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Understanding the impact of urban form attributes on household vehicle ownership and choice in metro Manila: Modeling, simulation, and application

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Abstract

Projected economic growth is expected to further increase vehicle ownership among households in Metropolitan Manila. This increase is likely to translate to higher energy requirements, elevated greenhouse gas emissions and air pollution, as well as a worsening of traffic congestion. A multinomial logit-based household vehicle ownership model was developed taking into account household characteristics and urban form peculiarities that are hypothesized to affect the level of vehicle ownership among households. The model utilized data gathered from a survey of 2,300 households from various areas of Metropolitan Manila. Results indicated that flooding susceptibility of communities does not affect vehicle ownership and type among its residents. Higher public transport density and closer proximity to essential facilities and services were found to be strong determinants that discourage vehicle ownership. Higher population density, contrary to findings in most studies, tends to reinforce vehicle ownership due to the inadequacy of public transport service, especially in crowded areas. The model was used to simulate “what if” shares of levels of vehicle ownership and apply the model under scenarios of 1) access to essential facilities, 2) improved road public transport line density, and 3) their combination. The results indicated that these interventions, relative to the baseline scenario, could respectively reduce vehicles owned by 26.63%, 35.02%, and 59.61% among the households surveyed and CO_2 emission by 1.33 million tonnes, 1.63 million tonnes, and 2.69 million tonnes.

Keywords: Multinomial logit model, Household vehicle ownership, Accessibility, Public transport, CO_2 emission, Metro Manila

1. Introduction

The Philippines is one of the faster growing economies with an average annual growth rate of 6.8% in the last three years [1]. However, the greenhouse gas (GHG)-to-GDP ratio of the Philippines is higher than the world average [2]. This growth is expected to further increase GHG production in the country if unchecked. The transport sector may be one of the key sectors in the environmental sustainability of Philippine’s econosphere, accounting for 30.4% of the country’s CO_2 emissions from fuel combustion in 2012 [3].

Various investigations have looked at transport’s long term GHG mitigation in the country including those by Regidor and Javier [4] and the Asian Development Bank [5], which emphasized the importance of managing ownership, usage, and energy intensity of private vehicles. For the road passenger transport sector in Metro Manila, private vehicles accounted for 31.7% of person trips and 71.3% of vehicle trips in 2012. The number of private vehicle trips has increased by 3.3% per annum from 1996 to 2012 [6]. The road public transport modes (i.e., Jeepney and bus) account for 68.3% in terms of person trips in 2012 [6]. It is interesting to note that the annual growth rate of the much bigger and more fuel consuming utility vehicles (UV), i.e., cross utility vehicles, sport utility vehicles, Asian utility vehicles, wagons, pickup trucks, minivans, and vans among households has been much greater than that of cars [7]. The increasing GDP in the country over the years has prompted and is expected to continuously fuel vehicle sales and use. Metro Manila has led all the regions in vehicle purchases, registering average annual sales of 204,404 passenger vehicles from 2015 to 2016 [7].

About 50% of Metro Manila roads are already operating at volume/capacity (V/C) ratios in excess of 0.80 [6], and the projected up-trend in vehicle ownership is expected to saturate the roads further. In fact, the continuous increase in vehicle use in the metropolis over the years has rapidly reduced the effectiveness of the vehicle reduction schemes that have been introduced [8-9].

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A better understanding of the determinants of household vehicle ownership and choice is vital in crafting appropriate interventions to manage vehicle ownership and use in Metro Manila. Factors covered in similar studies typically include household income, household demographics, operating cost, vehicle attributes, and urban form. In the cities of developing countries, specifically in Ho Chi Minh, Bengaluru, Delhi, Calcutta, Shiraz and China, household size and income were found to be major factors influencing vehicle ownership [10-13]. A greater number of regular salaried household members in India was found to increase probably of vehicle ownership in India [14]. Similarly, the presence of children and seniors in the household provide similar effects [11, 14]. Conversely, mixed land use has a negative effect on household vehicle dependency [12], while population density was found to be a non-factor [10]. Development of an urban transit system is associated with a reduction in private vehicle dependency [15].

Densification of urban areas, however, tends to discourage vehicle ownership and discourages the choice of bigger vehicles in more developed countries, which could most probably be attributed to the scarcity and cost of parking areas [16-22]. Similar to findings in developing countries, the presence of children in the household reinforces and mixed land-use discourages dependency on private vehicles in more developed countries [16, 23]. Better public transport access was found to promote lower vehicle ownership [17-18, 23]. Vehicle choices are influenced by vehicle cost [24-25] to a stronger degree when compared to fuel prices [25]. The differences between developed and developing countries and even among countries from within could be attributed to peculiarities in the areas, including urban form.

This study investigates household vehicle ownership and choice in Metro Manila, taking account these factors and covering urban form peculiarities. The state of the public transport system in Metro Manila is apparently different from that of developed countries. The Jeepney, whose features are like a minibus, is the dominant mass transit mode in Metro Manila. Jeepney stops are practically non-existent because passengers are loaded and unloaded anywhere along the roads. There are bus stops along the roads, but the buses (standard buses) also operate the same way as the Jeepney. In this context, we should consider the road public transport line density rather than the bus and Jeepney stop density. Comprehensive Land Use Plans (CLUP) in Metro Manila, and on a wider scale the whole country, are seldom realized due to the lack of strong mechanisms for their implementation [26]. The proximity of communities to essential destinations and services thus has not been ensured in all cases, possibly affecting decisions to own vehicles. A multi-criteria accessibility index was introduced to capture both the proximity of the areas to facilities and the importance of each destination as viewed by the people. Additionally, studies indicate that there is much to be desired from Metro Manila's public transport system, both in terms of comfort and functionality [27-28]. There are poor linkages between public transport planning and land use, and the routes are not systematically organized [29]. The inadequacy in public transport services becomes more pronounced during poor weather, due to its informal nature, wherein the government has very little control over its operation. It should be noted that more than 50% of barangays (communities) in some cities in Metro Manila are considered to be highly flood-prone [30]. The susceptibility of the area to flooding could also possibly be a factor in choosing bigger vehicles. Accessibility of public transport and flooding susceptibility of the areas were thus likewise taken into account.

The sensitivity of the levels of household vehicle ownership on each of these peculiarities was determined to provide insights on effective ways to lower vehicle ownership levels in Metro Manila. The developed model was also applied to determine the potential carbon dioxide (CO_2) emission reductions based on formulated scenarios. To the best of our knowledge, this is the first study to measure the impact of improvements due to urban form attributes toward a reduction in CO_2 emissions in Metro Manila.

2. Methodology

2.1 Model formulation

A Multinomial Logit (MNL) model was applied for estimating probabilities of each of the possible outcomes including:

- Alternative 1: No vehicle owned by household
- Alternative 2: One car owned by household
- Alternative 3: One UV owned by household
- Alternative 4: Two cars owned by household
- Alternative 5: Two vehicles with at least one UV owned by household (a household may own one car and one UV or household may own two UVs)

All vehicle types are classified into two categories. The first is a small car (i.e., sedan, hatchback, multipurpose vehicle, bug car, and coupe). The second is a utility vehicle (UV) is a type of large car (i.e., cross utility vehicle, sport utility vehicle, wagon, pickup, minivan, and van). The vehicle body types were classified based on Consumer Guide Automotive [31]. The factors covered consisted of household profile and built environment characteristics, see Table 1. The household profile includes household income-to-household size ratio, a number of household working members, number of preschoolers, number of primary and secondary students, number of university students, number of senior citizens, level of education of the head of the family, homeownership, and total regular travel requirements in units of person-kilometer-traveled (PKT). Urban form attributes for where the household lives were described using the accessibility index, susceptibility to flooding, public transport line density, road density, and population density.

The accessibility index describes the proximity of an area to critical destinations and facilities. It was computed using a multi-criteria gravity-based accessibility model taking into account the importance of the destinations, as expressed as equation (1):

$$Accessibility\ Index = \sum_j [W_j \sum_i (\frac{1}{e^{d_{ij}}})] \quad (1)$$

where distance d_{ij} represents the travel required to reach a point of interest i of destination category j, while weights W_j refers to the importance of destination category j. The weights W_j were adopted from [32] and are provided in Table 2. Destination categories covered included educational institutions, hospitals and medical care centers, public markets and supermarkets, as well as social, recreational and shopping areas. The importance weight of social, recreational and shopping facilities is higher than that of hospitals and medical care centers because Filipinos go to social, recreational and shopping facilities more often than to hospitals and medical care centers.

Table 1 Description of variables used to develop household vehicle ownership model

Variable	Description
Household characteristics	
Household income-to-household size ratio	Continuous variable (Php/person)
No. of household members employed	Continuous variable (persons)
No. of preschoolers	Continuous variable (persons)
No. of basic education students	Continuous variable (persons)
No. of university students	Continuous variable (persons)
No. of senior citizens (> 60 years old)	Continuous variable (persons)
Educational level of the household head	1 = if household head earned bachelor degree or above 0 = if household head earned degree below bachelor (reference)
Homeownership	1 = if household living in their house 0 = if household living in rent house (reference)
Urban form attributes	
Accessibility Index [a] of a residence in a barangay	Continuous variable
Susceptibility to flooding of residence in a barangay [b]	1 = if household reside in flood-prone barangay; 0 = if household does not reside in flood pone barangay (reference)
Road public transport line density [c] of residence zonal area [d]	Continuous variable (km/km^2)
Road density of residence zonal area [d]	Continuous variable (km/km^2)
Population density of residence zonal area [d]	Continuous variable (persons/km^2)
Vehicle usage	
Total household person-kilometer-travelled (PKT)	Continuous variable (km)

[a] See discussion below
[b] Based on [30]
[c] Covered length of Jeepney and bus routes within the zonal area
[d] Zoning was based on [33]

Table 2 Destination Importance Weights

Facility	Weight
Hospitals and medical care centers	20.9%
Educational institutions	
Primary schools	12.2%
Secondary schools	11.7%
Universities	8.9%
Public markets and supermarkets	10.7%
Social, recreational and shopping facilities	35.5%

A list of 655 licensed hospitals with official addresses was obtained from the Department of Health [34]. An official list of basic education schools (i.e., 508 primary schools and 310 secondary schools) with official addresses in Metro Manila were filtered from the national master lists of public primary schools and public secondary schools published by Department of Education [35]. A list of 203 colleges with official addresses in Metro Manila was obtained from the Commission on Higher Education [36]. Another list of 333 markets (i.e., 87 public markets and 246 supermarkets) and 161 recreation centers (shopping malls) was obtained from the pop-up menu of Google Maps since there exists no official list with addresses from any government departments or agencies. The approximate distance from home to a key facility was computed using the CDXDistance2WP function of the CDXZipStream tool [37]. This method is more accurate than the Euclidean and Manhattan methods.

Public transport line density sums the length of all public transport lines passing through the traffic zone in which residences belong and divides it by the total area of the zone. This took into account Jeepney (mini-bus), public utility vans, and bus services in the area.

2.2 Discrete choice modeling method

As discussed earlier, the MNL model was used to provide the probability of each outcome occurring given a set of variable values. This method is widely applied because its structure is simple and easily interpretable. Furthermore, it can handle a large number of alternatives and variables with revealed preference data. Each alternative made by each choice maker has a utility function that is composed of an observed term and an unobserved term. The observed term is expressed in a linear parameter form, while the unobserved term is assumed to be an identically and independently distributed (IID) Type I Extreme-Value [38]. The model takes the following form [39]:

$$Pr_n(t) = \frac{exp(\beta_t' x_{nt})}{\sum_T exp(\beta_T' x_{nT})} \quad (2)$$

where $\mathrm{Pr_n(t)}$ refers to the probability of an alternative t chosen by a household n. x_{nt} is a column vector of the explanatory variables (i.e., household demographic characteristics and urban form attributes) including a constant, and β'_t is a column vector of the corresponding coefficients. The maximum log-likelihood estimation approach was employed to estimate the coefficients.

Figure 1 The map of Metro Manila [32]

The significance of each of the variables was initially determined by the removal of insignificant factors using the backward elimination approach. To ensure better data fit, the final model included only factors determined significant. The package "mlogit" of R programming language was employed to model the sample data [40].

2.3 Data source

A guided interview survey was designed and implemented to gather revealed preference data from a total of 2,300 households in Metro Manila from April to May 2017. This sample size corresponds to a confidence level of 99% with a margin of error of 2.69% if we assume a standard deviation of 0.5, based on the Crochran formula. Therefore, the sample can be representative of the population. After cleaning the data, there were only 2,150 samples for data modeling. A simple random sampling technique was used to gather the sample data since the baseline distribution of household vehicle ownership in Metro Manila was not known. Metro Manila consists of sixteen cities and one municipality (see Figure 1), and the number of samples distributed in each city was based on the corresponding population distribution published in the 2017 Philippine Statistical Yearbook [7]. The demographics of the respondents are provided in Table 3.

Table 4 provides the distribution of the vehicle ownership of the households surveyed. The descriptive statistics of the urban form attributes among surveyed households are presented in Table 5.

2.4 Scenario analysis

Scenarios were formulated to simulate the effect of significant urban form parameters on the level of vehicle ownership shares. These are listed as follows:

- Scenario 1: Baseline
- Scenario 2: High accessibility
- Scenario 3: High public transport line density
- Scenario 4: High accessibility and public transport line density

The shares for each level of household vehicle ownership for the sampled households were determined for each scenario. For the high accessibility scenario, the proximity of all areas in Metro Manila to key destinations was assumed to be similar to the community with the highest accessibility among those surveyed. The high public transport line scenario sets the public transport line density in all communities equal to that with the densest public transport service, while the fourth scenario is supposed to quantify the combined effects of scenarios 2 and 3.

3. Results and discussion

This section is divided into three parts. The first sub-section provides the results of the model and its interpretation. The second part presents how the level of ownership share could have been different under the other scenarios listed earlier. Finally, the last part is an application of the model to estimate the potential reduction in CO_2 emissions under various scenarios.

3.1 Model estimation results

To remove the insignificant factors, a backward elimination method was applied with the critical χ^2 value of 9.488 at the 0.05 significance level for k = 4 degrees of freedom. The initial run found no relationship between flooding susceptibility and the level of vehicle ownership of households. This, however, might not necessarily indicate that the flooding situation in Metro Manila does not affect the vehicle choice mindset of households. It is possible, for example, that households might tend to favor bigger vehicles in general, regardless whether they live in flood or non-flood prone areas since they shall all be encountering floods when

Table 3 Household demographical distribution of respondents

Demographic		Frequency	% Share
Household income (Php/month)	< 5,000	9	0.42
	5,000 – 9,999	51	2.37
	10,000 – 14,999	152	7.07
	15,000 – 19,999	132	6.14
	20,000 – 29,999	232	10.79
	30,000 – 39,999	215	10.00
	40,000 – 59,999	345	16.05
	60,000 – 79,999	397	18.47
	80,000 – 99,999	201	9.35
	100,000 – 149,999	239	11.12
	150,000 – 299,999	149	6.93
	≥ 300,000	28	1.30
Household size	1	112	5.21
	2	381	17.72
	3	797	37.07
	4	569	26.47
	5	193	8.98
	6	63	2.93
	7 or more	35	1.63
Number of employed members	0	45	2.09
	1	700	32.56
	2	1091	50.74
	3	242	11.26
	4	55	2.56
	5	14	0.65
	6	3	0.14
Number of preschoolers	0	1786	83.07
	1	293	13.63
	2	62	2.88
	3	9	0.42
Number of K-12 education students	0	1382	64.28
	1	408	18.98
	2	263	12.23
	3	79	3.67
	4	16	0.74
	5	2	0.09
Number of university students	0	1767	82.19
	1	306	14.23
	2	71	3.30
	3	6	0.28
Number of senior citizens	1	1857	86.37
	2	163	7.58
	3	130	6.05
Educational level of head of the family	At least College	800	37.21
	Lower than College	1350	62.79
Homeownership	Owned	1384	64.37
	Not Owned	766	35.63

Table 4 Distribution of household vehicle holdings

Households	Zero-vehicle	One Vehicle		Two vehicles	
		One car	One UV	Two cars	At least one UV
Frequency	1012	711	288	69	70
% share	47.07	33.07	13.40	3.21	3.26

Table 5 Descriptive statistics of the urban form attributes and the household PKT

	Mean	SD	Min	Max
Urban form				
Accessibility index	4.547	1.237	$4.07x10^{-05}$	6.954
Susceptibility to flooding of residence barangay	0.150	0.357	0	1
Road public transport line density (km/km^2)	32.949	25.177	0	154.221
Road density (km/km^2)	8.455	4.345	1.244	31.487
Population density (10^3 persons/km^2)	58.151	39.380	1.624	329.732
Vehicle usage				
Total household PKT (10^2 km/month)	6.175	5.596	0.070	61.110

Table 6 Model estimation results – coefficient (t-value)

Variable	One vehicle		Two vehicles	
	One car	**One UV**	**Two cars**	**At least one UV**
Intercept	-2.801 (-6.89)***	-3.68 (-7.6)***	-10.204 (-9.89)***	-10.528 (-9.46)***
Household income-to-household size ratio	0.714 (11.05)***	0.91 (13.03)***	1.103 (13.58)***	1.118 (13.8)***
No. of household members employed	0.069 (0.73)	0.262 (2.28)*	0.538 (3.02)**	0.929 (5.19)***
No. of basic education students	0.057 (0.67)	0.432 (4.26)***	0.36 (1.77)	0.584 (3.13)**
No. of university students	0.309 (2.1)*	0.598 (3.57)***	0.921 (3.72)***	1.029 (4.11)***
Educational level of household head	2.015 (11.72)***	1.543 (7.06)***	2.128 (4.2)***	2.872 (4.51)***
Homeownership	0.800 (5.32)***	0.828 (4.33)***	1.787 (4.23)***	2.242 (4.47)***
Accessibility index	-0.673 (-9.7)***	-0.774 (-9.85)***	-0.208 (-1.67)	-0.607 (-5.26)***
Road public transport line density	-0.014 (-4.6)***	-0.02 (-4.87)***	-0.013 (-2.16)*	-0.013 (-2.17)*
Road density	0.261 (10.21)***	0.263 (9.14)***	0.214 (5.21)***	0.254 (6.49)***
Population density	0.007 (3.45)***	0.003 (1.34)	-0.008 (-1.88)	-0.005 (-1.17)
Total Household PKT	-0.005 (-0.37)	-0.007 (-0.39)	0.086 (3.87)***	0.021 (0.84)

Zero-vehicle alternative was used as the reference category.
Log-likelihood at convergence = -1703.5
McFadden R^2 = 0.346
Likelihood ratio test: chi-square of the final model = 1803.7
Significance at the 5% level *, at the 1% level **, and at the 0.1% ***

they move around. Other methods should be explored to capture this relationship. For example, 1) the stated preference survey could be conducted with various flooding depth levels, 2) the revealed preference survey should only focus on two choices, owning or not owning, and 3) the interactive effect between workplace and residential flooding susceptibility should be considered. The number of preschoolers and senior citizens in the household also exhibited an insignificant relationship with the level of vehicle ownership. Presence of preschoolers (<4 years old) indicates, typically, a start-up family where, in most cases, combined income is not enough to support the acquisition of vehicles. While there is a greater need for private vehicles for households with senior citizens, retired members often no longer earn a salary or wage thus affecting household income and their ability to support ownership of vehicles. It could be noted that unlike in developed countries, the pension support in the Philippines is very minimal and cannot adequately support the needs of the retirees.

The statistical analysis of the streamlined model (excludes flooding as well as preschooler and senior citizen counts) is provided in Table 6.

As expected, the household income-to-household size ratio tends to reinforce vehicle ownership as it increases the purchasing power of the household. Likewise, the number of working members reinforces ownership of additional and larger vehicles as they tend to increase total income and trip requirements. This is consistent with findings in India [14], China [41], Japan [17], Canada [23], and the USA [42]. Households with higher travel requirements were also found to encourage the ownership of more vehicles. Households with primary and secondary school students prefer the bigger space provided by utility vehicles, and should the household have two vehicles, there is a larger chance that one is a utility vehicle. Similar findings in the USA were also confirmed [21-22]. Typically, households gain enough annual income to buy a vehicle as the head of the family approaches mid-age, which is also just about the time that children are about to start university studies. For more well-off households, it is also the stage when children are provided their own vehicles. The educational attainment of the head of the family and homeownership were both found to reinforce all vehicle ownership levels as they are strongly linked with household income.

As hypothesized, better accessibility and higher public transport line densities tend to discourage ownership of vehicles in all levels. Similarly, better-mixed land use and higher transit station density discourage household vehicle dependency [12, 23, 41, 43]. Contrary to findings in more developed countries, population density encourages ownership of passenger cars among households in Metro Manila. It is worth noting however that it has no effect on the ownership of bigger vehicles as well as additional vehicles within the family. This indicates “forced ownership” wherein households strive to own and pay for a vehicle to avoid the inconvenience of the poor and inadequate public transport service which is more pronounced in crowded communities. Especially, the car is safer and more comfortable and functional than the motorcycle. The finding in Ho Chi Minh city confirmed that the population density is insignificant [10].

Road density, likewise, was found to encourage vehicle ownership. With a worsening traffic situation, the availability of alternate routes would be welcome. In addition, street parking in residential areas is very common in Metro Manila, and higher road density means more on-road parking space. The same findings in China also confirmed that the availability of road parking space encourages vehicle ownership [41].

3.2 Scenario analysis

Figure 2 provides simulated shares of levels of vehicle ownership if the interventions provided by the corresponding scenarios had been realized earlier.

Results for scenario 2 provides the “what if” percentage share of the level of vehicle ownership if accessibility indexes had been better. The improvement could have cut down the number of vehicles owned by the respondents by 26.63%. This could be traced to 12.93%, 7.41%, and 0.86% decreases in households owning one passenger car, one utility vehicle, and two units with at least one utility vehicle, respectively. A number of households originally owning two vehicles with at least one utility vehicle would have owned two private cars instead which explains the increase in the share of the latter.

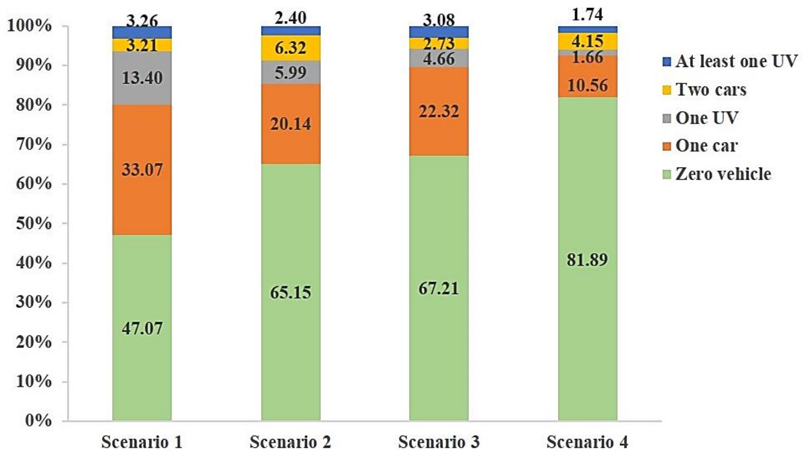

Figure 2 "What if" Scenario Effects

Table 7 Percentage changes in households owning vehicles

Scenario	One car	One UV	Two cars	At least one UV
Scenario 2	-12.93%	-7.41%	3.11%	-0.86%
Scenario 3	-10.75%	-8.74%	-0.48%	-0.17%
Scenario 4	-22.51%	-11.73%	0.94%	-1.52%

Table 8 Percentage shares of the public transport modes in terms of PKT

Mode	Jeepney [a, b]	Bus [a, b]	Rail [b]
% share	71.78%	22.31%	5.91%

[a] adopted from [44]
[b] adopted from [6]

Table 9 The total PKT and passengers

Scenario	Car (billion PKT)	UV (billion PKT)	Jeepney (billion PKT)	Bus (billion PKT)	Rail (persons)
Scenario 2	-4.81	-5.34	7.29	2.27	51,169
Scenario 3	-7.69	-5.68	9.60	2.98	67,413
Scenario 4	-14.21	-8.58	16.36	5.09	114,868

PKT: Person kilometers traveled

Should all the communities have had higher public transport line densities, the number of vehicles owned would have been lowered by 35.02%. This reduction is dominated by percentage decreases in households with a single car (10.75%) and single UV ownerships (8.74%). It is interesting to note that a significantly higher number of households (from 47.07% to 81.89%) would have chosen not to own vehicles should all the communities have had closer proximity with essential destinations and have been provided with the more comprehensive public transport system. This translates to a 59.61% reduction in total vehicles owned.

The figures also indicate that better proximity to essential facilities could have facilitated less UV ownership among families with two vehicles compared with better public transport service. The latter, alternatively, would have better encouraged ownership of passenger cars rather than UVs among households owning one vehicle.

3.3 Model application

The simulated percentage shares of the output variables were applied to determine the potential CO_2 emission reductions for passenger mobility in Metro Manila. Based on the simulated results in Subsection 3.2, the percentage changes of the vehicle households under scenarios 2 through 4 relative to the baseline scenario are presented in Table 7.

The percentage changes of the output variables listed in the table were converted into person-kilometers-traveled (PKT) in terms of private vehicles. The total number of households in Metro Manila in 2017 was 3,222 thousand, adopted from [7].

We assumed that the PKT of the total private vehicles is substituted by the dominant public transport modes, i.e., Jeepney, bus, and urban rail transit mode. The different percentage shares of the three public transport modes were adopted from the Family Income and Expenditure Survey (FIES) data published in 2015 [44] and ALMEC [6], (Table 8). Correspondingly, the PKT of private vehicles, Jeepney, and bus and the total passengers of rail transit modes (i.e., LRT1, LRT2, and MRT) are shown in Table 9. The CO_2 emission factor of each transport mode in Metro Manila is tabulated in Table 10.

The total CO_2 emissions are calculated using equation (3):

$$Total\ CO_2 = \sum_t PKT_t \times EF_t + Persons_{rail} \times EF_{rail} \qquad (3)$$

where t is the index representing transport mode (i.e., car, UV, Jeepney, and bus) and EF is the CO_2 emission factor.

Table 10 CO_2 emission factor of each transport mode

	Private		Public		
	Car [a]	UV [a]	Jeepney [b]	Bus [b]	Rail [c]
Unit	(kg/km-person)	(kg/km-person)	(kg/km-person)	(kg/km-person)	(kg/person)
Emission factor	0.127	0.212	0.048	0.029	0.113

[a] adopted from [45]
[b] adopted from [6]
[c] calculated by the authors

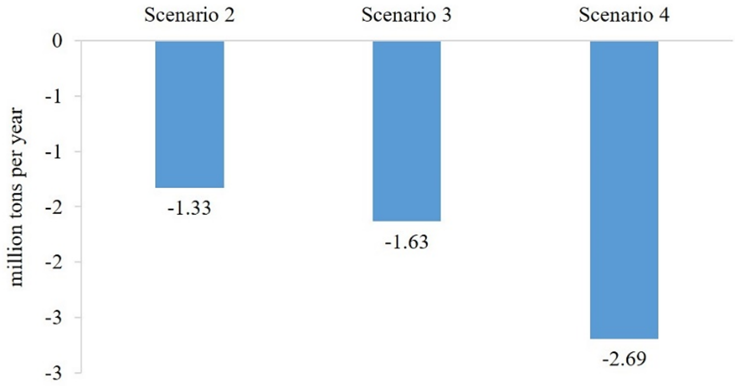

Figure 3 Potential reduction in CO_2 emission

Figure 3 illustrates the potential reduction in CO_2 emissions under the formulated scenarios relative to the baseline scenario. Evident from scenario 2, had the residential accessibility to the key facilities been maximized, the CO_2 emission for passenger mobility would have been diminished by 1.33 million tonnes in 2017. Similarly, the CO_2 emission would have been reduced by 1.63 million tonnes had the public transport line density of all the residential area been maximized. If the accessibility and public transport line density had been developed, the CO_2 emissions would have decreased by 2.69 million tonnes.

4. Conclusions and recommendations

Similar to other cities, higher income is a major determinant of the greater level of vehicle ownership in Metro Manila. Likewise, the presence of school-age children provides a similar effect as they tend to increase the mobility requirements of the family. Unlike in most studies, the population density was found to reinforce ownership of a vehicle among households which could be attributed to deficiencies in the public transport system as well as poor proximity to essential facilities and destinations in some communities. The effects of these determinants were further emphasized by the scenario results indicating that had improvements in these aspects been realized earlier, the total number of vehicles owned and CO_2 emission would have been reduced by 59.61% and 2.69 million tonnes, respectively. This signals that vehicle ownership has become some sort of a necessity in the metropolis due to the failure to properly plan the development of the area affecting convenient access to essential destinations and services in some communities. Likewise, it emphasizes the need to rationalize public transport to ensure that routes and amount of service are strongly linked with the mobility requirements of the people and ridership demand.

Even though the findings of this study provide innovative ideas for transportation policymakers and urban planners about how to craft proactive policies for a reduction in private vehicle dependency and CO_2 emissions by shifting from private vehicles to mass transit modes, further research effort is required to apply other discrete choice algorithms. Those algorithms can be nested logit regression, multinomial probit regression, Bayesian multivariate ordered probit and tobit (BMOPT) regression. It is a concern that the MNL regression might violate proper interpretation of parameters or prediction of market share due to its simple structure. However, this study does illustrate that the impact of built environment characteristics at the workplace has remained largely unexplored in Metro Manila.

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