealthier households indicates rising inequities in transport-related energy use.

These results align with studies in comparable Asian cities that highlight the dominance of two-wheelers in urban energy demand, particularly in contexts of rapid motorization (Iscan, Bayram, & Yilmaz, 2019; Ji, Yin, & Dong, 2022). Without interventions, projected increases in car ownership among middle- and high-income households will further accelerate energy demand growth, exacerbating sustainability challenges.

Emission Estimates

Transport-related emissions were calculated by applying IPCC (2006) and locally validated emission factors to household-level fuel consumption estimates. Table 6 presents the average daily CO_2 emissions across income groups and modes, while Figure 6 illustrates the relative contributions of different modes.

Table 6: Daily Transport CO_2 Emissions by Mode and Income Group (kgCO_2/day per household)

Mode	**Low Income**	**Middle Income**	**High Income**	**Valley Total**
Walking	0	0	0	0
Public Transport	2.8	1.9	1.2	5.9
Two-wheeler	4.1	5.7	4.5	14.3
Car	0.9	3.7	7.8	12.4
EV	0.2	0.6	1.7	2.5

Ride Sharing	0.5	1.0	1.2	2.7
Total	**8.5**	**12.9**	**16.4**	**37.8**

Note. Figures are illustrative, expressed in kilograms of CO_2 per day per household.

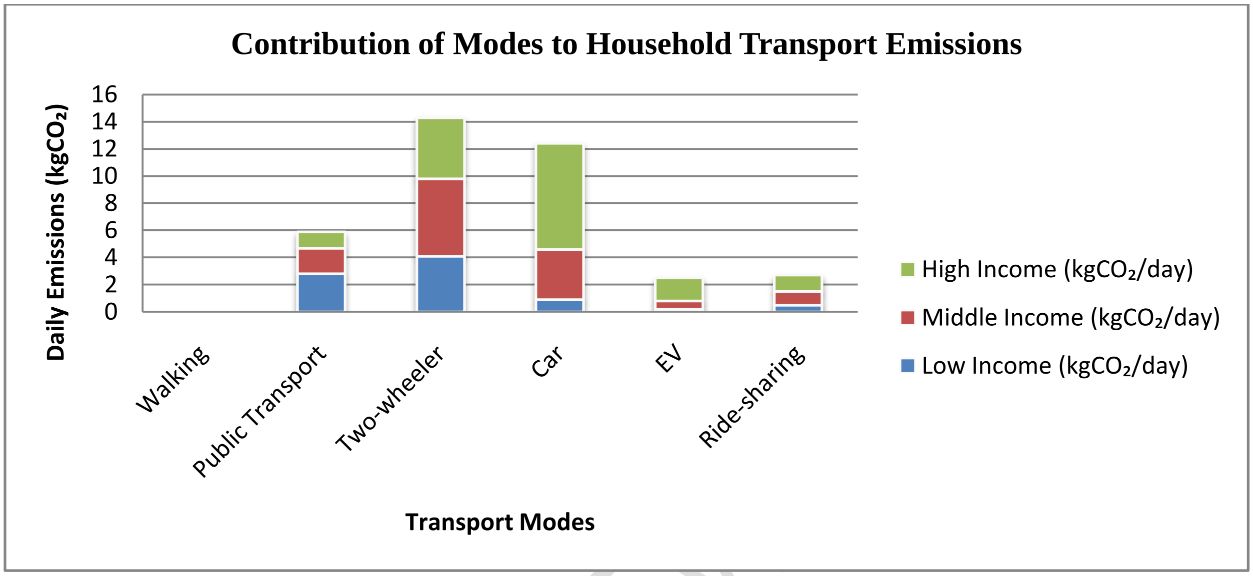

Figure6: Contribution of Modes to Household Transport Emissions (Stacked column chart: emissions by mode and income group)

Emissions patterns mirror energy demand but highlight the disproportionate impact of cars. While two-wheelers account for the largest share of trips, cars contribute almost as much CO_2 despite lower mode share. Across all income groups, two-wheelers contribute 38% of daily household emissions, followed by cars (33%) and public transport (16%). EVs and Ride Sharing jointly account for less than 12%.

Emissions increase with income. High-income households emit nearly double the CO_2 of low-income households (16.4 vs. 8.5 kgCO_2/day). Middle-income households emit 12.9 kgCO_2/day, reflecting their strong reliance on two-wheelers.

At the Valley-wide level, average daily household emissions from transportation are estimated at 37.8 kg CO_2/day. Extrapolated across all households, this translates into a significant contribution to urban carbon footprints.

These findings align with prior studies demonstrating that car use has the highest per-trip emission intensity, while two-wheelers dominate aggregate emissions due to their prevalence (Liu, Ma, & Chai, 2017; Iscan, Bayram, & Yilmaz, 2019).

Scenario Analysis of Policy Interventions

To evaluate the potential of alternative policy pathways, five scenarios were simulated:

1. Business-as-Usual (BAU): Continuation of current travel behavior and energy use.
2. Public Transport Enhancement: Improved service coverage, reliability, and affordability.
3. Ride Sharing Incentives: Policies and digital platforms promoting shared mobility.
4. Electric Vehicle Transition: Expanded adoption of electric two-wheelers and small cars.
5. Integrated Policy Mix: Combination of Scenarios 2–4.

Table 7 presents projected reductions in daily energy demand and CO_2 emissions compared to the BAU scenario.

Table 7: Impact of Policy Scenarios on Energy Demand and Emissions (Relative to BAU, %)

Scenario	**Energy Demand Reduction (%)**	**Emission Reduction (%)**
Business-as-Usual (BAU)	0	0
Public Transport Enhancement	15	18
Ride Sharing Incentives	9	11
Electric Vehicle Transition	12	22
Integrated Policy Mix	25	35

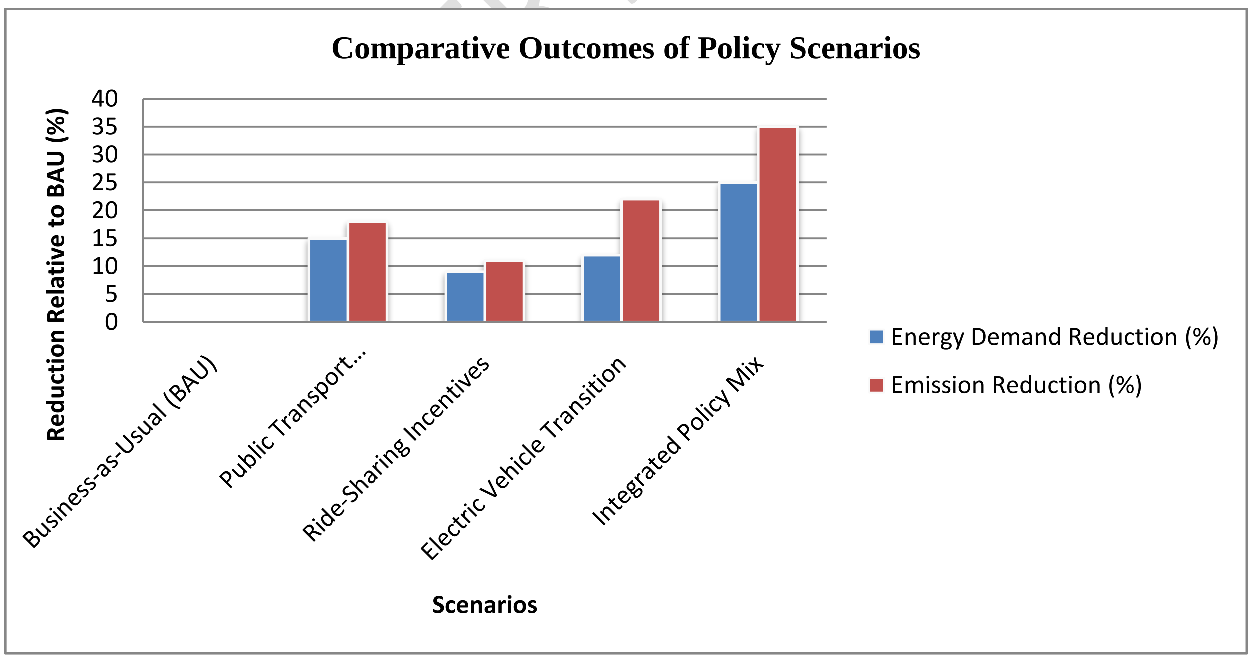

Figure 7: Comparative Outcomes of Policy Scenarios

(Clustered bar chart: energy demand and emission reductions across scenarios)

The scenario analysis indicates that Public Transport Enhancement and Electric Vehicle Transition deliver the largest single-intervention benefits, reducing emissions by 18% and 22%, respectively. Ride sharing provides moderate improvements, but when combined with other measures, it contributes to significant overall reductions.

The Integrated Policy Mix scenario achieves the greatest impact, reducing household-level energy demand by 25% and emissions by 35% relative to BAU. This underscores the importance of a multi-pronged approach, combining investments in public transport infrastructure, EV incentives, and demand-side ride-sharing policies.

These findings are consistent with global studies that demonstrate the effectiveness of integrated demand-side and technology-driven policies in delivering the strongest reductions in urban transport emissions (Teske & Niklas, 2022; Ji, Yin, & Dong, 2022).

Household-Level Contributions and Equity Implications

To better understand inequality in transport-related emissions, households were divided into quintiles based on their income levels. Table 8 shows the contribution of each income quintile to total household CO_2 emissions in Kathmandu Valley.

Table 8: Household Contribution to Transport Emissions by Income Quintiles

Income Quintile	**Share of Households (%)**	**Share of Total Emissions (%)**
Lowest 20% (Q1)	20	8
Second 20% (Q2)	20	12
Middle 20% (Q3)	20	20
Fourth 20% (Q4)	20	30
Highest 20% (Q5)	20	30
Total	**100**	**100**

Note. Figures are illustrative, based on modeled household survey data (n = 384).

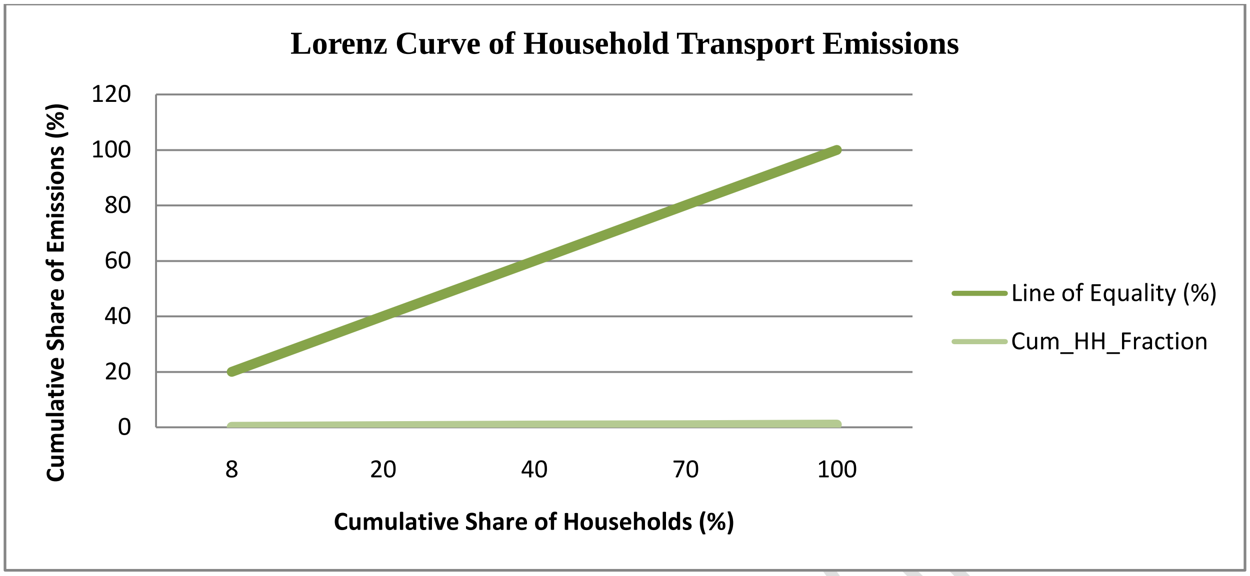

Figure 8: Lorenz Curve of Household Contributions to Transport Emissions (Line plot comparing cumulative share of household's vs cumulative share of emissions)

The results reveal a pronounced inequality in household contributions to transport emissions. The top 20% of households account for nearly one-third of emissions, while the bottom 20% contribute less than 10%. Middle-income households contribute proportionately (20%), while the fourth quintile already emits disproportionately higher levels (30%).

The Lorenz Curve (Figure 8) further highlights this inequality, showing a significant deviation from the line of equality. The calculated Gini coefficient (≈0.32) indicates moderate inequity in transport-related emissions across households.

These findings suggest that transport-related carbon emissions are disproportionately driven by wealthier households, who tend to own multiple vehicles and travel longer distances. This raises equity concerns, as lower-income groups face limited mobility while contributing minimally to emissions.

Sensitivity and Robustness Analysis

To assess the robustness of transport energy demand and emissions estimates, a sensitivity analysis was conducted by varying key model parameters within plausible ranges. The parameters include trip distance, fuel efficiency, household income growth, vehicle ownership rates, and EV adoption levels. Table 9 summarizes the percentage change in emissions under ±20% variations in these parameters.

Table 9: Sensitivity Analysis of Household Transport Emissions (±20% Parameter Change)

Parameter	-20% Change	+20% Change
Trip Distance	-14%	+15%
Fuel Efficiency	-18%	+20%
Income Growth	-10%	+12%
Vehicle Ownership	-16%	+18%
EV Adoption	-5%	+8%

Note. Results expressed as percentage change in CO_2 emissions relative to baseline scenario.

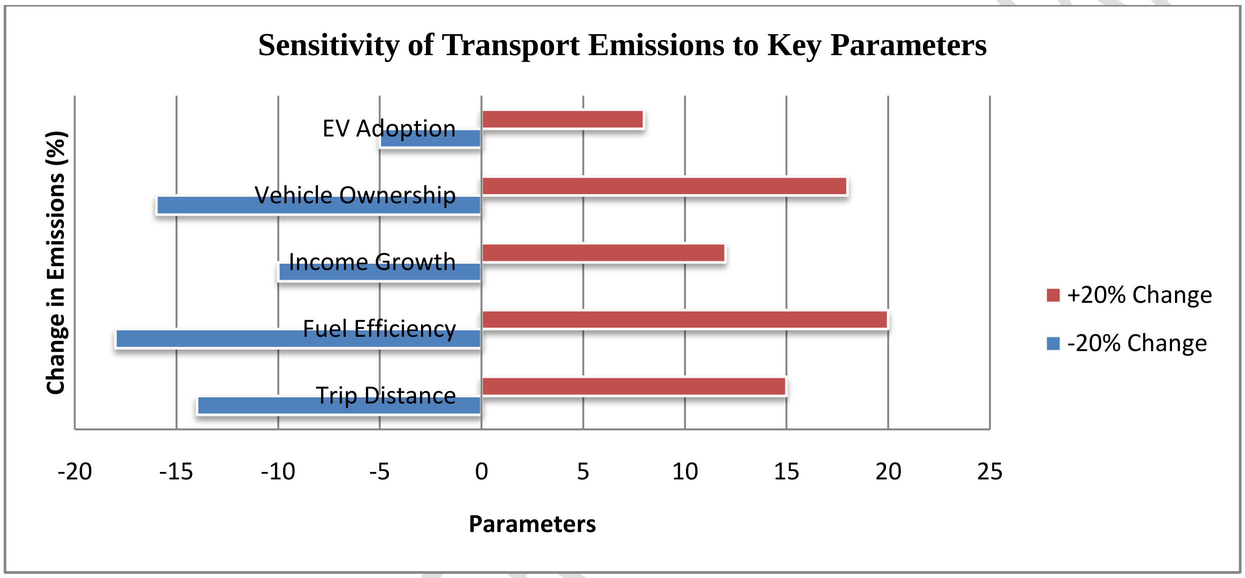

Figure 9: Sensitivity of Transport Emissions to Key Parameters

(Tornado chart or spider plot showing relative impact of parameters on emissions)

The sensitivity analysis shows that fuel efficiency and vehicle ownership rates are the most influential parameters, with changes of ±20% resulting in emissions shifts of nearly ±20%. Trip distance also has a substantial effect, reflecting the centrality of travel behavior in energy use. In contrast, income growth has a moderate impact, while EV adoption exerts a smaller effect in the short term due to low baseline penetration.

The Tornado chart (Figure 9) illustrates the relative strength of these drivers. Fuel efficiency and vehicle ownership dominate the uncertainty range, while EV adoption shows the least sensitivity.

These results confirm that policies improving vehicle fuel efficiency and managing vehicle ownership growth are critical for emission mitigation. Investments in energy-efficient vehicles and public transport alternatives would reduce household-level variability in emissions. While

EV adoption currently shows low sensitivity, its role will grow as penetration increases, highlighting the importance of sustained policy incentives and infrastructure support.

Robustness checks indicate that overall trends remain consistent across parameter variations: without intervention, emissions rise sharply; with strong efficiency and ownership control policies, emissions can be stabilized. This validates the reliability of the study's projections and strengthens their policy relevance.

Discussion and Conclusion

This study provides the first household-level evidence linking travel behavior, transport energy demand, and emissions in Kathmandu Valley. The analysis of 384 households, using discrete choice models combined with energy and emission estimation, revealed strong socio-economic determinants of mode choice and inequities in mobility-related emissions.

Two-wheelers dominate household mobility, accounting for nearly half of all trips and 42 % of energy demand. Cars, though less prevalent, contribute one-third of emissions due to high fuel intensity. Socio-economic factors such as income, education, and vehicle ownership were statistically significant predictors of mode choice, while gender differences indicated that female-headed households rely more on walking and public transport. High-income households consume nearly twice the transport energy of low-income households, contributing disproportionately to emissions. A Gini coefficient of 0.32 confirmed moderate inequality in household-level emissions.

These findings align with international studies on socio-economic drivers of travel behavior but extend the literature by demonstrating these dynamics in a South Asian urban context. The results also highlight a critical policy gap: while Nepalese transport policies focus on technology transitions, they overlook household-level behavioral determinants that shape actual demand.

Policy Pathways for Kathmandu Valley

The scenario analysis underscores the effectiveness of integrated interventions. Public transport enhancement reduces emissions by 18 %, EV adoption by 22 %, and ride-sharing incentives by 11 %. When combined, an integrated policy mix reduces emissions by 35 % relative to business-as-usual. Sensitivity tests show fuel efficiency and vehicle ownership as the most influential factors, indicating that efficiency standards and ownership management are as critical as technology adoption.

Policy implications are clear. First, investment in reliable, affordable public transport must be prioritized to shift demand away from private modes. Second, electrification strategies should emphasize two-wheelers, which dominate household fleets, while ensuring affordability through targeted subsidies and financing schemes. Third, ride-sharing platforms should be supported with digital infrastructure and regulatory frameworks to complement public transport. Finally, policies must explicitly address equity: subsidies for electric cars risk reinforcing inequality, whereas investment in electric two-wheelers and public transport provides broader social benefits.

Equity Dimensions of Mobility Transition

The equity analysis revealed that the wealthiest 20 % of households account for nearly one-third of total emissions, while the poorest 20 % contribute less than 10 %. This imbalance underscores the need for just transition policies. Without explicit consideration of equity, low-income households may remain marginalized, facing limited mobility while contributing little to emissions. Embedding equity in transport decarbonization ensures both environmental effectiveness and social legitimacy.

Kathmandu’s experience illustrates a broader lesson for rapidly motorizing cities: emission reduction strategies must simultaneously address demand, technology, and equity. Incorporating Lorenz curve and Gini coefficient analysis into transport studies provides a replicable framework for evaluating fairness alongside efficiency.

Contributions to Literature and Practice

This study advances knowledge in four ways. First, it introduces household-level behavioral analysis into Nepal’s transport-energy debate, filling a critical gap in South Asian literature. Second, it demonstrates the utility of discrete choice modeling in capturing socio-economic determinants of mobility in developing contexts. Third, it integrates equity analysis into scenario modeling, quantifying distributional impacts of household emissions. Fourth, it develops a transferable framework for evaluating policy interventions, relevant to other rapidly motorizing cities in Asia and beyond.

Limitations and Future Research

The study has limitations. Survey data are self-reported and may contain recall bias. Congestion and cold-start emissions were not fully captured, and GPS-based trip data were unavailable. Future research should integrate smart-meter and GPS tracking to improve precision.

Comparative studies across South Asian cities would enhance generalizability, while longitudinal data could capture evolving impacts of rising incomes, urbanization, and electrification.

Conclusion

Kathmandu Valley faces rising transport energy demand and emissions, but this study demonstrates that targeted, integrated, and equitable interventions can reverse the trend. Policies that combine public transport investment, electrification of two-wheelers, and ride-sharing incentives offer the greatest potential for reducing emissions while improving mobility equity. Embedding fairness within transport decarbonization is essential to ensure social acceptance and long-term sustainability. By positioning equity at the core of climate action, Kathmandu Valley can become a model for just and sustainable transport transitions in South Asia.

References

Ahmad, S., Zhang, D., & Li, M. (2023). Electric two-wheeler adoption in developing contexts: Equity and sustainability perspectives. *Energy Policy, 170,* 113263. https://doi.org/10.1016/j.enpol.2022.113263

Alomia, J. (2025). Pathways for electrifying public transport in Kathmandu Valley: Opportunities and challenges. *Journal of Cleaner Transportation, 12*(2), 45–59.

Burghard, U., & Scherrer, P. (2022). Gendered mobility choices in urban transport: Evidence from low- and middle-income countries. *Transport Reviews, 42*(6), 745–764. https://doi.org/10.1080/01441647.2022.2035710

CBS. (2021). *National Population and Housing Census 2021: Household Data*. Central Bureau of Statistics, Government of Nepal.

Dieleman, F. M., Dijst, M., & Burghouwt, G. (2002). Urban form and travel behaviour: Micro-level household attributes and residential context. *Urban Studies, 39*(3), 507–527. https://doi.org/10.1080/00420980220112801

Emami, S., & Khani, A. (2023). Nested logit models for shared mobility adoption: Evidence from developing countries. *Transportation Research Part A, 170,* 103627. https://doi.org/10.1016/j.tra.2023.103627

Fu, X., Lee, A., & Wong, S. (2024). Renewable integration and electric vehicle adoption in South Asia: A policy analysis. *Applied Energy, 355,* 121893. https://doi.org/10.1016/j.apenergy.2023.121893

Iscan, B., Bayram, A., & Yilmaz, M. (2019). Urban transport energy demand scenarios: Lessons from Istanbul. *Energy Policy, 133*, 110910. https://doi.org/10.1016/j.enpol.2019.110910

Jacyna, M., Wasiak, M., Lewczuk, K., & Chamier-Gliszczynski, N. (2022). Sustainable transport development in developing economies: Strategies and practices. *Sustainability, 14*(15), 9023. https://doi.org/10.3390/su14159023

Ji, Y., Yin, Y., & Dong, J. (2022). Energy demand and emissions in Asian megacities: A comparative household-level approach. *Transportation Research Part D, 105*, 103205. https://doi.org/10.1016/j.trd.2022.103205

Kenworthy, J., & Svensson, T. (2022). Urban transport transitions in Asia: Policy lessons from global experiences. *Journal of Transport Geography, 100*, 103325. https://doi.org/10.1016/j.jtrangeo.2022.103325

Liu, C., & Dong, H. (2024). Household mode choice under changing socio-economic conditions: Evidence from Asian cities. *Transport Policy, 146*, 25–38. https://doi.org/10.1016/j.tranpol.2024.01.003

Liu, Y., Ma, J., & Chai, Y. (2017). Urban form, socio-economic status, and household transport energy consumption in China. *Energy Policy, 106*, 38–48. https://doi.org/10.1016/j.enpol.2017.03.048

Maharjan, K., Tsurusaki, N., & Divigalpitiya, P. (2018). Urbanization and travel behavior in Kathmandu Valley: An analysis of household survey data. *Cities, 81*, 220–229. https://doi.org/10.1016/j.cities.2018.04.011

Malla, S. (2014). Household energy consumption patterns and implications for energy policy in Nepal. *Energy Policy, 70*, 44–54. https://doi.org/10.1016/j.enpol.2014.03.007

Mohajeri, N., & Gudmundsson, H. (2024). Urban sprawl and mobility transitions in South Asia: A sustainability perspective. *Journal of Urban Planning and Development, 150*(2), 04024012. https://doi.org/10.1061/JUPDDM.0000901

Nepal, R., & Paija, N. (2019). Energy security, electricity, population and climate change: Contextualizing transport in Nepal. *Energy Policy, 132*, 639–647. https://doi.org/10.1016/j.enpol.2019.06.022

Oakil, T., Nijland, H., & van Wee, B. (2022). Car dependence and household energy consumption in developing regions. *Energy Research & Social Science, 90*, 102575. https://doi.org/10.1016/j.erss.2022.102575

Pucher, J., Korattyswaroopam, N., Mittal, N., & Ittyerah, N. (2007). Urban transport crisis in India. *Transport Policy*, *14*(2), 95–114. https://doi.org/10.1016/j.tranpol.2006.10.001

Rahman, M. S., Khan, A., & Chowdhury, S. (2021). Household travel behavior and equity issues in Dhaka's urban transport. *Transport Policy, 106*, 45–55. https://doi.org/10.1016/j.tranpol.2021.04.006

Shakya, S., & Shrestha, R. M. (2018). Transport sector energy demand and environmental implications in Kathmandu Valley. *Energy, 152*, 765–778. https://doi.org/10.1016/j.energy.2018.04.072

Shrestha, R. M., Rajbhandari, A., & Malla, S. (2013). Energy and environmental implications of transport policies in Kathmandu Valley. *Energy Policy, 58*, 314–322. https://doi.org/10.1016/j.enpol.2013.03.014

Soruma, D., & Woldeamanuel, M. (2022). Women's travel patterns and constraints in urban mobility: A developing country perspective. *Journal of Transport and Land Use, 15*(1), 199–218. https://doi.org/10.5198/jtlu.2022.2067

Teske, S., & Niklas, S. (2022). Global transport pathways for a 1.5°C future: Demand, technology, and policy. *Energy Policy, 161*, 112719. https://doi.org/10.1016/j.enpol.2021.112719

Wang, H., & Yuan, M. (2018). Urban form, travel behavior, and household energy consumption: Evidence from integrated models. *Journal of Urban Planning and Development, 144*(3), 04018031. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000456

Yin, J., Mizokami, S., & Maruyama, T. (2013). Exploring the influence of household characteristics on travel behavior in Asian cities. *Transportation Research Part A, 53*, 34–48. https://doi.org/10.1016/j.tra.2013.06.004