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Urban Transportation Mode Choice and Carbon Emissions in Southeast Asia

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Abstract

Cities are growing differently across the world, even within the same region, and presenting different transportation trends and challenges. Existing transportation services and travel behavior are some of the key variables shaping future transportation trends and carbon emissions projections. This study uses five developing cities in Southeast Asia to illustrate how different policy scenarios can help cities achieve more sustainable transportation development. Cities in Southeast Asia encompass distinctive characteristics, such as a wide range of transportation alternatives, often in the form of informal transit, and although they are not growing as rapidly as Chinese or Indian cities, their levels of transportation emissions have been increasing consistently. This study examines how different policies and measures will affect transportation mode choice and carbon emissions through the construction of mode choice models and the application of three policy scenarios. Carbon emissions can be reduced by as much as 93% in 2050 if cities implement a combination of land use planning changes, public transportation development, and economic policies for a modal shift to more energy efficient mode choices. Such policies and measures will therefore be able to contribute to city level climate goals or national climate targets.

According to the International Transport Forum (ITF) (*1*), 43% of the world's transportation demand in passenger kilometers will be in China, India, and the rest of Asia by 2050. This is a region that has been projected to grow significantly and rapidly in population size, economic development, urbanization rate, and motorization level. The ten countries that make up the Association of Southeast Asian Nations (ASEAN) have a combined population of 645 million and a total GDP of US$2.72 trillion (*2*), with a projected average annual economic growth of 5.1% over 2017 to 2021 (*3*). On average, the rate of motorization in the region, mostly in the form of two wheelers, increased by 12% from 2002 to 2010. During the same period, fuel consumption increased by 10%, with an over 10% growth for Indonesia and Vietnam and between 2% and 6% for the Philippines and Malaysia (*4*).

Although increases in motorization will bring positive benefits and contribute to economic growth, high levels of congestion, energy consumption, local air pollution, and carbon dioxide (CO_2) emissions will often follow. There is no doubt that the growth in vehicle ownership, transportation demand, and emissions in Chinese and Indian cities is unprecedented but Southeast Asian cities, despite growing at a smaller magnitude but just as rapidly, cannot be ignored. Southeast Asian cities' transportation demand and subsequent CO_2 emissions have been growing steadily and will contribute significantly to the region's projected transportation CO_2 emissions (*1*). This study focuses on urban transportation trends and CO_2 emissions in five cities in Southeast Asia, namely, Hanoi, Jakarta, Kuala Lumpur, Manila, and Phnom Penh. A set of three policy scenarios is applied to evaluate the impact of a range of policies and measures on mode choice and CO_2 emissions levels, after constructing a mode choice model for each city. A better understanding of effective policies and measures for different cities will help guide city level climate goals that could be transformed into national level commitments or targets.

Transportation Demand in Southeast Asia

Transportation demand in Southeast Asia has been increasing steadily over the past three decades and has not shown any signs of slowing down. The majority of the private vehicles owned are two wheelers, such as scooters, mopeds, and motorcycles. Recent statistics from the IEA (*5*) show that the number of two wheelers grew by 177% in Vietnam between 2000 and 2013. At the

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same time, the growing middle class and rising household incomes have been driving urban motorization, partly because car ownership is a status symbol in Asia (*6*). The increase in light-duty vehicles (LDVs), which include cars, sports utility vehicles, and pick-up trucks, was 600% in Vietnam during the same period. In Malaysia, growth in LDVs was 148%, while the Philippines saw a relatively lower percentage at 44% between 2000 and 2013. Indonesia also experienced high vehicle growth rates for both two wheelers and LDVs, with increases of over 600% and 280% respectively. Most LDVs have also become single occupancy vehicles most of the time, leading to greater time delays and higher vehicular emission levels in urban areas. It is not surprising that due to their affordability and practicality, two wheelers are still the leading transportation mode choice in these countries. In Vietnam, 95% of all vehicles are two wheelers (*5*). These increases are a reflection of the lack of an adequate public transportation system and the general appeal of personal mobility over public transportation. In Kuala Lumpur, the poor state of public transportation services, as well as rising household incomes, have increased private vehicle ownership and decreased the use of public transportation systems simultaneously (*7*).

Transportation Externalities

Local air pollution from transportation activities and their consequent health impact, along with traffic congestion, are pressing challenges in many Southeast Asian countries. For example, traffic congestion costs Cambodia around US$6 million per month as a result of lower economic efficiency and the loss of working time and fuel (*8*). In Kuala Lumpur, the World Bank estimated the costs of traffic congestion at between 1.0% and 1.8% of the national GDP in 2014 (*9*). Congestion is further accentuated by the patterns of motorization and the predominance of motorcycles on the road in Southeast Asian cities. In Phnom Penh, disorderly use of the road by motorcycles, which comprise 70% of the city road traffic, fosters urban congestion and is responsible for traffic fatalities (*10*).

Although current transportation priorities in Southeast Asia are local air pollution and traffic congestion, this is a region that has increasingly become a larger contributor of global CO_2 emissions. The increasing motorization rate in Vietnam led to a 190% increase in its greenhouse gas (GHG) emissions from the transportation sector between 2000 and 2010, which is higher than China (160%) and India (100%) over the same period (*11*). Indonesia, Cambodia, and Malaysia also recorded significant increases of transportation-induced GHG emissions, at 63%, 46%, and 37% respectively between 2000 and 2010 (*11*). The Philippines was the only country selected in this study to see a slight decrease (3%) in its transportation GHG emissions. As GHG emissions become a growing concern in the region, there is now a greater sense of urgency for Southeast Asian cities to adopt more sustainable transportation development policies and measures, which are aligned with their national climate targets and commitments.

Current Studies

While current mode choice analyses for Southeast Asia often offer policy insights for cities (*7*, *12*, *13*), most studies have not tied mode choice with transportation planning or transportation demand projections for cities. Moreover, the policy measures recommended in the existing literature fail to evaluate the impact of combined policies on transportation demand and emissions. Most of the existing mode choice analyses are focused on the differences in motorization patterns between developed and developing Asian cities (*7*) and the impact of vehicle ownership trends on private vehicle use and preferences (*12*). Hyodo et al. (*14*) conducted an overview of urban travel behavior in 13 global cities, including Southeast Asian cities, but did not go beyond a comparison of descriptive statistics. Most of the current studies on transportation development in Southeast Asia are only focused on transit-oriented development as a solution for congestion, while comparative analyses have addressed different patterns of transportation development and urban sprawl, which is leading to longer travel distance (*15*, *16*). Densely populated cities in Southeast Asia provide an ideal urban landscape for the successful implementation of intensive public transportation policies. However, the abundance of informal transportation systems in Southeast Asian cities will hinder the development of public transportation unless they can be integrated into the transportation system (*17*).

Policies that support the adoption of advanced vehicle technology and alternative fuels, such as fuel efficiency standards, will reduce CO_2 emission by increasing energy efficiency. At the same time, it is just as critical to include non-technological measures to prevent the increase in private vehicle use and transportation demand, which could surpass the improvements made in energy efficiency. Therefore, a comprehensive range of policies and measures, including land use planning, public transportation development, economic instruments, and government regulations, need to be implemented for low-carbon transportation systems. This study created three policy scenarios that reflect a combination of such policies and evaluated their impact on transportation mode choice and CO_2 emissions in five cities in Southeast Asia, after the construction of a separate mode choice model for each city.

Table 1. Transportation Choice Set and Data

City	Sample size	Number of observations	Transportation alternatives in mode choice model
Hanoi	204,232	187,830	walk; bicycle; two wheeler (motorcycle); LDV (drive) (car); taxi; bus; three wheeler ("cyclo")
Jakarta	1,083,280	1,079,821	walk; bicycle; two wheeler (motorcycle); LDV (drive) (sedan, jeep, "kijang," pick-up truck); taxi; bus; train/rail; three wheeler ("bajaj," "becak")
Kuala Lumpur	218,460	216,527	walk; bicycle; two wheeler (motorcycle); LDV (drive) (car, small van, pick-up truck); taxi; bus; train
Manila	471,035	466,301	walk; bicycle; two wheeler (motorcycle); LDV (drive) (car, jeep); taxi; bus; train/rail; three wheeler (pedicab, tricycle)
Phnom Penh	40,368	39,013	walk; bicycle; two wheeler (motorcycle, "motodop," "motorumo"); LDV (drive) (passenger, pick-up truck, van); taxi; bus; three wheeler ("cyclo")

Methodology

This study applied discrete choice analysis to construct mode choice models that offer insights into travel behavior and policy, as well as to use the parameters derived from the choice models to conduct mode choice and CO_2 emission projections to 2050 under a mix of policy decisions. Household travel survey data, which included mode choice, travel distance, travel time, and socioeconomic variables, collected by the Japan International Cooperation Agency (JICA) for the cities of Hanoi, Jakarta, Kuala Lumpur, Manila, and Phnom Penh were used to estimate a disaggregate transportation mode choice model for each city. This enabled the evaluation of land use and transportation planning measures, pricing policies, and government regulations on mode choice and CO_2 emissions subsequently.

Disaggregate demand models can capture the variation in individual characteristics; they do not assume homogeneity among different consumers (*18*, *19*) and can include a large set of transportation attributes (*20*). Disaggregate models are sometimes also known as behavioral models because they depict individual travel choices (*21*) and can explain behavior directly at the level of a person, household, or firm. Since these models often analyze choices among discrete and not continuous alternatives, they are also known as discrete choice models. In this study, household trip level data were used to develop five multinomial logit models, which allowed the projections of 2050 travel demand and CO_2 emissions for five different cities.

Mode Choice Model

Transportation mode choice is analyzed in this study using a multinomial logit (MNL) model, which is a commonly used form of discrete choice analysis (*22*, *23*). The outcomes of MNL models are logit choice probabilities of each alternative as a function of the systematic portion of the utility of all the alternatives available in a choice set. In this study, a separate MNL model was constructed for the mode choice of each city.

Since the data collected differ across the five cities, each choice model is slightly different. The final choice set for each city contains at least seven alternatives (Hanoi, Kuala Lumpur, and Phnom Penh), while the other two cities have eight alternatives. These alternatives were derived from a much larger group of alternatives from the original surveys that ranged from 13 (Phnom Penh) to 21 (Jakarta) alternatives, some of which specified different types of LDVs, two wheelers, or three wheelers, as well as informal transit services, most of which have been combined and recoded into one of the final seven or eight alternatives as presented in Table 1.

Table 1 also shows the number of observations for each choice model, which is different from the original sample size for each city because incomplete observations were removed from the final models. In addition, only choices that were available to each household (as indicated in the household travel surveys), either in the form of ownership or use for LDVs, two wheelers, and bicycles, were included in the final mode choice models.

Utility Functions

The utility of each alternative in the choice set is expressed as follows, where U_{in} is the utility of the ith alternative for the nth individual:

$$U_{in} = \alpha_i + \beta_i X_{in} + \varepsilon_{in} \quad (1)$$

where α_i is the alternative specific constant (ASC), β_i is the vector of unknown parameters, X_{in} represents the vectors of known variables (e.g. travel time, travel cost, and socioeconomic variables), while ε_{in} is the unobserved error term.

An example utility function for LDV used in the model specification for Hanoi is shown below in Equation 2:

$$\begin{aligned} U_{LDV} = {} & \alpha_{LDV} + \beta_{TRAVEL\ TIME} LDV\ TRAVEL\ TIME \\ & + \beta_{TRAVEL\ COST} LDV\ TRAVEL\ COST \\ & + \beta_{HOUSEHOLD\ SIZE} HOUSEHOLD\ SIZE \\ & + \beta_{HOUSEHOLD\ INCOME} HOUSEHOLD\ INCOME \\ & + \beta_{AGE} AGE + \beta_{GENDER} GENDER \end{aligned} \quad (2)$$

The "walk" alternative was normalized to zero in all five mode choice models, which implies that this alternative was used as a base with a zero constant and other constants would therefore be interpreted as relative to choosing to "walk" as a primary transportation mode.

All of the five mode choice models included travel time, travel cost, and household income, which are key variables that have been shown to affect mode choice. Household size, age, and gender variables were also included for most of the cities. Data on age and gender were unavailable for Phnom Penh, while the survey for Jakarta did not include household size data.

Travel Time, Distance, and Cost Estimations

Since most trips usually consist of multiple modes and unless the primary mode choice for each observation was already indicated on the survey (e.g., Phnom Penh), a primary mode choice was selected to represent the mode used to travel the longest distance. The mode with the maximum distance traveled was estimated when the travel time for each mode within the same trip was provided in the survey data (Hanoi and Kuala Lumpur). Travel distance was then estimated using an average speed for each mode. If travel time (or distance) per each mode segment was unavailable or could not be estimated, a mode hierarchy was applied (for Jakarta and Manila). This method was applied because of the lack of detailed origin and destination locations which prevented the geocoding of latitude and longitude coordinates. In the mode hierarchy, the selection of the primary mode choice is based on the order: rail public transport, bus, taxi, drive (LDV), motorcycle (or two wheeler), bicycle, three wheeler, and walk.

Travel time was estimated for the primary mode choice and the alternatives using the departure and arrival time data when travel time data were not specified in the survey. In fact, only Phnom Penh's survey provided travel time data for the primary mode choice. Travel cost was also estimated for each primary mode choice and every alternative, except for walk and bicycle choices. Travel cost was estimated for two wheelers and LDVs by multiplying trip distance with fuel cost and fuel economy, while LDV also included the addition of parking cost, that is ((distance * fuel cost * fuel economy) + parking cost). Travel cost for taxis was estimated by multiplying trip distance and per km cost and the addition of a fixed cost which differs by city. Categorical variables were created for bus and three wheeler costs, which may be dependent upon travel distance, based on transit fares and pricing structure in each city.

Transportation Demand and CO_2 Emission Forecasts in Three Policy Scenarios

Discrete choice models have the ability to forecast future behavior under different circumstances as captured by the variables included in the models. The outcomes (parameter estimates) of the MNL models in this study were used as inputs to estimate changes in travel behavior and CO_2 emissions under three scenarios in 2050.

The outcomes of MNL models are logit choice probabilities of each alternative as a function of the systematic portion of the utility of all the alternatives available in a choice set. The model assumes that each individual chooses an alternative based on the theory of maximum utility, where the maximum likelihood estimation is applied (*22*). Since the utility function is assumed to be linear in parameters (β), implying $V_{nj} = \beta X_{nj}$, where β is a row vector of unknown parameters and X_{nj} is a column vector of observed variables associated with alternative j, the logit probabilities can be expressed as Equation 3:

$$P_{ni} = \frac{e^{\beta X_{ni}}}{\sum_j e^{\beta X_{nj}}} \quad (3)$$

The logit probability of each alternative was estimated using the parameter (β) derived from the choice models and the constructed utility functions such as Equation 2.2. The next step was then to develop aggregate forecasts using the logit probabilities from the disaggregate models. The classification aggregation method (*24*, *19*) was applied in this study by grouping the sample population according to household income (up to 14 groups). Disaggregate probabilities by income were estimated by dividing the sum of the product of choice probability and expansion factor or weight (provided in the household travel survey datasets) by the sum of expansion factor. Changes in household income over time, up to 2050, were modeled upon the GDP growth rate of each city for the same period of time. A new set of disaggregate mode share for each city was then derived using the estimated weighted probability values.

Transportation Behavior and Demand Estimation. The annual passenger kilometer (pkm) was estimated based on the disaggregate choice probability for each alternative, multiplied by the population size (*25*), average trip distance, daily trip rate, and 365 days. Average trip distance was estimated based on the elasticity of trip distance with respect to population, which was assumed to be 0.4555 (*1*). The average trip distance for the base year was derived from the survey data for each mode in each city. The average trip rate (number of trips per day per person) was assumed to be a function of GDP per capita, as shown in Equation 4, with the parameters estimated from a regression analysis using regional data for Southeast Asia:

$$Trip\,Rate = 2.09 + (0.0193 * (GDP\,per\,Capita)) \quad (4)$$

The vehicle kilometer (vkm) was estimated by multiplying the pkm with load factor for two wheeler, LDV, bus, taxi, and three wheeler alternatives. The load factors used in this study were based on the IEA's assumptions (*5*).

Transportation Energy and CO_2 Emission Estimation. Energy use was estimated for each mode based on the IEA's assumptions (*5*), which include a detailed characterization of vehicle technology and fuel mix, including internal combustion engines that run on gasoline, diesel, compressed natural gas, or liquid petroleum gas, hybrid electric, plug-in hybrid electric, electric, and fuel cell powertrains. Related fuel options include: gasoline and diesel, biofuel, and synthetic fuel alternatives to liquid fuels, gaseous fuels including natural gas and hydrogen, and electricity. Total energy use (E) for vehicle type i can therefore, be estimated using the following equation:

$$E_i = \sum (N_i * I_{i*} D_i) \quad (5)$$

where E_i is the total energy use, N_i is the total number of vehicle type i, I_i is the energy intensity for vehicle type i, which also reflects fuel type, and D_i is the average distance traveled by vehicle type i. Total CO_2 emissions were then estimated for each fuel type using coefficients of carbon per unit of energy consumed in vehicle type i.

Policy Scenarios. There are three policy scenarios designed for each city, which reflect a range of policies and measures, such as land use planning, public transport development, economic instruments, and government regulations that have been shown to influence transport demand and emissions. In the Baseline scenario, it is assumed that there will be no implementation of significant policies and measures. The underlying factors driving transportation demand, such as population, household income, trip distance, and trip rate will continue to grow but there will be no changes in mode share or travel time and cost. Load factors for LDV and bus were assumed to decrease by 10% from 2015 to 2030 and by 27% in 2050. In the second scenario, Robust Governance (ROG), local governments will play a more significant role by introducing economic instruments, such as parking pricing, road tolls, and higher subsidies for public transportation. The third scenario, Integrated Land Use and Transport Planning (LUT), assumes the same set of economic instruments shown in Robust Governance but coupled with changes in land use and transportation planning that will decrease public transportation travel time, as well as an average trip distance that is equivalent to the 2015 level. In all three scenarios, the fuel economy standards, which reflect fuel mix and market penetration of different vehicle technologies, will follow the IEA's assumptions (*5*). Apart from the Baseline, the other two scenarios follow a stringent set of fuel economy standards that will lead to a global CO_2 emission reduction of almost 60% between 2013 and 2050.

The scenario outcomes are not predictions, but different possible futures based on the assumptions applied in each scenario. The impacts of the policies and measures in each scenario are evaluated by changing the relevant components (e.g., travel time and cost) in the utility functions based on the assumptions indicated in the scenarios (Table 2). Probabilities (Equation 3) for all the alternatives were then calculated again under the three different scenarios.

Mode Choice Model Estimation Results

The model estimation results of transportation mode choice in five Southeast Asian cities are presented in Table 3. A separate mode choice was estimated for each city. The most preferred mode choice (as indicated by the constant parameter estimates) is different for each city. Other than Phnom Penh, where two wheeler is the most preferred mode choice, walking seems to be most preferable in the other four cities. This is quite unusual but could be due to the high level of traffic congestion that affects the other modes and the relatively short travel distances. Bicycle is the second most preferred choice in Hanoi, followed by two wheeler and LDV. Public transportation in Hanoi is not as preferable as personal transportation, which provides a greater sense of freedom and flexibility. Bus ridership in Hanoi has always been low, constituting just 3% of the total mode share. In fact, the mode share for two wheeler was 12 times higher than bus, including both mini and standard buses. Despite increases in the share of bus mode over the past decade, recent data have shown declining bus ridership once again (*26*). Similarly, bus is not a preferred mode choice in Phnom Penh, which is another city with a high share

Table 2. Key Assumptions for Policy Scenarios

Scenario	Baseline		ROG		LUT	
	2030	2050	2030	2050	2030	2050
Public transport development						
Bus travel time[a] decrease (%)	-	-	-	-	30	60
Rail travel time[a] decrease (%)	-	-	-	-	30	60
Economic instruments						
Fuel tax increase[b] (%)	-	-	33	63	33	63
Parking pricing increase (%)	-	-	80	160	80	160
Road tolls (US$)[c]	-	-	1.02	1.36	1.02	1.36
Bus subsidy increase (%)	-	-	30	50	30	50
Rail subsidy increase (%)	-	-	30	50	30	50
Government regulations						
Fuel economy standards[d]	IEA 4DS	IEA 4DS	IEA 2DS	IEA 2DS	IEA 2DS	IEA 2DS

[a]Based on household travel survey data from each city. In the Baseline and ROG scenarios, the travel time for all modes used in the mode choice and emission models were all from the household travel survey data. In the LUT scenario, travel time for bus and train would decrease by 30% in 2030 and by 60% in 2050.
[b]Tax increase rates are based on Korea and Japan's fuel tax percentages.
[c]Road tolls, which are uncommon in Southeast Asian cities, are assumed to be implemented in all cities in the ROG and LUT scenarios.
[d]Fuel economy standards reflect the type of fuel mix and are based on IEA's assumptions in the 4°C Scenario (4DS) and the 2°C Scenario (2DS). The 4°C Scenario (4DS) takes into account countries' current intentions to limit emissions and improve energy efficiency that will limit the long-term temperature increase to 4°C. The 2DS reduces CO_2 emissions by almost 60% by 2050 (compared with 2013) and a projection of declining carbon emissions post 2050 until carbon neutrality is reached (*5*).

of two wheeler mode. However, public transportation (bus) is the second most preferred mode choice in Jakarta and Manila. Bus as a primary mode choice is also prefeered over most other modes in Kuala Lumpur. Such differences across these three cities are due to the disparities in the level of bus frequency and network size. The bus alternative in all choice sets also includes informal bus services, where applicable. Such bus services can be more convenient than other modes, especially for lower household income groups and for cities without a well-connected transportation system. None of the five cities, apart from Phnom Penh, showed driving (i.e., LDV use) as a relatively highly preferred mode choice. LDV is also not as preferable as two wheeler use in Hanoi, Jakarta, Kuala Lumpur, and Phnom Penh. However, in Manila, two wheeler use is the least preferred mode across all eight alternatives (Table 3).

The parameter estimates for travel time for all the five cities are negative and highly significant, as the longer the travel time, the less attractive the alternatives will be. Since it was assumed that the impact of time on preferences would be equal across all alternatives, the parameter for travel time was constrained to be the same for all alternatives in all five cities. On the other hand, the parameter for travel cost was only constrained across all alternatives for Hanoi, Jakarta, and Manila, which is a common practice for mode choice models which assume that travel cost affects all alternatives the same way. Different parameters were used for the travel costs of two wheeler, LDV, taxi, bus, train, and three wheeler in the choice models for Kuala Lumpur and Phnom Penh because in these two cities it was found that travel cost affects the utility of each mode differently. Travel costs of taxi and bus alternatives were in fact insignificant for respondents in Phnom Penh. The travel cost parameter estimates for all the other four cities are negative and significant (Table 3).

The socioeconomic characteristics, such as household size, household income, age, and gender of the respondents were also included in the five mode choice models as shown in Table 3.

The impact of household size on mode choice does not follow a clear trend across the cities. It is a significant variable for most modes in most cities, but it is especially insignificant for taxi in Hanoi and Kuala Lumpur, train in Kuala Lumpur (but not in Manila, where the larger the household size, the less attractive the train mode becomes), and two wheeler, LDV, bus, and three wheeler use in Phnom Penh.

Household income is highly significant for all modes in Manila, all modes but train in Kuala Lumpur and Jakarta, and all modes but bicycle in Phnom Penh. Household income is also insignificant for bicycle use in Hanoi. The use of two wheeler becomes more attractive when household income rises for all cities except in Jakarta, where rising income will decrease its appeal instead. This is also true for LDV, where rising income will increase its utility in all cities but Jakarta. In Hanoi and Kuala Lumpur, the utility for bus mode will decrease when household income increases, while in Manila and Phnom Penh taxi becomes more attractive when household income increases.

Table 3. MNL Models Estimation Results of Transportation Mode Choices in Five Cities

	Hanoi			Jakarta			Kuala Lumpur			Manila			Phnom Penh		
Explanatory variables	Parameter estimates	T-test	*P*-value	Parameter estimates	T-test	*P*-value	Parameter estimates	T-test	*P*-value	Parameter estimates	T-test	*P*-value	Parameter estimates	T-test	*P*-value
Walk constant	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bicycle constant	−1.77	−49.39	0.00	−4.28	−213.56	0.00	−4.98	−71.18	0.00	−6.42	−76.44	0.00	−8.79	−9.03	0.00
Two wheeler (2W) constant	−5.77	−101.21	0.00	−5.53	−330.42	0.00	−6.85	−106.97	0.00	−14.50	−79.01	0.00	0.60	15.69	0.00
LDV constant	−6.70	−78.31	0.00	−5.22	−365.73	0.00	−5.95	−95.31	0.00	−10.10	−154.36	0.00	−1.17	−8.24	0.00
Taxi constant	−19.90	−41.92	0.00	−4.36	−254.85	0.00	−0.17	−0.04	0.97	−7.77	−122.01	0.00	−6.55	−15.14	0.00
Bus constant	−9.15	−17.08	0.00	−1.33	−216.77	0.00	−3.05	−11.89	0.00	−0.93	−65.58	0.00	−6.23	−0.75	0.45
Train constant	-	-	-	−6.46	−237.65	0.00	−8.66	−25.36	0.00	−6.95	−124.44	0.00	-	-	-
Three wheeler (3W) constant	−13.00	−8.45	0.00	−4.46	−182.47	0.00	-	-	-	−1.05	−52.59	0.00	−3.10	−22.88	0.00
Household size - bicycle	−0.03	−6.45	0.00	-	-	-	0.05	6.67	0.00	0.01	1.24	0.22	−0.22	−13.94	0.00
Household size - 2W	−0.05	−8.16	0.40	-	-	-	-0.03	−4.93	0.12	0.02	0.71	0.48	0.01	1.62	0.11
Household size - LDV	−0.14	−11.98	0.00	-	-	-	-0.04	−7.74	0.00	−0.01	−1.15	0.25	0.01	1.20	0.23
Household size - taxi	0.39	10.06	0.00	-	-	-	-0.83	−3.34	0.00	−0.15	−19.18	0.00	0.11	3.31	0.00
Household size - bus	0.18	3.45	0.00	-	-	-	0.02	3.98	0.00	−0.06	−27.66	0.00	0.03	0.57	0.57
Household size - train	-	-	-	-	-	-	0.07	1.54	0.00	−0.06	−7.27	0.00	-	-	-
Household size - 3W	−0.16	−0.83	0.00	-	-	-	-	-	-	−0.02	−6.01	0.00	0.02	1.38	0.17
Household income - bicycle	0.00	−1.20	0.00	−0.01	−3.76	0.00	0.00	−6.00	0.00	−0.12	−9.20	0.00	0.36	0.96	0.34
Household income - 2W	0.04	20.11	0.07	−0.04	−15.63	0.00	0.00	5.48	0.63	0.21	9.66	0.00	0.19	17.04	0.00
Household income - LDV	0.03	10.75	0.03	−0.04	−16.73	0.00	0.00	−3.61	0.00	0.61	78.98	0.00	0.39	21.81	0.00
Household income - taxi	−0.12	−2.23	0.00	−0.01	−2.45	0.01	−0.77	−4.09	0.00	0.46	66.55	0.00	0.69	16.58	0.00
Household income - bus	−0.45	−5.76	0.00	0.00	2.22	0.03	0.00	−8.95	0.00	0.15	56.61	0.00	0.19	2.72	0.01
Household income - train	-	-	-	0.00	0.42	0.68	0.00	−0.48	0.00	0.31	40.58	0.00	-	-	-
Household income - 3W	−0.15	−1.79	0.00	−0.01	−2.25	0.02	-	-	-	−0.02	−5.86	0.00	0.33	12.39	0.00
Age - bicycle	−0.02	−52.71	0.00	0.01	22.55	0.00	−0.01	−7.30	0.00	0.03	34.14	0.00	-	-	-
Age - 2W	0.00	−9.32	0.00	0.03	107.13	0.00	0.01	11.73	0.00	0.01	4.77	0.00	-	-	-
Age - LDV	−0.03	−22.25	0.00	0.03	125.56	0.00	0.03	20.04	0.00	0.04	45.94	0.00	-	-	-

(continued)

Table 3. (continued)

Explanatory variables	Hanoi			Jakarta			Kuala Lumpur			Manila			Phnom Penh		
	Parameter estimates	T-test	*P*-value	Parameter estimates	T-test	*P*-value	Parameter estimates	T-test	*P*-value	Parameter estimates	T-test	*P*-value	Parameter estimates	T-test	*P*-value
Age - taxi	−0.12	−51.76	0.00	0.02	55.51	0.00	−2.41	−4.71	0.01	0.03	46.75	0.00	-	-	-
Age - bus	0.03	4.36	0.00	0.00	13.70	0.00	−0.02	−15.87	0.00	0.01	46.07	0.00	-	-	-
Age - train	-	-	-	0.02	36.56	0.00	0.02	2.78	0.00	0.00	5.19	0.00	-	-	-
Age - 3W	−0.41	−53.11	0.23	0.02	31.60	0.00	-	-	-	0.00	1.97	0.05	-	-	-
Gender - bicycle	−0.15	−11.14	0.00	0.54	39.17	0.00	0.50	16.21	0.14	1.53	33.54	0.00	-	-	-
Gender - 2W	0.76	39.18	0.00	0.75	72.16	0.00	1.50	61.88	0.88	2.00	21.78	0.00	-	-	-
Gender - LDV	0.43	13.32	0.00	0.51	52.07	0.00	0.15	6.72	0.00	0.83	32.55	0.00	-	-	-
Gender - taxi	1.63	4.50	0.00	−0.09	−8.05	0.00	−0.09	−0.15	0.00	0.20	8.68	0.00	-	-	-
Gender - bus	1.58	5.08	0.00	0.04	10.22	0.00	−0.03	−1.49	0.00	−0.03	−3.84	0.00	-	-	-
Gender - train	-	-	-	0.47	25.30	0.00	−1.06	−4.78	0.00	0.12	4.38	0.00	-	-	-
Gender - 3W	0.43	1.97	0.05	−0.53	−27.10	0.00	-	-	-	−0.13	−13.04	0.00	-	-	-
Travel cost (US$)	−4.03	−31.31	0.00	−0.08	−56.24	0.00	-	-	-	−0.26	−37.74	0.00	-	-	-
Travel cost - 2W (US$)	-	-	-	-	-	-	−20.10	−50.98	0.00	-	-	-	−29.40	−16.75	0.00
Travel cost - LDV (US$)	-	-	-	-	-	-	−9.19	−44.36	0.00	-	-	-	−53.30	−12.56	0.00
Travel cost - taxi (US$)	-	-	-	-	-	-	−0.61	−6.40	0.00	-	-	-	−0.04	−1.25	0.21
Travel cost - bus (US$)	-	-	-	-	-	-	−1.67	−4.12	0.00	-	-	-	−2.29	−0.10	0.92
Travel cost - train (US$)	-	-	-	-	-	-	−5.81	−22.99	0.00	-	-	-	-	-	-
Travel cost - 3W (US$)	-	-	-	-	-	-	-	-	-	-	-	-	−0.22	−5.77	0.00
Travel time (min)	−0.23	−122.55	0.00	−0.03	−493.22	0.00	−0.26	−74.54	0.00	−0.06	−196.39	0.00	−0.02	−13.33	0.00
Summary statistics															
Number of observations	187,830			1,079,821			216,527			466,301			39,013		
Rho square	0.44			0.20			0.28			0.24			0.29		

Note: Missing data denote parameters that are unavailable due to model constraints or variables not included in the original surveys.

Table 4. Value of Time Estimates

Value of time	Hanoi	Jakarta	Kuala Lumpur	Manila	Phnom Penh
Constrained (US$/hr)	3.45	22.12		14.20	
2W (US$/hr)			0.79		0.04
LDV (US$/hr)			1.72		0.02
Taxi (US$/hr)			26.14		30.00
Bus (US$/hr)			9.49		0.52
Train (US$/hr)			2.73		-
3W (US$/hr)			-		5.45

Note: The values of time for three wheeler in Kuala Lumpur and for train in Phnom Penh are not estimated because these modes were unavailable in the respective city and, hence, excluded from its respective mode choice model.

Age is highly significant for all modes in all cities, except for taxi in Hanoi and Kuala Lumpur. Although age is a significant variable, its impact on different modes across the cities varies. For example, older respondents tend to find bicycle more attractive as a primary mode choice in Jakarta and Manila, but the opposite is the case in Hanoi and Kuala Lumpur. The utility of two wheeler remains high among older respondents in all cities, where age does not seem to be a concern when using two wheelers. Older respondents also tend to find LDV more attractive in all cities but Hanoi.

The parameter estimates for gender, where male = 1 in the dummy variable, are positive for all cities in the two wheeler and LDV alternatives. This implies that men choose two wheeler and LDV modes as their primary mode choice more than women. Women choose to bicycle more than men in Hanoi, while the opposite is true in Jakarta, Kuala Lumpur, and Manila. Women also choose to take taxis more than men in Jakarta and Kuala Lumpur, and they ride buses more than men in Kuala Lumpur and Manila. Kuala Lumpur is the only city where women found train to be a more attractive mode choice than men. In Jakarta and Manila, female travelers were also found to choose three wheelers more than male travelers (Table 3). Public transportation modes are, therefore, not always more attractive for women.

The parameters estimated from the mode choice models were used to calculate the value of travel. The value of travel time depends on the utility that an individual attaches to time spent in a particular mode and the opportunity cost of travel time (*27*). A high value of time can be the result of a high opportunity cost of time or a high level of disutility of time spent on a transportation mode (*20*). The value of time is also the marginal rate of substitution of time for cost ($MRS_{Time\text{-}Cost} = \frac{\beta_{Travel\ Time}}{\beta_{Travel\ Cost}}$), which expresses the willingness to pay for a specific transportation mode and the trade-off between time and cost while still maintaining the same level of utility. This value is different for each individual as it depends on observed travel time and wage rate and could change as trip purpose changes. The value of time can also change according to the characteristics of the traveler, time of travel, and trip duration (*28*). Table 4 shows the value of time estimates in the five different cities. Travelers in Jakarta have the highest value of time of US$22 per hour, compared with travelers in Hanoi and Manila, while taxi users have exceptionally high values of time in Kuala Lumpur and Phnom Penh (Table 4). The values of time of other modes apart from taxi in Phnom Penh are significantly lower than the other four cities. This is due to the relatively low average wage in Phnom Penh, which was US$ 0.44 per hour in 2011 (*29*) and is most likely much lower when the household travel survey was collected. Since the value of time is usually associated with the average wage rate (*30*, *28*), the differences in the value of time among the cities thus reflect different levels of wages.

Policy Scenario Results

The parameters derived from the mode choice models were used to estimate the probabilities of each mode (Equation 2.3), which were then used to forecast changes in future mode choice under three different policy scenarios, as described in the Policy Scenarios subsection. Since the household travel survey data were collected from different years, ranging from 1996 to 2005 depending on the city, the base year of 2015 was selected to standardize the estimations and each set of probability estimations was then calibrated accordingly, based on the expansion rate by household income growth (up to 2050). This section presents transportation demand in passenger kilometer (pkm) (Figure 1), vehicle kilometer (vkm) (Figure 2) and CO_2 emissions (Figure 3) in three scenarios in 2050.

As shown in Figure 1, pkm is the lowest in the LUT scenario for all five cities, though the magnitude of change for each city varies. The pkm levels in the Baseline and ROG scenarios are very similar for Hanoi, Jakarta, and Manila, while the greatest difference in

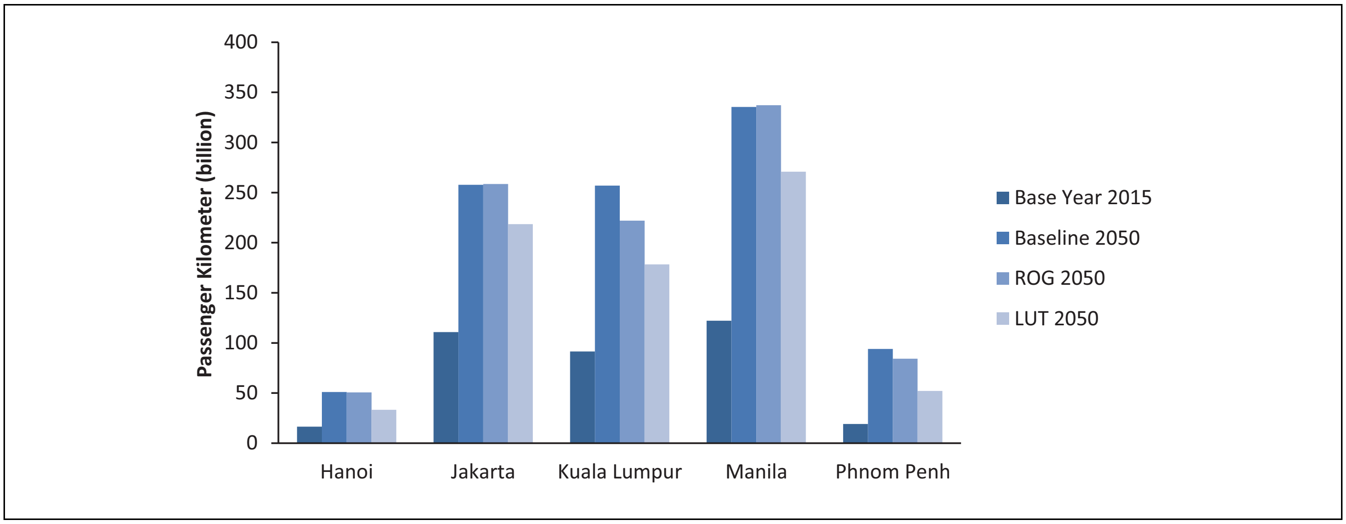

Figure 1. Total transportation demand in passenger kilometer (pkm) under three policy scenarios for five cities in 2050.

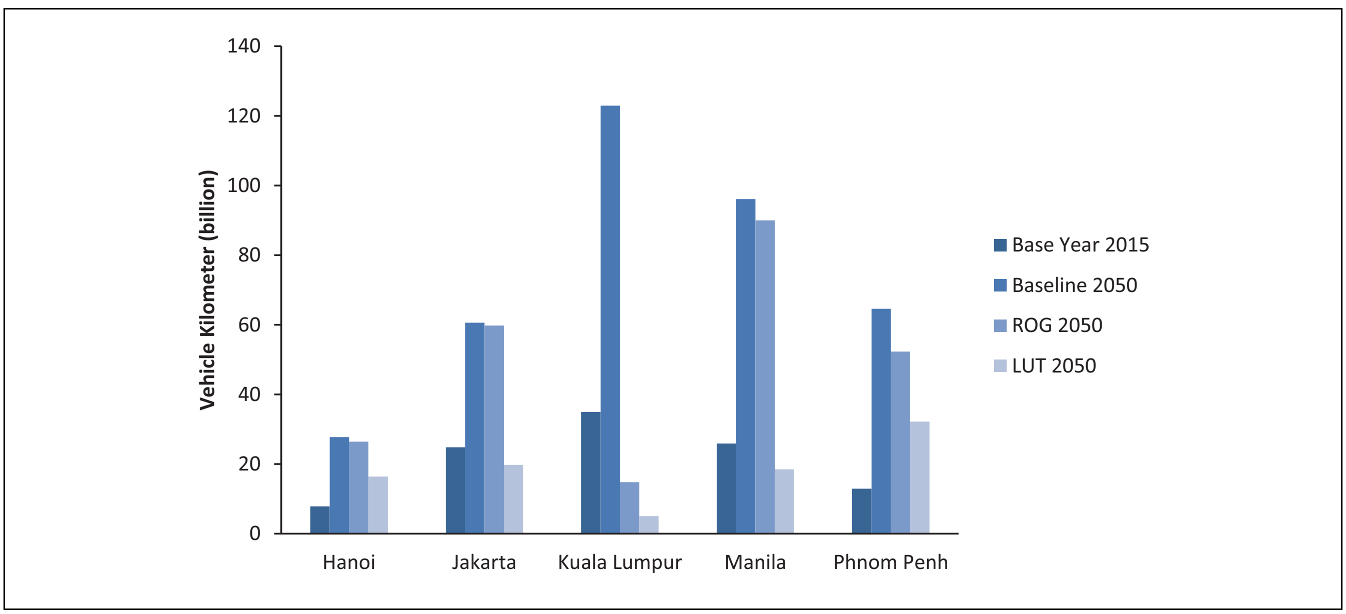

Figure 2. Total transportation demand in vehicle kilometer (vkm) under three policy scenarios for five cities in 2050.

pkm between the Baseline and ROG scenarios can be found in Kuala Lumpur (14%). This implies that the pricing policies implemented in the ROG scenario are not as effective in regulating transportation demand in the three former cities as they are in Kuala Lumpur and Phnom Penh. Even in the LUT scenarios, which have more stringent policy assumptions, pkm levels in 2050 are projected to be higher than in the 2015 base year in all cities.

In general, total pkm will increase from the base year under all three scenarios, ranging between 95% (Kuala Lumpur in LUT scenario) and almost 400% (Phnom Penh in Baseline scenario) in 2050. These trends are consistent with economic growth projections for the five cities. As a result of the integrated planning assumptions in LUT, pkm will increase at a lower rate from the base year compared with the Baseline and ROG scenarios because of changes in travel distance in all cities.

When converted to vkm, transportation demand is significantly lower in LUT than in the Baseline and ROG scenarios across all cities, with Jakarta, Kuala Lumpur, and Manila having lower vkm levels in the LUT scenario in 2050 than in the 2015 base year (Figure 2). This decline in vkm is due to the increase in public transport ridership

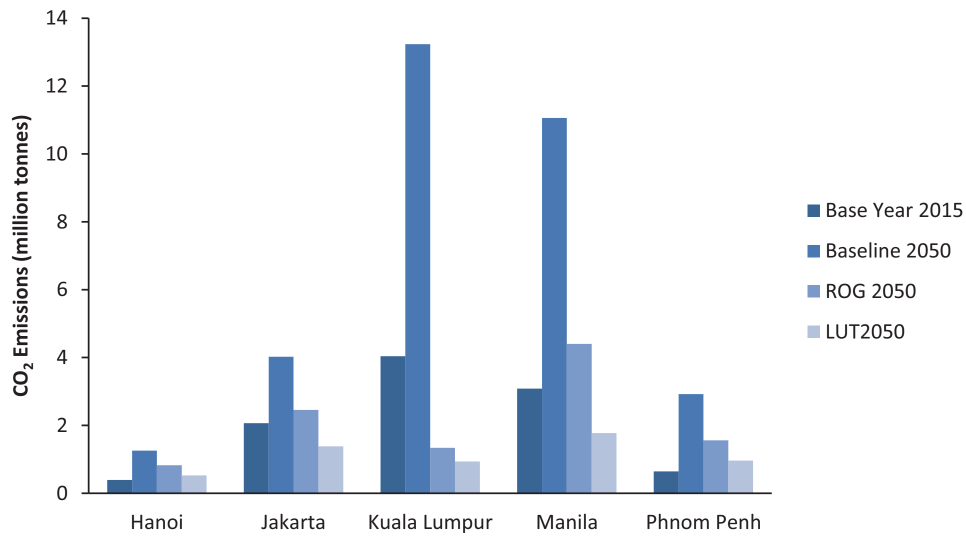

Figure 3. Total CO_2 emissions under three policy scenarios in 2050.

triggered by improvements in the quality of train and bus services and the reduction in their travel time. The difference in vkm between the Baseline and ROG scenarios can be as high as 88%, as seen in Kuala Lumpur, or as low as 1% in Jakarta. The wide range of impact reflects the varying influence different pricing policies have on mode choice and different preferences in mode choice in different cities. For example, the pricing policies assumed in the ROG scenario are more effective in regulating vkm in Kuala Lumpur than in Hanoi or Jakarta. The significant decrease in vkm in both the ROG and LUT scenarios in Kuala Lumpur is due to a substantial modal shift from LDVs (or private vehicles) to public transport. This shows that there can be another vkm growth alternative for Kuala Lumpur, one that does not rely heavily on the use of private vehicles as indicated in the Baseline scenario.

Integrated land use and transport planning assumptions seem to be most effective in Manila as vkm decreased by 80% from the ROG to LUT scenario, while land use measures have a smaller impact in Hanoi and Phnom Penh (both with a 38% decrease in vkm in LUT 2050), whose dominating mode choice is two wheeler even in 2050. The low share of public transportation in these two cities is the key reason why vkm in LUT 2050 remains higher than vkm in the 2015 base year, despite the implementation of robust policies and measures. Without better transportation alternatives, two wheelers will continue to dominate mode share in Hanoi and Phnom Penh.

Total CO_2 emission levels vary by city but, following vkm projection trends, they are lower in the LUT 2050 scenario than in the 2015 base year for Jakarta, Kuala Lumpur, and Manila (Figure 3). The policy scenarios have triggered the largest decrease in CO_2 emissions from the Baseline to LUT scenario in 2050 for Kuala Lumpur (93%), followed by Manila (84%). The difference in CO_2 emission reduction between the LUT and ROG scenarios ranged between 30% (Kuala Lumpur) and 60% (Manila), which showed that the impact of the same combination of policy measures on CO_2 emissions will vary depending on a city's transportation mode choice, preferences, existing and potential transportation alternatives, and fuel efficiency of vehicle fleet. With appropriate policies and measures, CO_2 emissions can be significantly reduced from the Baseline scenario by 2050, as even in Hanoi, where the smallest emission reduction was observed, the emission level in LUT will still be 58% lower than in the Baseline scenario. A low-carbon transportation future in Southeast Asian cities requires the implementation of specific pricing policies and land use measures that will target their distinctive mix of vehicle type, transportation services, and transit ridership.

Discussion and Conclusions

Cities are growing differently across the world, even within the same region, where there are different transportation trends and challenges. Existing transportation services and travel behavior are some of the key variables shaping future transportation trends and carbon emissions projections. Cities in Southeast Asia encompass distinctive characteristics, such as the wide range of transportation alternatives, often in the form of informal transit and two wheelers, including scooters, mopeds, and motorcycles. The most pressing transportation challenge experienced by Southeast Asian cities is not CO_2 emission but congestion or the lack of efficient public transportation services, which could lead to extended travel time delays and indirectly result in additional local air pollution and global CO_2 emissions. The abundance of informal public transportation services and high two wheeler use could hinder development of public transportation as they serve as alternative transportation services that are often perceived to be more flexible and convenient. For the cases of Hanoi and Phnom Penh, where two wheelers dominated the transportation mode share in 2015 (55% and 74% respectively) and will continue to do so in the LUT 2050 scenario (56% and 68% respectively), it would be difficult to shift two wheeler users to public transportation, as the freedom of mobility associated with two wheelers is the preferred choice. The utility of two wheelers in Hanoi and Phnom Penh is clearly higher than public transportation modes (Table 3). The quality of public transportation services, including shorter travel time, an extended network, and higher service frequencies, would have to be significantly improved in order to gain higher levels of ridership and reduce emissions in the long term. A cleaner two wheeler fleet composed of electric vehicles could also directly reduce local air pollution and CO_2 emissions.

Due to the high share of two wheelers in Hanoi, Jakarta, Kuala Lumpur, and Phnom Penh, any economic instruments implemented should always apply to both LDVs and two wheelers. Such instruments, including road tolls and parking policies, will then serve as transportation demand management tools for both types of vehicle. In addition, the high share of two wheelers reflects low public transportation and LDV mode shares. If cities were to regulate the use of two wheelers, the quality of public transportation would have to be improved at the same time to offer good alternatives.

Public transportation ridership, especially bus services, is projected to increase in Manila, Jakarta, and Kuala Lumpur, where public transportation will become the dominating mode choice in the LUT scenario in 2050. Public transportation ridership, including informal transit services, was already high in Manila and Jakarta in 2015. However, without robust pricing policies and land use measures to reduce the growth of private vehicle use, LDV mode share in Manila could increase to 28% in Baseline 2050 from 16% in 2015. The mode choice estimations (Table 3) show that LDV use in Manila is less attractive than public transportation, both bus and train. Hence, with further improvements made to its public transportation services, coupled with a range of policies and measures implemented to regulate private vehicle use, LDV mode share can be reduced to 2% in the LUT scenario in 2050, which explains the significant decrease in CO_2 emissions (Figure 3).

Kuala Lumpur is the only city in this study with a dominating LDV mode share in 2015 (46%) and Baseline 2050 (51%). It is also the city with the largest reduction in CO_2 emissions due to the changes in mode share triggered by different policies and measures, as illustrated in the policy scenarios. In both ROG and LUT 2050, bus and train mode shares will dominate and increase substantially to over 80% from 20% in Baseline 2050. This is a city with a high potential for massive public transportation development and improvement.

A key barrier to public transportation development in Southeast Asian cities is the wide range of informal public transportation services. Such services, which are also common in Latin American and African cities, provide more flexible route options and often at a lower cost than structured public transportation. High public transportation mode share can only be achieved when the provision of informal public transportation services is first addressed.

As shown in Table 4, the value of time estimates are relatively higher for bus and train when compared with LDV and two wheeler in Kuala Lumpur and Phnom Penh. In Jakarta, which has the highest constrained value of time across all modes, transportation users will be willing to pay more to spend less time traveling. Hence, the improvement of public transportation quality by reducing travel time will be more effective in increasing its attractiveness than reducing cost through transit subsidies.

A low-carbon transportation sector is possible to achieve even for rapidly growing Asian cities, as the increase in pkm does not necessarily imply a subsequent increase in vkm and CO_2 emissions, as seen in Jakarta, Kuala Lumpur, and Manila. Transportation demand in pkm can continue to grow but in a more sustainable manner that will keep vkm and CO_2 emissions low. The policy scenarios in this study illustrate that achieving low-carbon mobility requires targeted policies, which will differ by city according to the varying transportation preferences, constraints, and needs found in different cities. Pricing policies, such as fuel tax, parking, and road pricing, and bus and rail transit subsidies, are more effective in regulating pkm and vkm in Kuala Lumpur than in other cities. This is likely due to the high LDV mode share in Kuala Lumpur, which responds to the increased cost of driving and its greater bus utility (than LDV) which made it a more attractive mode when bus travel cost decreased while LDV travel cost increased. Having a set of robust pricing policies would therefore be an optimal way for Kuala Lumpur to reduce its transportation CO_2 emissions and improve its transportation services through additional pricing revenue. On the other hand, land use measures that will reduce average travel distance and transit travel time tend to have a greater impact on reducing transportation demand in Manila than in other cities. The diverse mix of transportation modes, including informal transit and three wheelers, will continue to provide services though not as much as in the base year. Land use measures, such as mixed use planning and transit-oriented development in neighborhoods that already have high density levels, will be successful in achieving high shares of sustainable modes. For Manila, the improvement of bus and train services, together with the integration of informal transit services to the structured transportation network will be critical to its success.

Although certain policies have a higher impact on transportation demand than others and are more effective in some cities than others, the influence of one policy on another is often uncertain and difficult to evaluate. A policy with a relatively smaller impact than another policy can serve a complementary or supporting role in a complex transportation system. In addition, the same set of policies and measures can also trigger different outcomes, as shown in this study. Cities are diverse in terms of their existing mode choice and transportation services, which will lead to different policy impacts, even within the same country or region.

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Author Contributions

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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