Low Emission Scenarios Analysis in The Urban Transportation in Dhaka, Bangladesh Using the Co-Benefits Approach

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Abstract

After the energy sector, the transportation sector is considered the second largest producer of greenhouse gas (GHG) emissions. The fastest-growing sector for GHG emissions is the road transportation industry. The major sources of air pollution in Dhaka City are the transportation sector and brick kilns. In Dhaka, most vehicles lack routine maintenance and are either old or rebuilt. Heavy traffic, poor parking management, contaminated gas, overloading, and friction-related dust from the roads are the main causes of air pollution.

This thesis analyzes two low-emission scenarios of the Dhaka transport sector, including CNG vehicle-fleet and nonmotorized transportation, using a co-benefits assessment modeling framework based on the A-S-I (Avoid-Shift-Improvement) strategy, which is used to quantify the expected environmental and public health benefits from implementing the proposed scenarios in the transport sector of Dhaka.

The avoided emissions, including GHG, $PM_{2.5}$, and other pollutants, are estimated based on the future projection of the vehicles' passenger kilometers (PKM) in the transport sector of Dhaka city is calculated. The future projection of vehicles in this city is estimated, using a Gompertz model, which indicates the saturation level for CNG-run vehicles at 14.48 per 1000 inhabitants in Dhaka city. After implementing the CNG fuel policy, about 12% of GHG (Greenhouse gas), 27% NOx, 70% SO_2, 16% $PM_{2.5}$,8.4% CO and 7.3% HC can be reduced. The impact of low fuel price on VKT (Vehicle kilometer) is also analyzed, indicating a 2.42% increase in VKT for motorized CNG vehicles in Dhaka city. The improved air quality can lead to improved public health. Public health co-benefit assessment is also quantified. After using better fuel, about 14% of all-cause mortality can be prevented.

The greatest solution to address the rising use of motorized cars and the associated health and environmental problems is to increase the usage of non-motorized vehicles, especially for short to medium distances. The factors that affect the use of non-motorized vehicles in Dhaka city are explored in this thesis. An online survey was conducted in Dhaka city to analyze the willingness to use nonmotorized vehicles, using collected data on demographic, socioeconomic, travel mode, and travel behavior characteristics. A logistic regression model is developed, and future PKM is forecasted till 2036 based on the willingness level. According to the results, the city of Dhaka will have about 34.74 billion passenger kilometers (BPKM) of nonmotorized vehicles in 2035, and each person will travel 35.57 passenger kilometers per month in nonmotorized vehicles. The result suggests that 21% of $PM_{2.5}$ can be reduced by using nonmotorized vehicles and a potential reduction in the mortality rate of almost 19%. The study sheds light on the factors influencing the use of non-motorized vehicles, helps in comprehending the psychology of travelers, and identifies potential policy initiatives.

Keywords: Co-benefit assessment, CNG policy, Willingness analysis for nonmotorized vehicles, Future projection, Logistic Regression, Health impact analysis

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Chapter 1
Introduction

1.1. Background:

Dhaka, the capital city of Bangladesh, has a history dating back more than 400 years.[1] The geographic area of Dhaka city is 1463.60 sq. km, and the coordinates of this city lie between 23°42'37.4" North 90°24'26.8" East[2] . One of the world's cities with the most population density is Dhaka. According to the World Bank, the population of Dhaka city is more than 21 million. Being a megacity, Dhaka experiences significant migratory pressure because most of Bangladesh's living accommodations and economic prospects are concentrated in the capital. This condition has led to significant traffic congestion and issues in the Dhaka metropolitan Area, which have exacerbated the city's mounting social and economic issues, including the major health risks that air pollution poses to its residents.

The road network in Dhaka makes up around 7% of the entire built-up area and spans 3,000 km (200 km of principal roads, 110 km of secondary roads, 50 km of feeder roads, and 2,640 km of narrow roads) with few other connector roads[2] . In the Dhaka Metropolitan Area (DMA), there are 237 bus stops and 152 bus routes, only 5 of which run eastward or westward. Only 400km of footpaths exist within this entire network, and roughly 40% of them are unlawfully used and covered in mud. Recently, the pattern has changed as the authority works to develop a network of connected walkways and footpaths with universal accessibility across every structure [3]. The majority of Dhaka's transportation system relies on road transportation, which is characterized by a disorganized mix of automobiles, buses, autorickshaws, rickshaws, motorcycles, CNG vehicles, bicycles, etc. In Dhaka City, the most common forms of transportation include motorbikes, rickshaws, public buses, auto-tempo, private cars, CNG, minibuses, and taxis. The percentage of automobiles in Dhaka City that were registered in 2018 is depicted in Figure 1.1.

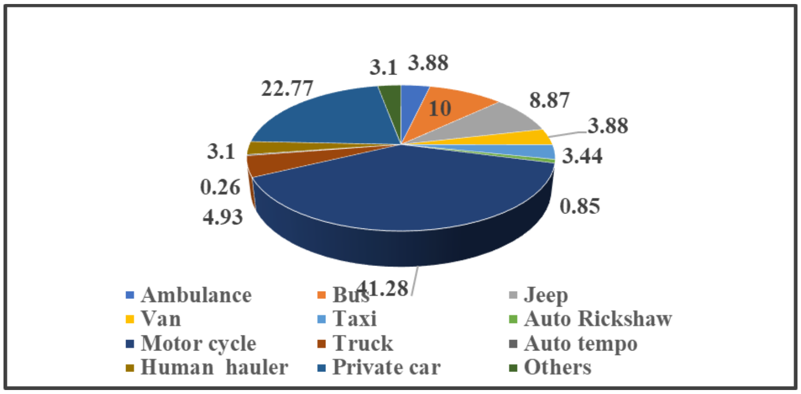

Fig 1.1: Share of the Registered Vehicles in Dhaka City

There are bus hubs inside Dhaka Metropolitan Area. There are essentially three key places where roads connect. For buses traveling to and from the eastern region of the country, including

Sylhet and Chittagong Division, Sayeedabad Bus Station operates as the depot. Buses to and from the country's western region, including Jessore, Khulna, and Rajshahi Division, stop at the Gabtoli Bus Station. Buses for destinations north of Dhaka, like Tangail and Mymensingh, arrive at the Mohakhali Bus Station. Numerous additional bus depots are located inside the city, including the Kallyanpur, Fakirapool, Gulistan, and Kolabaghan bus stations, all of which act as crucial connecting hubs. The Hazrat Shahjalal International Airport, the main airport, can be found in Dhaka’s northern region. The majority of Bangladesh's private airlines, notably Biman Bangladesh Airlines, Regent Airways, Novoair, and US-Bangla Airlines, have their hubs at this airport. It has connections with all six domestic airports, six short takeoff and landing ports, and three other international airports. In Dhaka Metropolitan Area, there are five train stations: Kamlapur, Tejgaon, Cantonment, Banani, and Airport. These two rail stations are Kamlapur Railway Station (Central Station) and Airport Railway Station (North of Central Station), both of which are often utilized. Dhaka is connected to all of the nation's train stations by three directional lines. First, travel southeast to Narayanganj from the central station. From Tongi Junction, two sections cover the nation's northern regions: one travels through Narsingdi to Chittagong and Sylhet. In Dhaka in 2009, rickshaws covered 38.7% of all trips for all economic levels [4]. A "progressive ban" on rickshaws on major highways was maintained, according to the National Land Transport Policy of 2004, to halve rickshaw journeys by 2014 and allow cars to make up to 30% of all mechanized trips by the year 2022 [4].

The city of Dhaka's current transportation status is extremely fragile from an environmental standpoint. Being a densely populated city, Dhaka is vulnerable to the air-polluting impacts of the extensive usage of cars, motorcycles, and trucks. Many of these vehicles are not subject to tight rules regarding the age or quality of their engines or the fuels they burn [5]. According to the World Air Quality Report in 2019, the most polluted country is Bangladesh for $PM_{2.5}$ exposure. Dhaka is the second highest polluted city in the world. Three Continuous Air Monitoring Stations (CAMS) have been installed in Dhaka as part of the Clear Air and Sustainable Environment (CASE) initiative to monitor air quality.

In the metropolis of Dhaka, unplanned industrialization and urbanization are frequent occurrences. This city is growing outward without taking environmental deterioration into account. This is one of the main reasons why the air pollution in Dhaka is getting worse. In addition, roads are being overrun by motorized vehicles, which is further lowering air quality. The air in the city contains significant amounts of smoke, sulfur dioxide, particulate matter, organic compounds, and carbon monoxide. In Dhaka, the air quality has gotten worse. The air in Dhaka has been found to contain higher concentrations of hazardous particles.

According to a recent air pollution monitoring report, Bangladesh is ranked fourth among 91 nations for having the worst urban air quality[6]. About 90% of the populace in these cities was exposed to unhealthy air pollution levels. Unplanned urbanization and industry are factors that contribute to the rise in air pollution in Dhaka. Due to the congestion in Dhaka, these groups of individuals have been enduring an unhealthy atmosphere. Using the daily fuel consumption and overall traffic flows in Dhaka, the total daily emissions of NO_X, HC, CO, PM2.5, and SO_X are estimated. The total mortality among the south Asian megacities tops five megacities on this list after Karachi is Dhaka (14,700 per year), Cairo (14,100 per year), Beijing (11,500 per year), and Delhi (10,500 per year). Consequently, compared to other megacities, these cities are characterized by a higher health risk of air pollution, in the case of respiratory mortality, with no excess instances in Tokyo, Sao Paulo, Osaka, and New York. The highest number of instances are found in Dhaka (2100 cases annually) and Karachi (2100 cases annually), followed in decreasing order by Beijing (1600 cases annually), Delhi (1600 cases annually), and Kolkata (1300 cases annually)[7] . Compared to other megacities, Dhaka has a higher rate of cardiovascular illness and COPD hospital admissions. In light of this, it is vital that city residents in Dhaka reflect critically and take the appropriate action.

1.2. Low emission Scenarios in Dhaka Transport Sector:

By the end of 1990, public attention on air pollution in Dhaka city and its detrimental effects on human health and welfare had increased significantly. This contributed to a stronger government commitment to decreasing air pollution and switching to CNG fuel. Early in 2001, as a solution to Dhaka's transportation issues, 12000 CNG-powered taxis were gradually deployed [8]. This gave the CNG supply business some momentum. Over the past ten years, there have been several attempts to assess the effects of the CNG fuel policy in Dhaka. Prior studies examined the effects of using CNG fuel in Dhaka city on improving air quality, social and health benefits, and avoiding premature deaths. [8] ,[9],[10],[11]

It is noted that, Dhaka is a city of rickshaws (peddle-powered three-wheeler). Since they arrived in the late 1930s and early 1940s, rickshaws have dominated the city's transportation sector. But now, cars and motorcycles account for roughly 80% of all motorized traffic [12]. In the city of Dhaka, rickshaws are one of the primary modes of public transportation. When the administration of Dhaka stated plans to ban pedicabs entirely from the city based on safety, the active rickshaw restriction initiatives started in April 1987. However, at the time, political and widespread opposition prevented the implementation of this prohibition, but it was followed in 1989 by non-motorized vehicle license restrictions, restricted registration, and high spare part taxes. Throughout the 1990s, these stringent policies remained in place. A proposal to gradually remove cycle rickshaws from eight of Dhaka's major highways was adopted in 2002. The government reports, such as the Human Development Research Centre (HDRC) report and the DUTP Implementation Completion and Result Report, highlighted the detrimental socioeconomic effects of the rickshaw ban concerning the Mirpur demonstration corridor. The monthly income of rickshaw drivers has decreased by 34%, negatively impacting their quality of life and health. For users, the average monthly travel expense increased by 10%, the difficulty of travel was made worse for women and children, the frequency of social and recreational trips decreased, and there was inefficiency when making short trips (one to five kilometers), which is the case for 75% of travelers [13]. The other significant evaluation report used a comparison between the pre-rickshaw ban (2000) and post-rickshaw ban (2000) scenarios to show the detrimental/marginal traffic operational effect of such policy actions to prohibit rickshaws

(2005). There has been a little increase in speed (3.6%) and a decrease in travel time (5.7%) for motorized transports' typical journey times. Due to the high variability of trip time data, this difference is not regarded statistically as being significant. Contrarily, the average bus journey time has shrunk by 26.1%.

Prior research largely focuses on the impact of non-motorized vehicles on urban road traffic flow and non-motorized vehicle-related accidents in Dhaka. The majority of research recommends banning nonmotorized vehicles from the different parts of Dhaka city. The government took the policy to ban rickshaws because the nonmotorized vehicle's density and speed decrease the speed of motorized vehicles, leading to traffic congestion and consuming time.

1.3. Co-benefits of the Low emission strategies in the transport sector:

In the transportation sector, a number of demand-side policy interventions and infrastructure, such as vehicle fleet renewal programs, improved traffic management, environmental standards, and supply-side resilience strategies, can result in climate co-benefits. Researchers demonstrated that investing in public transportation in major cities will result in considerable improvements in co-benefits from a reduction in local emissions, and it is proposed that earlier decisions to prioritize public transportation and non-motorized transportation investments can result in long-term co-benefits by studying the environmental impact of urban transportation in Eastern Asia. Depending on how they depict the interactions between the transport sector and society, approaches used to assess climate co-benefits in the transportation industry vary from an analytical standpoint. The evaluation of co-benefits at the national level has been supported by a variety of techniques that have been created. But only a few have been created for the transportation sector. A quantitative tool has been made by Colombia's Ministry of Environment and Sustainable Development to assess the climatic benefits connected to national low-carbon development objectives. The NAMA-SDE (National Appropriate Mitigation Action Sustainable Development Evaluation) tool, which was created for NAMA (Nationally Appropriate Mitigation Action) developers and policymakers looking for co-benefits and synergies across various aims, has been given access by the UNDP (United Nations Development Program). The Japanese government has published a guideline for the quantitative evaluation of the co-benefit approach to climate change, which enables one to quantify the benefits of the environment, such as the management of trash and the enhancement of water quality. The co-benefits of climate change mitigation can be assessed and addressed using each of the approaches reviewed above.[14]

1.4. What will be elucidated in this research:

In line with earlier studies, this study provides an overview of current environmental circumstances and an outlook for the transport sector in Dhaka. Most similar techniques aim to determine a project's effects after an investment has been made. The decision-makers are, therefore, able to choose which possibilities offer the best return before they come up with the policy and project, depending on the variety of data available and with explicit consideration of the environmental co-benefits as the intended benefits. An overview of Dhaka's public transportation system is provided in this study. The first scenario analyzes the climate benefits of the CNG fuel transition in Dhaka's transportation sector using the co-benefit assessment tool (ASIF methodology). Future projections of the CNG fuel-run vehicle population and its associated emissions have been projected based on historical data from the Dhaka transportation industry. Vehicle kilometer of CNG fuel-run vehicles is assessed to 2050 as well. Benefits to public health are calculated for six diseases for CNG fuel. The second scenario involves investigating the current state of nonmotorized vehicle utilization based on willingness. Due to the metropolitan Dhaka area's rapid urbanization process, high vehicular population growth and mobility, insufficient transportation facilities and policies, lack of a dependable public transportation system, and ineffective traffic management practices, traffic and environmental issues have significantly worsened. Public transportation's ability to effectively relieve current traffic congestion is still debatable, especially for its poor accessibility. An effective non-motorized transportation system and its integration with public transportation can be significant in resolving the issues in Dhaka. Nonmotorized vehicles are an affordable form of transportation, and nonmotorized transport, particularly walking, bicycling, and rickshaws, have proven to be quite efficient for short distances and may be able to offer bus riders in Dhaka city a reliable door-to-door service. Public transportation and nonmotorized options are both energy efficient. This study examines the residents of Dhaka City's willingness to utilize non-motorized vehicles and the influences of socioeconomic factors, travel characteristics, required trips, and optional excursions (such as those for shopping and recreation) on this willingness. This study uses a pooled estimate of the RR values for six health outcomes, including overall mortality, COPD, cardiovascular mortality, respiratory mortality, morbidity, and related hospital admissions, to more precisely estimate the avoided mortality cases from the avoided emissions for both scenarios. The health advantages of utilizing nonmotorized vehicles for six diseases are analyzed in the future projections of PKM of nonmotorized vehicles in Dhaka.

Chapter 2
Model Development for Two Low Emissions Scenarios of the Dhaka Transport Sector

2.1. Co-benefits Approach:

Understanding a policy's various aspects beyond its intended benefit is the fundamental idea behind co-benefits. A brand-new project-based strategy called the co-benefits approach aims to solve climate change issues while simultaneously enhancing local advantages. The concept of taking potential co-benefits into account when planning GHG reduction measures is gaining popularity. In the transport sector, the A-S-I (avoid-shift-improve) strategy evaluates the benefits of enhanced air quality and its impact on public health in addition to the avoided local air pollution and carbon emissions. The following figure shows the A-S-I approach in the urban transport sector.

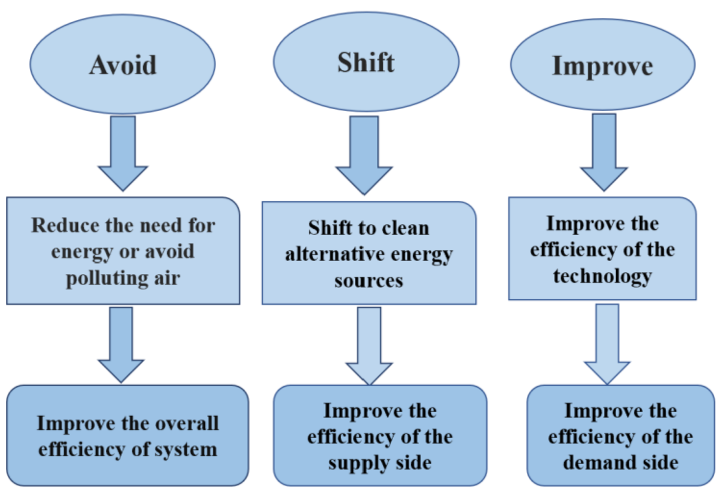

Fig 2.1. The A-S-I approach in the Transport Sector [14]

In the transport sector, avoid refers to the requirement to increase the overall effectiveness of the energy system by reducing the energy demand directly. The term shift refers to switching from a fuel with a higher carbon content to one with a lower carbon content, which can cut overall emissions. Finally, the term improve relates to improving energy efficiency and lowering carbon intensity.

This thesis uses the co-benefit evaluation method to study two scenarios of the Dhaka transportation sector.

2.2. Scenario analysis:

2.2.1. CNG transport fleet Scenario:

The main steps of the research methodology used in analyzing the CNG vehicle scenario are shown in Figure 2.2. There are five steps to the research process. First, a new saturation level for CNG-fueled vehicles is estimated using the autoregressive distributed lag approach, and the vehicle population is calculated using the Gompertz model until 2050. The avoided emissions from replacing petrol and diesel-fueled cars with CNG are also computed using VKT(Vehicles Kilometers Travels). The impact of lower fuel prices on VKT is calculated using the distributed ordinary least square approach. The environmental impact of introducing the CNG policy of the Bangladesh Government is evaluated. The air quality health risk assessment is used to calculate the health benefits of reduced PM2.5 levels as a result of the use of CNG fuel. The health impact assessment takes six health outcomes into account.

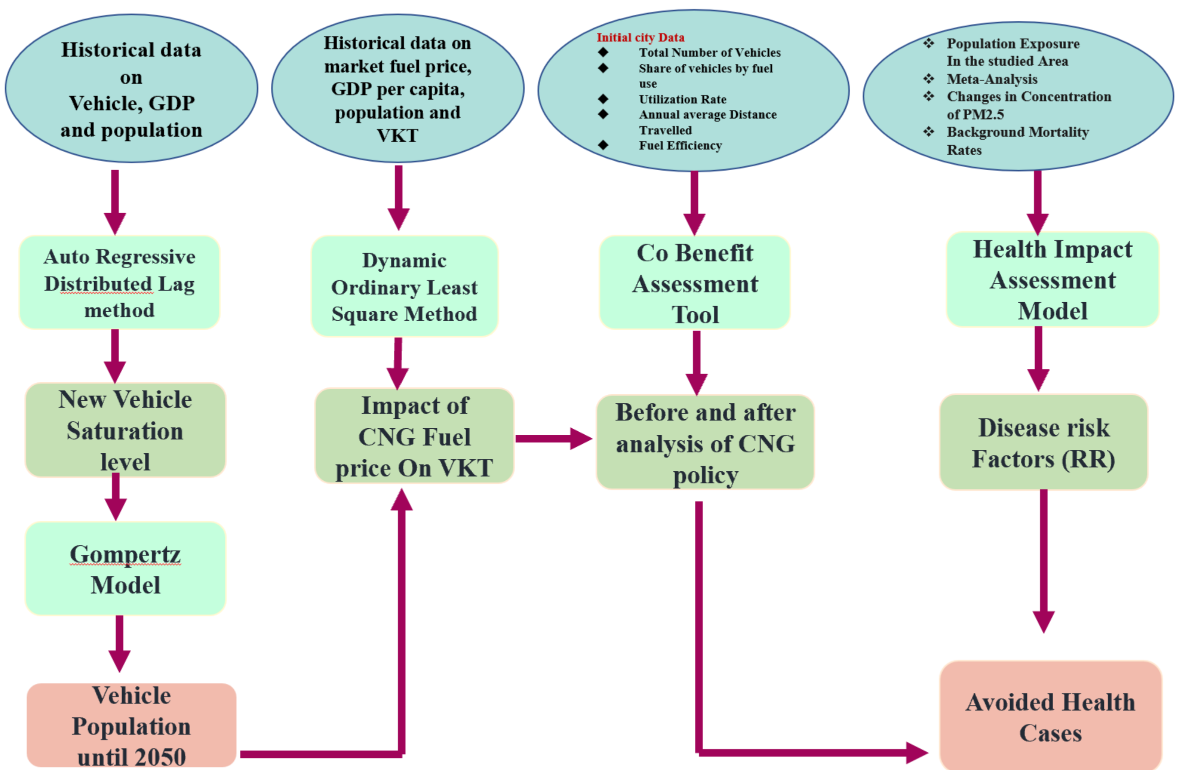

Fig 2.2. The Methodological Approach used in the CNG transport feet Scenario

2.2.1.1. Vehicle population projection:

For the planning and analysis of policy, CNG vehicle forecasting is crucial. Its ownership is a significant factor in improving lifestyle and is related to financial security. The fundamental of general prediction algorithms is the simple linear or polynomial data fitting theory. They are easy to understand and require basic calculations, but they have a short prediction time. Therefore, more errors will be made when the prediction time is extended. Furthermore, simple linear or polynomial data fitting techniques cannot capture the system's essential development law. The fundamental drawback of the logarithm model is that the demand curve's position is unaffected by the fixed elasticity coefficient. The Gompertz model is more versatile. The Gompertz curve is an S-shaped curve that forecasts the expansion of the automotive industry in three stages: a period of slow growth at the beginning (when economic levels are low), a period of boom, and a period of saturation (when vehicle population growth approaches the saturation level). The Gompertz can be explained in large part by the GDP per capita as follows:

$$V_{i=} \; e^{\delta e^{\mu (GDP)_i}} \tag{2.1}$$

Where,
V_i = Vehicles in use in the year i (vehicles per 1000 people)
V = Ultimate saturation level of vehicle ownership (Vehicles per 1000 people)
$\delta \; and \; \mu =$ The two parameters that determine the shape of the S- shape curve of vehicle ownership growth over economic growth
Based on GDP per capita, this function forecasts the number of vehicles owned per 1000 persons. Therefore, using the anticipated automobiles per 1000 residents, the total number of motor vehicles in the city may be calculated based on the expected total population.

2.2.1.2. Saturation level of vehicle ownership:

In this study, in order to estimate the ultimate saturation level of vehicle ownership (V), the multivariate dynamic regression approach was developed to estimate the upper limit of vehicle ownership in 2050. The population and GDP per capita are two key factors in determining the number of vehicles owned; the recommended econometric model is an autoregressive distributed lag one:

$$lnV_t = \kappa + \sum_{i=1}^{l} \alpha_i lnV_{t-i} + \sum_{j=0}^{m} \beta_j \ln GDP_{t-j} + \sum_{k=0}^{n} \gamma_k lnP_{t-k} + \varepsilon_t \tag{2.2}$$

Where,
V= Number of vehicles
GDP= GDP per capita
P= population
α, β, ϒ, k = parameters
ε_t = Error term
The Auto-Regressive Model and Distributed Lagged Model (ARDL) method was employed due to appropriate lag selection and residual correlation to solve the above regression model. ARDL are two terms used to describe simple regression models that also take the lag of the explanatory variable into account. The ARDL Model considers the delays of the related time series variables and can be configured in many ways to account for various analytic aspects. The order of the ARDL Model is the sum of the lags of both types of variables. The ability to host enough lags

allows for the most accurate capture of the data generated by the process mechanism. The unit root test is the most significant part of the ARDL analysis. It provides information on the level of integration of each variable. The following formula for performing the ADF Test for time series (y_t), where $\Delta y = y_t - y_{t-1}$ represents the first difference and k is the number of lags taken into account.

$$\Delta \boldsymbol{y_t} = \boldsymbol{\alpha_0} + (\boldsymbol{\alpha_1} - \mathbf{1})\, \boldsymbol{y_{t-1}} + \sum_{i=1}^{k} \boldsymbol{\beta_i y_{t-i}} + \boldsymbol{\varepsilon}_t \qquad (2.3)$$

For model analysis, the outcomes of the p-value can also be applied as a stationary determinist factor. If the p-value is less than 0.05, the null hypothesis will be rejected, and the time series will be stationary. Each variable must be i (0) or i (1) to satisfy the bound test assumption of the ARDL models. It should also be mentioned that the dependent variables should be I (1). The time series is I(o), which means that it is stationary at levels, i (1) means stationary at first difference.

2.2.1.3. Impact of CNG fuel price:

Car ownership in Bangladesh has not increased due to CNG conversion. CNG is less expensive than diesel and gasoline. Therefore, Vehicle-Kilometer (VKT) is affected by lower fuel prices. The influence of economic growth, fuel prices, and other demographic parameters on VKT were analyzed, using DOLS (Dynamic Ordinary Least Square) method as follows:

$$lnVKT = \beta_1 \ln P\,\mathrm{R} + \beta_2 lnGDP + \beta_3 lnP + \varepsilon_t \qquad (2.4)$$

Here:
VKT = vehicle kilometer travel
PR = Fuel price(petrol)
GDP = GDP per capita
P= population
To analyze the effects, we take into account two different fuel prices. The cost of CNG fuel is another option using the same method.

$$lnVKT = \beta_1 lnCNG + \beta_2 lnGDP + \beta_3 lnP + \varepsilon_t \qquad (2.5)$$

Where:
VKT = Vehicle Kilometers Travel
CNG = Fuel price of CNG
GDP = GDP per Capita
P = Population
VKT is calculated, and other data are from the world bank database(World bank, 2020).

Recent advancements in economics offer reliable estimators for the cointegrated series with limited sample numbers. A modified Dicky-Fuller test is conducted to determine the level of integration of each individual series. The null hypothesis to be evaluated is that the series is non-stationary for the first difference, second difference, and so on. The OLS (Ordinary Least Square) approach assumes that the explanatory variable is zero and that there is no association between the error term and the regressors. Though there is a connection, therefore, the coefficient value may be biased. The Dynamic Ordinary Least Square (DOLS) approach considers autocorrelation and is applicable to small sample sizes. The coefficient may occasionally be skewed due to the feedback effect between dependent and independent factors. Since endogenous factors are known to result from various factors, the DOLS approach is considerably more reliable. A co-integrating estimator is DOLS. DOLS can be used whenever there is a mixture of stationary and non-stationary variables.

2.2.1.4. Avoided emissions from the CNG scenario:

The co-benefit assessment tool represented the city's transport sector in a simplified manner. It combines a quantitative spreadsheet with an institutional one to evaluate not only the magnitude of emission reductions from the city's air pollution and carbon emissions but also to determine e the barriers to implementing policies. The ASIF framework is applied in this tool. In addition, the scenario approach has been used in the development of the tool. A scenario is considered a convincing explanation of a potential short-term growth pattern for the city's transportation industry, characterized mainly by the direction of local government policy.

The tool uses the ASIF Framework, which calculates emissions by each mode according to the following formula:

$$\sum_{Modes} A * S * I * F \tag{2.6}$$

A= Total travel demand in passenger kilometers = PKM

A defined as $\sum Number\ of\ Vehicles * Utilization\ Rate * Annual\ distance\ travel * Occupancy\ rate$

S= Percent share of each mode; Calculated from A

I= Intensity of the mode defined as:

I= $\frac{1}{Fuel\ efficiency * Occupancy\ rate}$

F = Emission factor for each pollutant for each fuel

The avoided emissions by each scenario can be calculated as follows:

$$\Delta E = E_b - E_a \tag{2.7}$$

ΔE is the avoided emissions, E_b is the baseline emissions and E_a is the emissions after implementing the policies.

The overall flowchart of the Co-benefit Assessment tool is shown below:

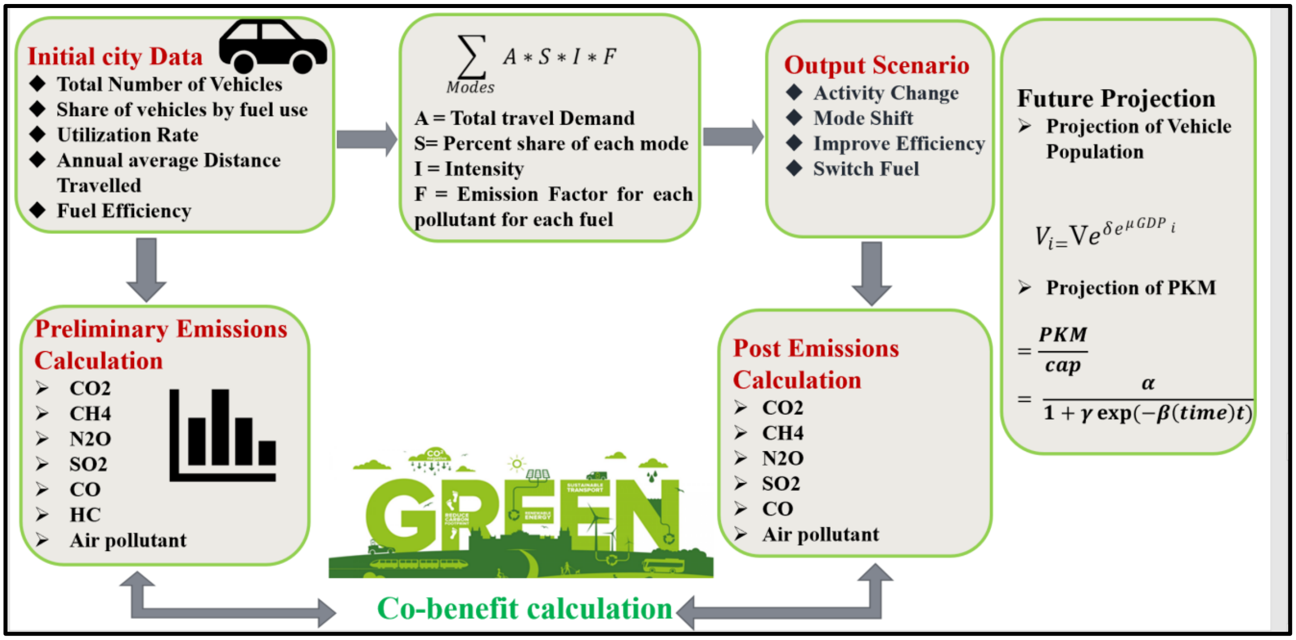

Fig 2.3.The overall flowchart of the Co-benefit Assessment Tool [16]

2.2.2. Non-motorized Transportation Scenario:

Appropriate infrastructure development for non-motorized vehicles is required but motivating people to use them is a considerable issue. Comfort is the primary issue, although other factors such as age, gender, socioeconomic status, journey distance, rainfall, road laying pattern, social awareness, and driving cost have also been found to impact the decision. A binary logistic model is used to analyze the willingness to use non-motorized vehicles. Based on the data collected from a survey of 289 city residents of Dhaka, the effect of various characteristics such as age, gender, occupation, income, and travel modes on the likelihood of willingness to use NMT is examined. PKM (Passenger kilometer) of nonmotorized vehicles is calculated and forecasted the PKM of nonmotorized vehicles until 2036 based on willingness. Avoided Emissions Until 2036 are calculated based on the PKM. To calculate the connection between avoided PM2.5 exposure and health benefits, the concentration-response function (CRF) for many diseases was used. The CRF coefficient values utilized in this study were based on the relative risk (RR) level. The study's values for the RR were derived through a comprehensive meta-analysis which was used to calculate the avoided mortality due to avoided emissions. In Fig 2.4, the methodological approach is shown.

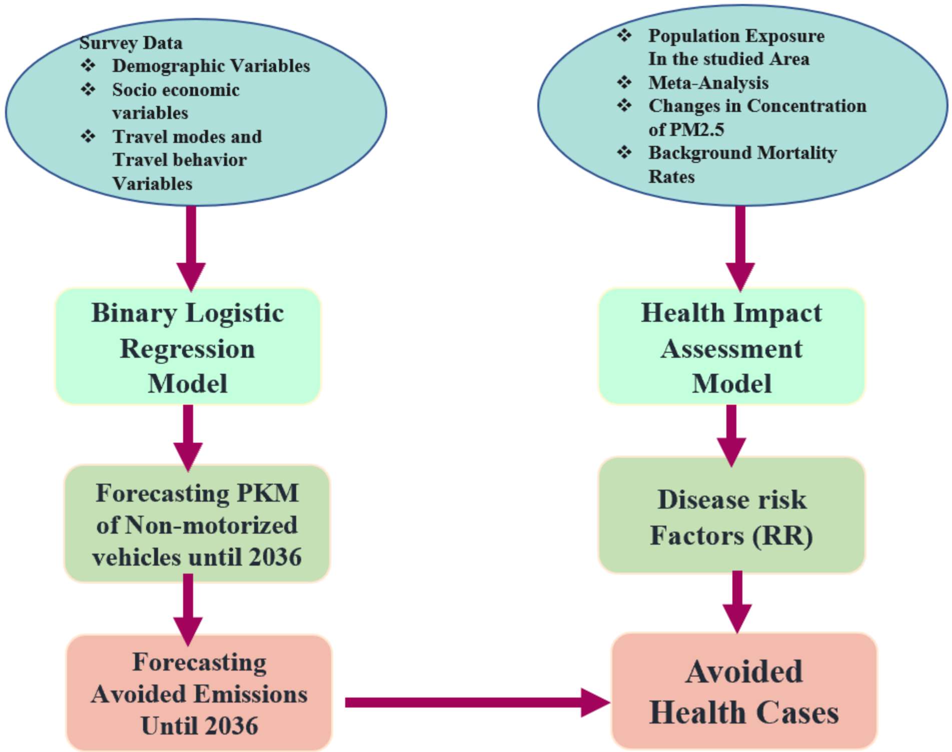

Fig 2.4. The methodological approach in scenario 2

A binary logistic model is used to analyze the impact of willingness to use nonmotorized vehicles:

$$P = \frac{1}{1+e^{-Z}} \tag{2.8}$$

The model can be estimated by ordinary least square,

$$ln\left[\frac{P}{1-P}\right] = Z = \beta_i X_i = \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \varepsilon \ \ (i = 1,2,3 \ldots \ldots \ldots n) \tag{2.9}$$

Where,
P= proportion of individuals who wants to use cycle
Z= represents the relative attractiveness of cycling
β = the coefficient of each independent variable of X
e = Natural log

To analyze the willingness to utilize nonmotorized, the seven following parameters are considered:

1. Age
2. Gender
3. Occupation
4. Income range
5. Having a Driving license
6. Travel mode for mandatory trips
7. Travel mode for non-mandatory

Based on the demographic variables (Age, Gender, Occupation), Socio-Economic variable (Income Range), travel modes, and travel behavior of passengers (Mandatory trips, Nonmandatory trips, and Having a Driving license), the impact of willingness to use non-motorized vehicles is considered. All variables are categorical variables in this study.
The estimated coefficients of the aforementioned model are interpreted through odds ratios (ORs). The Odds ratios can be estimated as given below:

$$OR = e^{\beta i} \qquad (2.10)$$

A questionnaire was designed to collect data to examine the willingness to use nonmotorized vehicles. There were 258 respondents to that survey.
In logistic regression, the overall strength of a particular model is expressed as a number between zero and one for binary or multinomial outcomes. The benchmark for such measurements is the linear regression model's coefficient of determination R^2. Their functional value in logistic regression always ranges from 0 to 1 and is put into a probability. A logit model's parameters are mostly calculated using maximum likelihood estimation. The LL function is maximized via the iterative process. The likelihood of the specific outcome of the parameter is represented by LL. Comparisons between the LLs of the estimated model and the null model are performed using LL-based pseudo R^2 measures. The improvement in pseudo-R^2 over the null model in terms of LL can be viewed as a measure of goodness of fit. In this research, McFadden's pseudo-R^2, Cox snell pseudo $R^{2,}$ and T_{jur} pseudo R^2 are calculated to ensure the robustness of the results. Table 2.1 summarizes the three Pseudo R^2 :

Table 2.1: Equations of Pseudo R2

Source	**Pseudo R^2**	**Range of value**
McFadden	$R^2 = 1- \frac{LLv}{LLo}$	$0 \leqslant R^2 \leqslant 1$
Cox and Snell	$R^2 = 1- \exp(- \frac{2(LLv-LLo)}{n})$	$0 \leqslant R^2 \leqslant 1$
Tjur	$R^2 = \frac{1}{n1}\sum \hat{\pi}(Y = 1) - \frac{1}{no}\sum \hat{\pi}\ (Y = 0)$	$0 \leqslant R^2 \leqslant 1$

The maximum value of the LL function of the model examined (LL_v) is confronted with the maximum value of the LL function under the null model (LL_o).

2.3. Health Impact Analysis:

The most harmful pollutants to health are $PM_{2.5}$ particles because they are known to raise the risk of premature death. The air quality health risk assessment (AP-HRA), with particular concentration-response functions and relative risks, is used to calculate the health benefits of averted PM2.5 levels. The six health outcomes that were taken into consideration for the health impact analysis in this research were total mortality, COPD, cardiovascular mortality, respiratory mortality, lung cancer, and associated hospital admissions. To calculate the link between a change in air pollutant concentration (in this case, PM2.5) and a change in health consequences, concentration-response functions (CRFs) are used (usually an incidence or mortality rate). The relative risk (RR), which represents the likelihood of an undesirable health outcome among the population exposed to a higher ambient air pollution level than a lower ambient level, is typically used to calculate the CRF coefficient value.

$$RR = \exp\left[\beta(C - C_o)\right] \quad (2.11)$$

Where,

β = coefficient that assesses a health outcome's reaction to a change in pollutant concentration

C = Pollutant concentration in the baseline scenario

C_o=Pollutant concertation intervention scenario

To calculate the concentration of $PM_{2.5}$, the following formula is used [14]:

$$C = \frac{E}{v.L.H} \quad (2.12)$$

Where,

E = Annual emission for $PM_{2.5}$

v = Wind Speed(m/s)

L = Length(m) of the selected location

H = Height (m) of the selected location

A thorough $PM_{2.5}$-related RR meta-analysis was carried out for a number of diseases from earlier studies conducted in Asian countries. A total of 86 studies were included. Meta-analysis is a statistical analysis that integrates the findings of various scientific investigations. When several scientific studies address the same issue, and each one reports measurements that are anticipated to have some degree of inaccuracy, meta-analyses can be carried out. In this research, a total of 86 Asian countries were considered for total mortality, COPD, Cardiovascular Mortality, Respiratory mortality, LC, and associated hospital admission.

In Fig 2.5, the geographical distribution of selected studies for meta-analysis is shown.

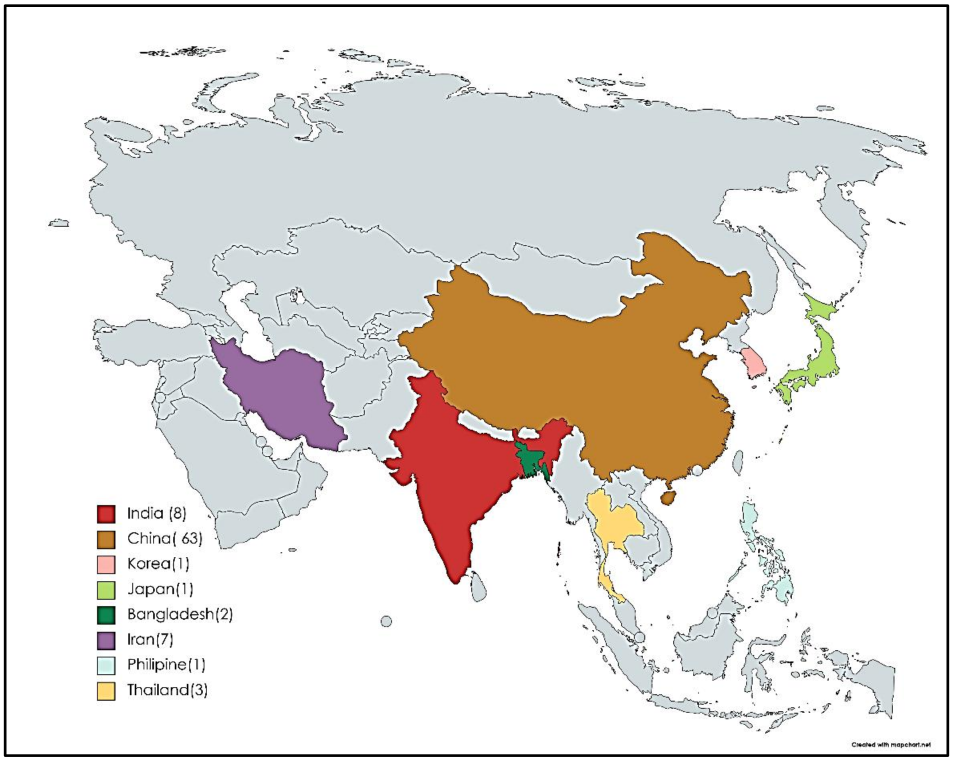

Fig 2.5. The geographical distribution of the selected studies for meta-analysis

The pooled value extracted from the meta-analysis (RR^p)is estimated as follows:[17]

$$RR^p = \frac{\sum y_i RR_i}{\sum yi} \tag{2.13}$$

$$y_i = \frac{1}{SE\{\log RR_i\}^2} \tag{2.14}$$

SE is the standard error. Excess deaths or illnesses derived from an increase in concentration in terms of the population-attributable fraction can be calculated as follows:

$$ED = PAF * I * P \tag{2.15}$$

Where,
PAF (population attributable fraction) = the proportion of illness burden owing to pollution,
I = annual baseline mortality rate
P = denotes the total population
The overall flowchart of the health impact assessment model is given below:

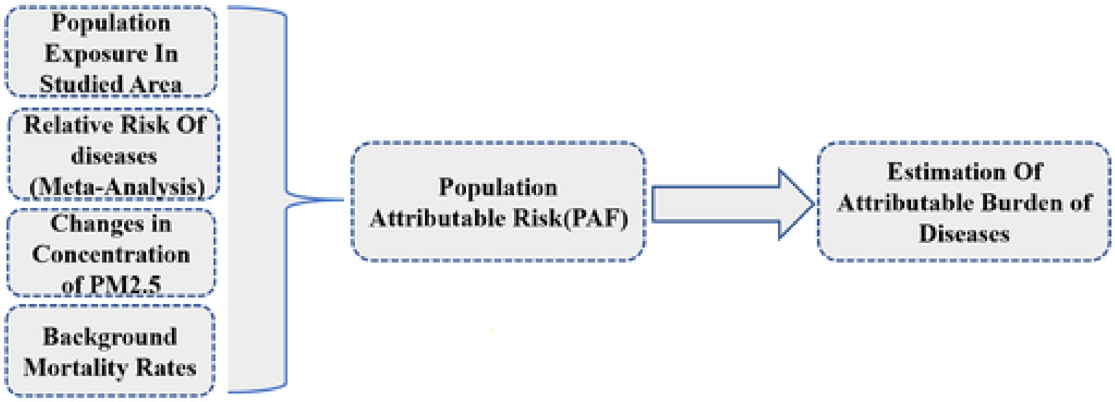

Fig 2.6. The overall flowchart of the health impact assessment model

Chapter 3
Results And Discussion

3.1. Results of CNG transport feet Scenario:

3.1.1. Baseline Scenario:

To calculate the baseline scenario or an initial emissions assessment of the transport sector of Dhaka city, data on the total number of vehicles, the share of vehicles by fuel use, utilization rate, annual average distance travel, and fuel efficiency are used. 2020 is the baseline year, covering an overview of Dhaka city transport. The Vehicles number and occupancy number data are collected from the Bangladesh Road Transport Authority (BRTA) [18].

In 2020, according to the baseline scenario, the number of vehicles by fuel use was 1,880,024. The total vehicle kilometers are 43,033 million kilometers. Annual passenger kilometers are 289,985 million kilometers. The following pie chart shows the modes share of the contribution of vehicles in total emissions.

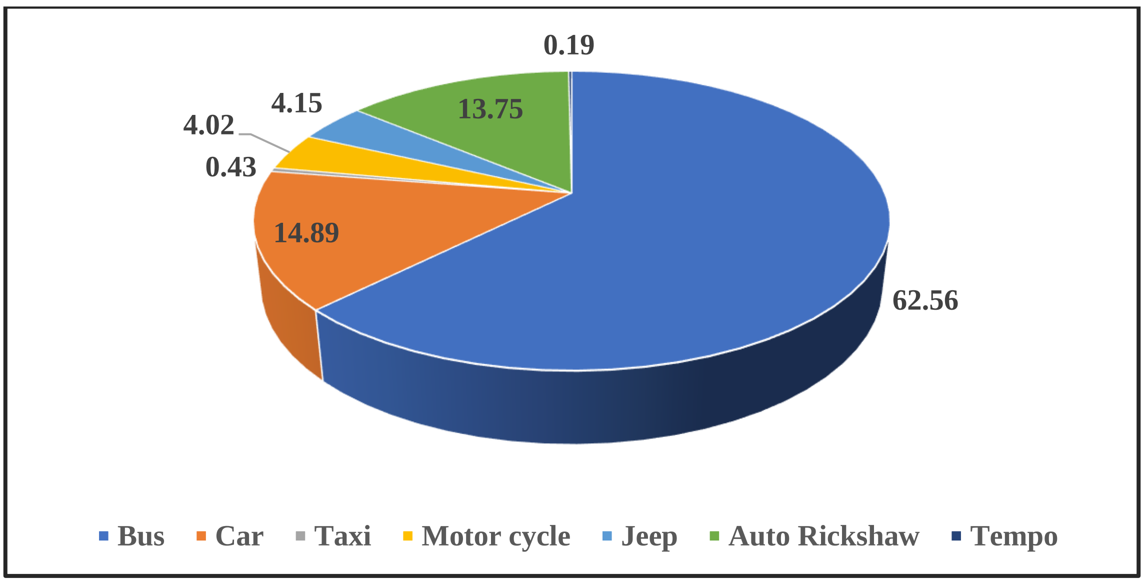

Fig 3.1. Modes share of vehicles (%)

The total emission is computed in the base year. The transport sector is responsible for 9.5 million tons of the city of Dhaka's total GHG emissions. The estimated emissions of SO_2, NOx, $PM_{2.5}$, CO 12.15, 68.28, 4.16, and 132.07 kilotons, respectively. The total emissions in the base year are depicted in the following graph.

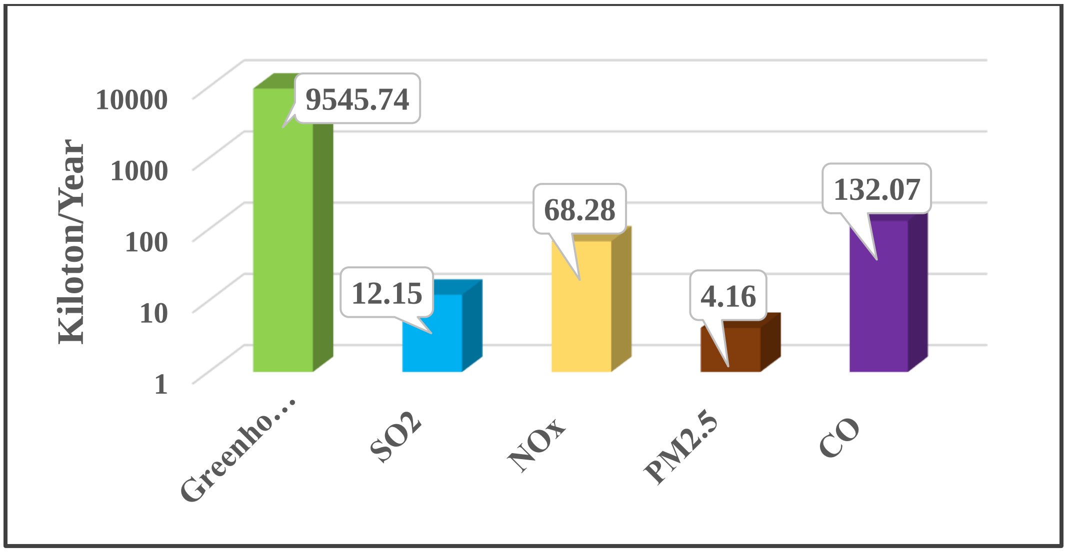

Fig 3.2. Emissions in the base year

3.1.2. Calculation of New Saturation Level:

An important consideration for determining the population of all automobiles is the saturation level of vehicle ownership per 1000 people. For the 26 countries, Daragey and Gateley's calculations used a saturation threshold of 850 vehicles overall per 1000 people and 620 cars per 1000 people [19].

Bangladesh is not one of the 26 nations. Using the econometric model, this study determines a new saturation level for CNG fuel-powered automobiles in Dhaka city. The time series data from 1988 to 2020 for the number of vehicles, GDP, and population is used to calculate the new saturation level. Data on GDP and population were collected from the World Development Indicator Database [15]. In this study, EViews software was used to analyze the data sets [20]. The Augment Dickey-Fuller (ADF) test is used to verify the stationarity of time series data. Table 3.1 summarizes the result for the stationary test of all the time series; t-stat and p-value are the test determinates. The result reveals that variable Population (LnP) is stationary at its level I(0). The other two variables are stationary in 1st difference I (1). This suggests that multiple regression cannot be applied, and it leads to apply the Autoregressive Distributed Lag (ARDL)model.

Table 3.1. Results for Augmented Dicky- Fuller test to check stationary

Variables	t-stat (Level)	P-value (level)	Decision	P- value (1^{st} difference)	t-stat (1^{st} difference)	Decision
Number of vehicles (LnV)	-2.38	0.154	Nonstationary	0.01<0.05	- 3.6	Stationary
Ln GDP	3.188	1.0	Nonstationary	0.02<0.05	- 3.204	Stationary
Population (LnP)	-3.46	0.10	Stationary			

Table 3.2 summarize the result of the ARDL model. The lags are selected based on the smallest number of Akaike Information Criteria (AIC). From Table 3.2, It is noted that, the coefficient of the number of vehicles and GDP are significant, the R-square is 0.993, and the adjusted R-Squared is 0.922, which indicates the fitness of the model. Durbin-Watson's stat is also in range.

Table 3.2. Results of ARDL

Variables	Coefficient	p-value
LNV(-1)	0.74	0.0007<0.05
LNV(-2)	-0.08	0.68>0.05
LNP	0.99	0.11>0.05
LNGDP	0.10	0.08>0.05
C	-15.01	0.13>0.05
R-Squared 0.993	Adjusted R-Squared 0.992	Durbin-Watson stat 2.019

Based on the coefficient from Table 3.2, the new saturation level for CNG fuel-run vehicles in Dhaka city is calculated. Fig 3.3 shows the saturation level is 14.48 per 1000 inhabitants.

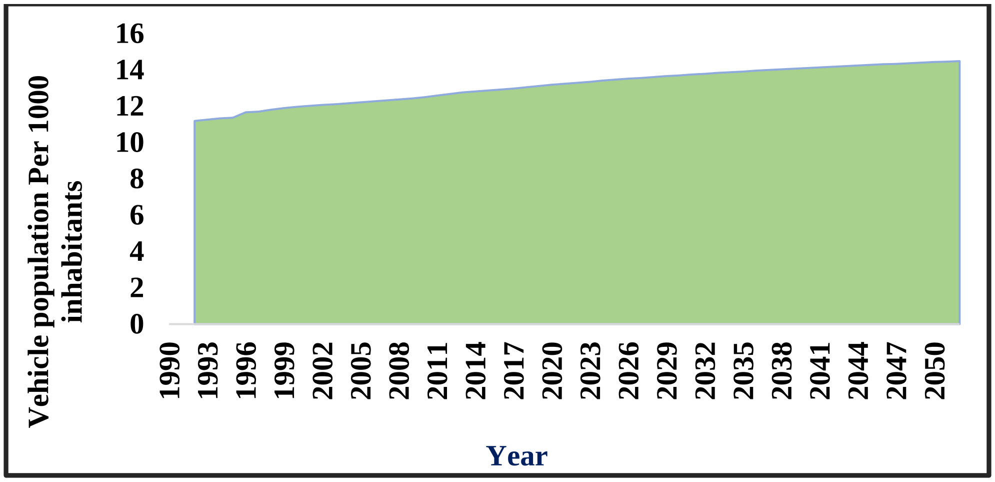

Fig 3.3. Estimation of the vehicle saturation level up to 2050

3.1.3. Future projection of CNG fuel run Vehicles:

Using the Gompertz equation, vehicle population was calculated until 2050. Then, based on economic growth, this function forecasts the number of vehicles owned per 1000 persons. Based on the result shown in Fig 3.3, three saturation levels were examined as the input values in the Gompertz equation (1) as low, mid, and high levels. To determine the low, mid, and high saturation levels, it was considered 1.2 times of saturation level (14.48) for the low saturation level, 1.5 times 14.48 for the mid saturation level, and 2 times 14.48 for the higher saturation level. The regression results for three saturation levels are shown in Table 3.3. All three levels' coefficients are significant, and R-squared is 0.99.

Table 3.3. Results of the Gompertz model

Variables	Coefficient	p-Value	Saturation Level
δ	1.13	2.9E-28	Low saturation level (14.48*1.2 = 17)
μ	-0.00039	2.53E-13	
δ	1.20	5.58E-30	Mid saturation level (14.48*1.5 = 21)
μ	-0.00036	4.73E-13	
δ	1.28	5.38E-32	High saturation level (14.48*2 = 28)
μ	-0.00032	8.98E-13	

Figure 3.4 shows the CNG vehicle ownership per 1000 inhabitants for three saturation levels until 2050. At the lower saturation level, 17 vehicles per 1000 inhabitants, and at the higher saturation level, 28 vehicles per 1000 inhabitants. Finally, at the medium saturation level, it shows 21 CNG vehicles owner per 1000 inhabitants.

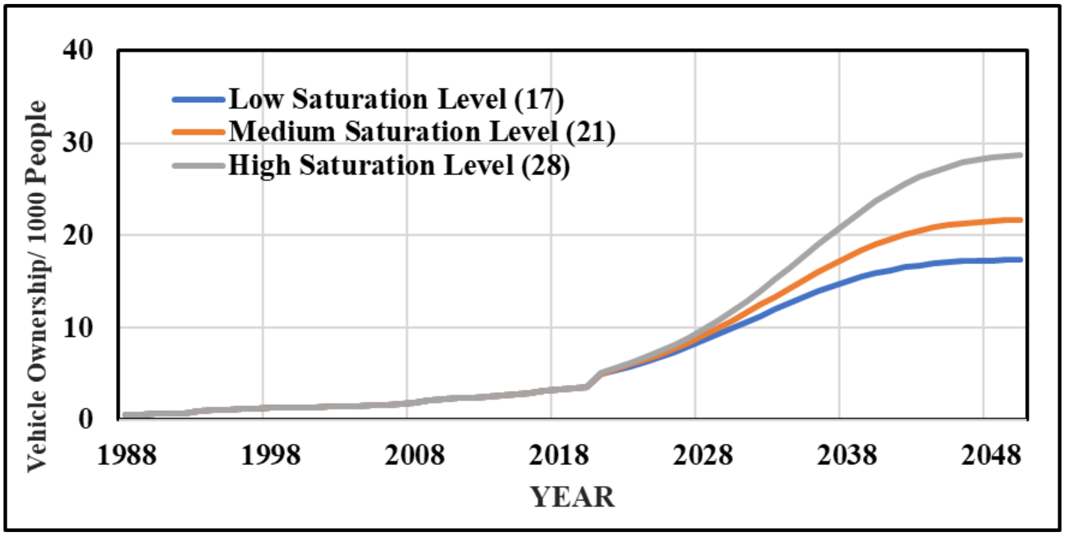

Fig 3.4. Future projection of CNG-run vehicles using the Gompertz Equation

3.1.4. Impact of lower fuel price on VKT (Vehicles Kilometers Travel):

Using the Dynamic Ordinary Least Square Method (DOLS), the impact of less fuel price has been analyzed. The time series data from 1995 to 2020 was taken for each variable. GDP, population, and fuel price were considered explanatory variables. Table 4.4 summarize the result of the Augmented Dicky Fuller test to check the stationarity of all the time series data, and t-stat and p-value are the test determinates. Only the variable, population, is stationary at the level. All other variables are stationary at 1st difference except the variable vehicle kilometers. This result leads to the DOLS method. DOLS method can be used in the combination of stationary and nonstationary variables. The DOLS method's lag was selected based on the lowest AIC value.

Table 3.4. Results of Augmented Dicky Fuller Test

Variables	t-stat (Level)	P- value (level)	Result	P- value (1st difference)	t-stat (1st difference)	Result
Ln VKT	-1.99	0.5>0.05	Nonstationary	0.07>0.05	-3.10	Nonstationary
Ln GDP	-0.56	0.9>0.05	Nonstationary	0.02<0.05	-5.96	Stationary
Ln P (Population)	-3.97	0.02<0.05	Stationary			
Ln PR (Petrol Price)	-1.02	0.92>0.05	Nonstationary	0.001<0.05	-5.70	Stationary
Ln CNG (CNG Price)	-1.16	0.67>0.5	Nonstationary	0.002<0.05	-5.52	Stationary

Tables 3.5 and 3.6 show the results of optimal lag selection for CNG and petrol fuel prices, respectively. The lag was selected based on the lowest Akaike Information Criterion (AIC) value. The lowest value of AIC indicates the lag 1 for both prices. LR indicates sequential modified LR test statistics; SC is the Schwarz information criterion, HQ is the Hannan-Quinn information criterion, and FPE is the Final Prediction Error. Each test was held at a 5% level.

Table 3.5. Results of optimal lag selection for CNG fuel price

Lag	LR	FPE	AIC	SC	HQ
0	NA	3.16e -10	-10.52	-10.33	-10.47
1	313.8	1.78e-16	-24.93*	-23.96	-24.66

Table 3.6. Results of optimal lag selection for petrol fuel price

Lag	LR	FPE	AIC	SC	HQ
0	NA	3.16e-10	-10.52	-10.33	-10.47
1	313.81	1.78e-16	-24.93*	-23.96	-24.66

***** Indicates the lowest value of AIC

Table 3.7 shows the result of the DOLS method for both fuel prices. Table 3.7 shows the significance of all variables except CNG fuel price. The R^2 value is 0.99, and the adjusted R^2 value is 0.99, which indicates the fitness of the model. The results for Petrol fuel price and p-value for each variable suggest the significance of petrol fuel price. The coefficient of CNG fuel price is -0.22, which means if the price is reduced by 1 percent, VKT will increase by 0.22 percent. The coefficient of gasoline price (LNPR) is -0.03, and the p-value is noteworthy. By reducing the price of petrol by 1 percent, the VKT will rise by 0.3 percent. Comparing the coefficient of the two fuel prices, VKT is increasing by 0.19 percent. CNG fuel was introduced in Dhaka city in 2002. Comparing the VKT of 2001 and 2002 of Dhaka city, it can be observed that the VKT has increased by 2.42 percent, indicating that lower gasoline prices have raised the VKT of Dhaka city.

Table 3.7. Estimation of the regression coefficients for both fuel price

	Variables	Coefficient	p-value
For CNG fuel price	LNCNG	-0.22	0.06>0.05
	LNGDP	0.32	0.00<0.05
	LNP	3.54	0.04<0.05

	C	-45.92	0.002<0.05
For petrol fuel price	LNPR(Petrol)	-0.03	0.0518<0.05
	LNGDP	0.38	0.00<0.05
	LNP	1.85	0.00<0.05
	C	-14.03	0.078<0.05

3.1.5. Calculation of Avoided Emissions:

Switching to CNG has a significant influence on reducing pollution. CNG conversion helped to reduce air pollution in Dhaka city, which had been extremely bad. CNG contains 85% methene (CH4), so it entirely oxidizes in normal conditions due to its low carbon content. Since the CNG fuel system is totally sealed, there are no evaporation emissions from CNG vehicles. The conversion quality of the car has an effect on emissions as well. About 70 percent of buses and 83 percent of vehicles in Dhaka have been converted to CNG fuel. The VKT increased by 2.42 percent as a result. The reduction of air pollutants from the implementation of the CNG vehicle scenario is shown in Fig 3.5. GHG, SO_2, NO_x, $PM_{2.5}$, CO, and HC have decreased by 12%, 70%, 27%, 16%, 8.4%, and 7.3%, respectively. The 70% decrease in SO_2 is apparent. Burning low-sulfur fuels like natural gas, which have a low sulfur content, is an efficient way to lower SO_x emissions since sulfur emissions are proportional to the sulfur concentration of the fuel.

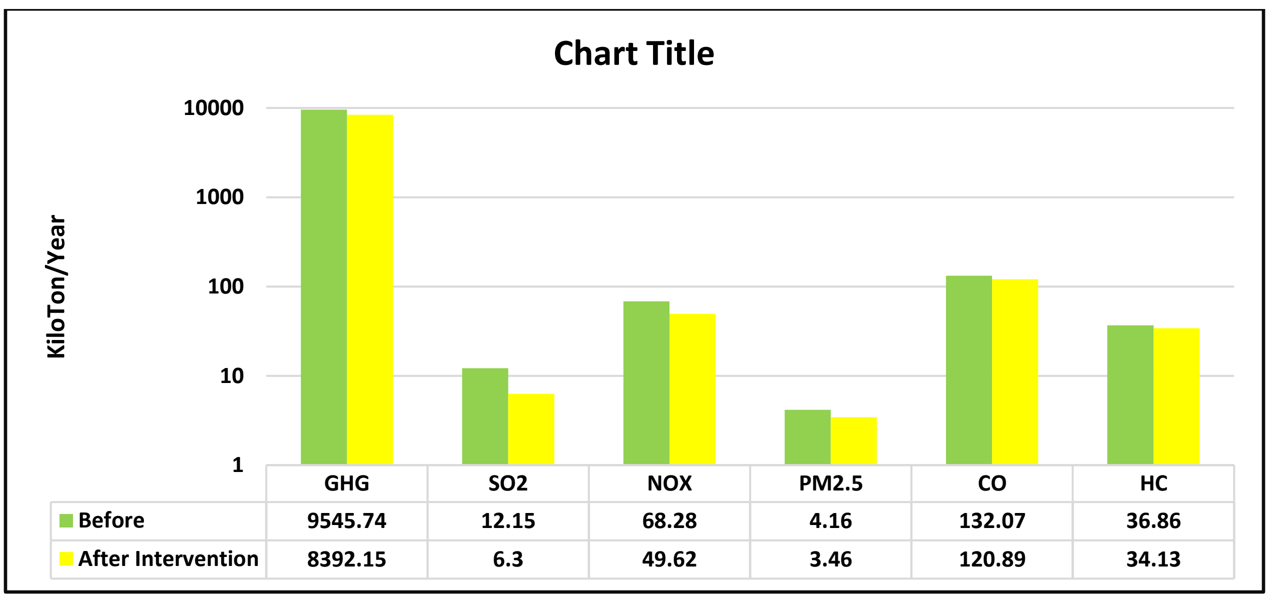

Fig 3.5. Expected GHG Emissions and Pollutants Reduction from the CNG fuel policy

3.1.6. Public health Co-benefits from the utilization of CNG fuel Policy:

Along with reducing emissions, the CNG policy's implementation has also markedly improved public health. In this study, Total mortality, COPD, cardiovascular mortality, respiratory mortality, lung cancer, and related hospital admissions total the six health outcomes that are considered to quantify the health benefits of avoided PM2.5 in Dhaka city.

The association between a change in air pollutant concentration and a change in health effects is estimated using concentration-response functions. A detailed $PM_{2.5}$-related RR meta-analysis was conducted in this study for several diseases from earlier studies conducted in Asian nations. The meta-analysis was based on a systematic quantitative review in which all relevant and important empirical data that complies with the eligibility criteria and standards was gathered, combined, and subjected to statistical analysis to produce a pooled estimate that was as close as possible to the RR Value specified for Dhaka city. The yearly concentration of avoided PM2.5 was calculated.

Table 3.8 shows RR values per 10 µg reduction in $PM_{2.5}$ concentration extracted from the meta-analysis. The total number of studied countries was 86. I^2 indicates the heterogeneity test, and p denotes the p-value of the statistical test. All tests are held in a 95% Confidence Interval (CI).

Table 3.8. RR values per 10 µg reduction in PM2.5 concentration extracted from the meta-analysis

	Avoided all-cause mortality	COPD	LC	Respiratory Diseases Related Hospital visits	Cardiovascular Mortality	Respiratory Mortality
RR (95% CI)	1.01	1.04	1.04	1.01	1.01	1.01
Statistical test	I^2=98%, P=0.00001	I^2=97%, P=0.00001	I^2=97%, P=0.00001	I^2=87%, P=0.00001	I^2=96%, P=0.00001	I^2=62%, P=0.0003

The baseline incident rates of diseases in Dhaka used in this study are shown in table 3.9.

Table 3.9. The baseline mortality per 100,000 inhabitants [21]

Mortality	Baseline Incidence per 100000
Cardiovascular mortality	497
All-cause mortality	1013
Respiratory Mortality	66
Hospital visits (respiratory disease)	1260
Lung cancer	9.06
COPD	101

After implementing the CNG fuel policy in Dhaka city, the annual avoided health burden was calculated. The annual avoided all-cause mortality is calculated at 1013. From Table 3.10, the avoided mortality cases anticipated from reducing $PM_{2.5}$ exposure. In this study, Eq (2.12) is used to calculate the change in PM2.5 concentration after implementing both low-emission scenarios. It is assumed that the wind speed and the geographical parameters (length and height of the location) remain unchanged across the period. The change in PM2.5 concentration after the implementation of the scenario is calculated based on the change in avoided PM2.5 emissions. The maximum $PM_{2.5}$ concentration in Dhaka city is 172.2 μg/m^3 and is due to the transportation sector [22]. To determine baseline mortality, 172.2 μg/m^3 is considered the concentration of $PM_{2.5}$. Almost 14% of total mortality can be avoided after implementing the CNG policy.

Table 3.10 The avoided mortality after adopting the CNG Fuel Policy

Diseases	Baseline Mortality	Avoided Mortality
Cardiovascular mortality	16,435	2,459
All-cause mortality	33,498	5,012
Respiratory Mortality	2,182	326
Hospital visits (respiratory disease)	41,666	6,234
Lung cancer	934	111
COPD	10,414	1,239

3.2. Results of Non-motorized Transportation Scenario :

3.2.1. Field Data Survey:

To analyze the impact of willingness to use nonmotorized vehicles (cycle, rickshaw, and walking), an online survey was conducted among the inhabitants of Dhaka city from October 1 to October 10, 2022, in the city of Dhaka to assess people's willingness to use non-motorized vehicles. There were 10 questions in all. All of the chosen covariates were categorized based on the survey data to distinguish the likelihood of willingness for the various categories of the related predictor, as shown in Table 3.11.

A total of 258 people participated in the survey. Age, gender, occupation, income, and driving license were analyzed to determine their effects on using non-motorized vehicles. It also gives an overview of the behavior on to choose transport modes for Mandatory trips (work and education-related trips) and Nonmandatory trips (shopping and recreation trips). According to the survey data, people prefer 3 to 5 kilometers distance to use nonmotorized. Students, professionals in the private sector, government employees, and housewives' homemakers participated in this survey. Three age ranges (15 – 25, 26 – 40, and 41 – 60) were considered.

In this study, four income ranges low (20,000 - 31,000 Taka), mid (31,000 - 99999 Taka), mid-high (1,00000– 249999 Taka), and (250000 - Above) are considered. According to the survey data, mid-age group people who are mostly involved in different occupations prefer more nonmotorized vehicles.

Table 3.11. Detailed Questionnaires used in the survey

Questions	Responses
1. Gender	• Male • Female
2. Age	• 15-25 • 26-40 • 40-60
3. Occupation	• Student • Private job • Government Job • Housewife
4. Income range	• 20,000-31,000 BDT • 31,000-99,999 BDT • 100,000-249,999 BDT • 250,000- Above
5. Having Driving License	• Yes • No
6. Mandatory transport mode	• Bus • Car • Rickshaw • Motorcycle • Bicycle • Walking
7. Nonmandatory transport mode	• Bus • Car • Rickshaw • Motorcycle • Bicycle • Walking
8. Distance	• 2-4 km • 4-6 km • 6-8 km
9. Willingness to use nonmotorized vehicles	• Yes • No
10. Reasons behind choosing or not choosing Nonmotorized vehicles	

Table 3.12 shows the impact of age on willingness according to survey data.

Table 3.12. The cross table of Age range and willingness based on the survey

Age range	No willingness	Having Willingness
15-25	12	17
26-40	92	96
41-60	30	11

Income is an important parameter. According to the survey, low- and middle-class people choose nonmotorized vehicles more than middle- and high-class consumers. The cross table of income and willingness to use nonmotorized is shown in Table 3.13.

Table 3.13. The cross table of Income and willingness

Income	No willingness	Having willingness
Low	9	42
Mid	20	50
High mid	95	32
High	10	0

According to survey results, those with driving licenses are less likely to utilize non-motorized vehicles than people without one. The cross table shows the impact of having a driving license on willingness to choose nonmotorized vehicles in Table 3.14

Table 3.14 The cross table of Having driving license and willingness

	No willingness	Having willingness
Have driving license	73	24
No Driving License	61	100

People choose rickshaws and buses more for required travel, as the two most popular forms of public transportation in Dhaka. According to survey results, people prefer cars and rickshaws for leisurely travel. Low- and middle-class people use public transportation for errands. According to survey data, the following graph depicts the preferred mode of transportation for both required and recreational trips.

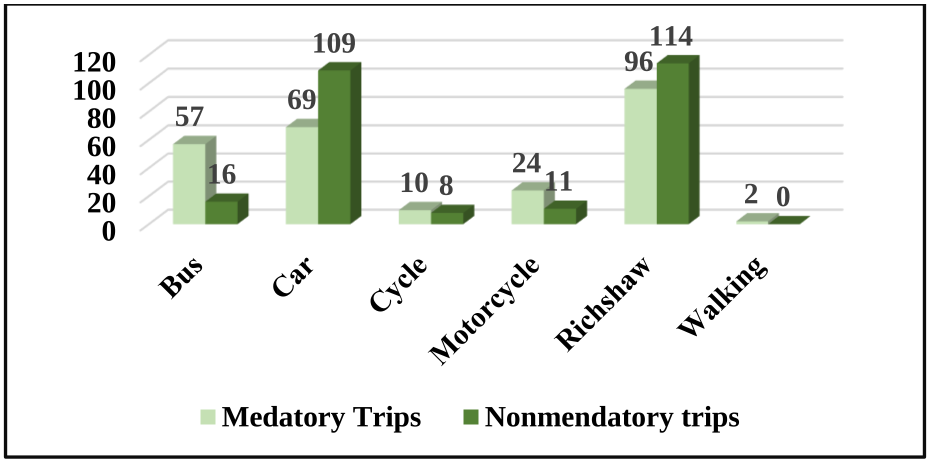

Fig 3.6. Mode's choice for mandatory and nonmandatory trips

3.2.2. Estimation of the Impact of Willingness to Use Nonmotorized transportation:

Table 3.15 shows the total impact of all variables on willingness to use nonmotorized vehicles. Estimated coefficients, p-value, and odds ratios are shown below in Table 3.15 Income and Mandatory travel modes were found to be significant factors in the willingness to choose nonmotorized vehicles. The ease and convenience associated with the conventional mode of transport psychologically affect the willingness to use non-motorized vehicles. In this study, the income and mandatory trips coefficient was found to be negative. For income, the odds ratio is estimated at 75%. It shows that the propensity to utilize nonmotorized vehicles declines by 75% for every 1% increase in income. For mandatory travel, the willingness declines by 27% for every 1% increase. The coefficient of nonmandatory travel was positive, and the odds ratio was calculated at 12%. This suggests that as travels rise by 1%, willingness also rises by 12%, as low, mid, and high-income people prefer rickshaws most for nonmandatory trips. Negative outcomes were also found for the driving license coefficient. The odds ratio is calculated at 45%. It indicates that the willingness to utilize nonmotorized vehicles declines by 45% for every 1% increase in having a driving license. The Mcfadden, Cox snell, and Tjur's pseudo R^2 is in the range of 0.2 to 0.4, indicating the model's very good fit.

Table 3.15. Estimation of coefficients, p-value and odd ratio

Variables	Coefficient	P-value	Odd Ratio
Intercept	3.313	8.42e-05	
Gender	-0.137	0.6724	13%
Income	-1.419	9.52e-11	75%
Non-Mandatory travel modes	0.1202	0.5552	12%
Mandatory Travel Modes	-0.311	0.0219	27%
Occupation	-0.067	0.6547	7%

Age	0.3024	0.3834	35%
License	-0.5815	0.0638	45%
McFadden Pseudo R^2	0.2767		
Cox snell Pseudo R^2	0.3183		
Tjur's pseudo R^2	0.3451		

However, looking at the p-values of the estimated coefficient, only income, and Mandatory Travel Modes can pass the linearity null hypothesis. Therefore, the collected data were categorized into three different groups, and also, the total impact of all variables on willingness was evaluated. Age, gender, and occupation were taken into account in demographic factors. As socioeconomic factors, income is taken into account. Choosing transport modes for mandatory and optional journeys and the impact of having a driving license are taken into account. The result of the three variables is presented in table 3.16 Gender, Income, mandatory trips, and having a driving license significantly impact willingness to choose nonmotorized vehicles. The coefficients of significant variables were found negative. This means that, the willingness is inversely proportional to these variables. If the income increases, the willingness to choose nonmotorized vehicles will decrease. Similarly, if the number of mandatory trips increases, the willingness to choose nonmotorized vehicles will decrease, and having a driving license will decrease the willingness to travel by nonmotorized vehicles.

Table 3.16. Estimated Coefficients and p-value from LR model

Co variates	Demographic variables		(Socio-Economic + Demographic Variables)		(Income+ Travel Modes)	
	Coefficient	P-Value	Coefficient	P-value	Coefficient	P-value
Intercept	1.9159	0.00104	2.88232	1.68e-05	3.5741	2.47e-07
Age	-0.5069	0.06871	0.25331	0.446		
Gender	-0.7635	0.00311	-0.29441	0.336		
Occupation	-0.2499	0.12938	-0.06817	0.629		
Income			-1.47972	3.33e-12	-1.3856	1.66e-12
Mandatory Trips					-0.3015	0.0258
Non-mandatory Trips					0.1372	0.4991
Driving License					-1.3856	1.66e-12

In the case of McFadden, Cox snell, and Tjur's Pseudo R^2, 0.2 to 0.4 indicate a perfect model fit (Table 3.17). Pseudo R^2 is a measure of how closely the data is in a regression line in the sample. Closer the Pseudo r-squared value is to 1, the better the fit. An R-squared value of 0 indicates that the regression line does not fit the data at all, while an R-squared value of 1 indicates a perfect fit. From table 3.17, it is observed that model 2 and model 3 are within the acceptable range of 0.2 to 0.4. However, Model 1 is not within the range. Therefore Model 3 was selected as the best model to estimate the PKM (Passenger kilometer) of the NMT based on the willingness in the next section.

Table 3.17 The results of different Pseudo R^2

Pseudo R square	Model 1 (Demographic Variables)	Model2 (Socioeconomic - Demographic variables)	Model3 (Income +Travel Modes)
Cox snell	0.075	0.286	0.315
Mc Fadden	0.0569	0.244	0.274
Tjur's	0.074	0.309	0.342

3.2.3. Forecasting of the PKM of Nonmotorized Vehicles Based on NMT Willingness:

A simple linear regression model estimated the relationship between the PKM of non-motorized vehicles and income. Income was regarded as a covariate and PKM as a dependent variable. From Table 3.18, it is observed that the p-value indicates the significance of the relation

Table 3.18. Estimated coefficients of linear regression

Variables	Coefficient	p-Value
Intercept	1938	<0.05
Income	-51.48	<0.05

Considering the estimated coefficient on income in Model 3, the relationship between the willingness and PKM of the NMT can be expressed as follows:

$$PKM = 37.14 \times Willingness \quad (3.1)$$

According to the above equation, the monthly per capita kilometers spent on NMT in Dhaka is estimated at 37.14. Based on this finding, it is estimated that in 2021, 21% of motorized vehicles is replaced with nonmotorized in Dhaka city. This large share of nonmotorized vehicles consists of rickshaws, rickshaw vans, bicycles, and walking. However, rickshaws are the main mode of NMT in Dhaka city. Although the Bangladesh Road Transport Authority does not keep track of the number of rickshaws, relatively recent research has also found that the number of nonmotorized vehicles is declining in Dhaka city. According to the JICA report in 2009, 38.19% of vehicles were nonmotorized vehicles in Dhaka city [12]. In 2022, Almost 80% of motorized vehicles are now in Dhaka City [12].

Figure 3.7 represents the forecasted PKM of NMT in Dhaka based on the estimated value of willingness to use NMT in this city. The PKM of NMT was calculated based on willingness. According to the survey, 48% of people are willing to use NMT vehicles. From equation (3.1), the monthly PKM of NMT per capita is calculated, and the yearly total PKM of NMT for the people who have the willingness is estimated.

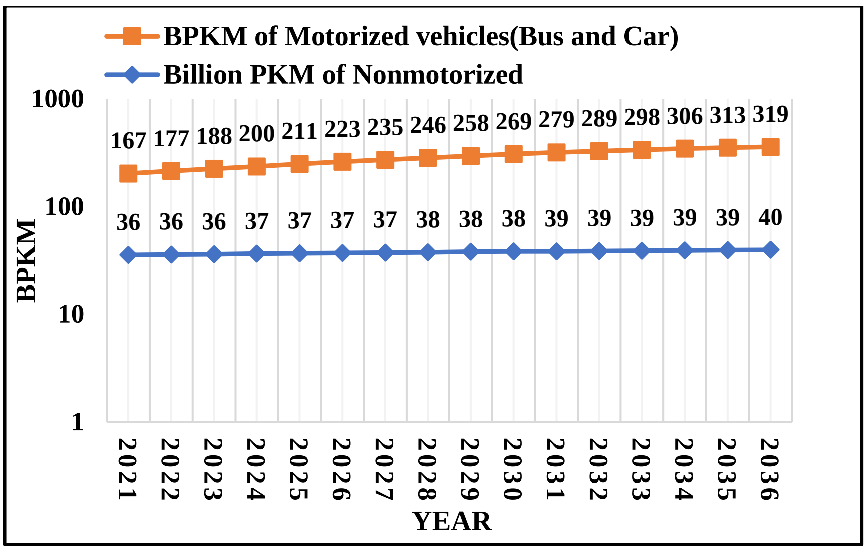

Fig 3.7. PKM projection of Nonmotorized vehicles of Dhaka city

3.2.4. Avoided emissions and mortalities from the NMT scenario

This study uses the PKM of non-motorized vehicles to calculate the avoided $PM_{2.5}$ from motorized vehicles (Buses and cars). It can be reduced $PM_{2.5}$ by 21% in 2021. Until 2036, the avoided PM2.5 is shown in Figure 3.8. It is estimated that non-motorized vehicles will reduce $PM_{2.5}$ by 17% in 2025, 14% in 2030, and 12% in 2035.

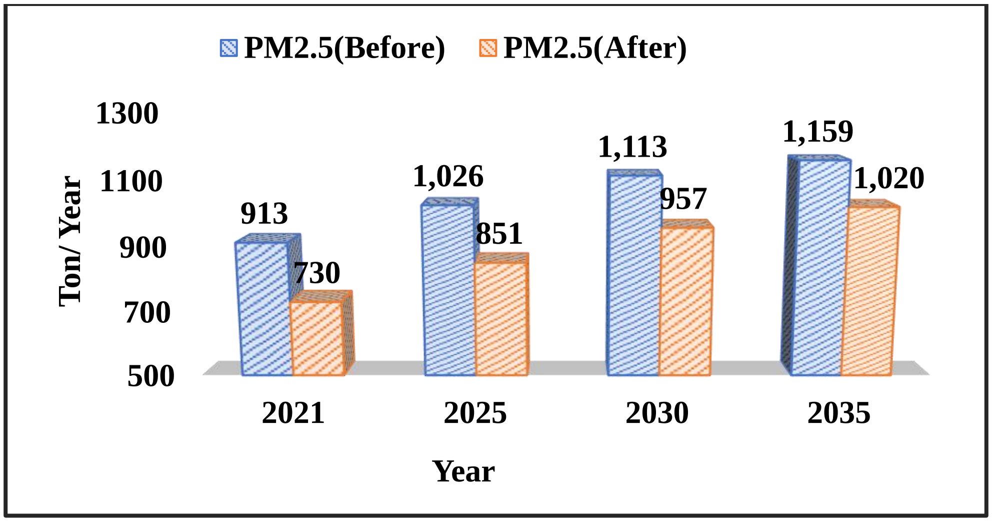

Fig 3.8. Avoided $PM_{2.5}$ due to the use of nonmotorized transport

The avoided health burden is calculated for six diseases for avoided $PM_{2.5}$ emissions due to the use of non-motorized vehicles in 2021. The avoided mortalities are shown in Table 3.19. It shows that almost 19% of the total avoided health burden can be achieved.

Table 3.19. The avoided mortality for nonmotorized vehicles

Diseases	Baseline Mortality	Avoided Mortality
Cardiovascular mortality	16,435	3,236
All-cause mortality	33,498	6,595
Respiratory Mortality	2,182	429
Hospital visits (respiratory disease)	41,666	8,204
Lung cancer	934	148
COPD	10,414	1,652

The annual co-benefits of two low-emission scenarios are summarized in Table 3.20.

Table 3.20. The annual co-benefits of two low-emission scenarios

Co benefits	Scenario1 (CNG Policy)	Scenario2 (NMT transport mode)
Avoided $PM_{2.5}$	16%	21%
All-cause mortality	5,012	6,595

It has been demonstrated clearly that the switch to CNG has had a significant positive impact on the air quality of Dhaka residents. Benefit from local air pollution ($PM_{2.5}$) 16% reduced. In the densely populated city of Dhaka, where traffic is a major source of air pollution, any improvement in the quality of the air immediately affects a sizable portion of the population. All-cause mortality is reduced by 5,012 yearly because of CNG conversion. This research found that nonmotorized vehicles in Dhaka city benefit larger from keeping the environment pollution free. Existing nonmotorized vehicles keep contributing to cutting 21% of $PM_{2.5}$ in the city of Dhaka, which has a greater health impact because it can prevent 6,595 total deaths per year. It is abundantly evident that nonmotorized vehicles contribute significantly to preventing environmental degradation. The expenses of transitioning to CNG need to be estimated through more research. The Bangladesh government has implemented a wide range of strategies to tackle the pollution issue in Dhaka. However, the majority of the policies cost money and take time to implement. By comparing the two low emissions scenarios, it can be concluded that the city of Dhaka will benefit more if nonmotorized vehicle implementation is prioritized. According to this study, buses remain the main form of public transport in Dhaka. High-quality public transportation is required. The bus service situation can be improved by increasing the frequency of the bus service, designing new bus routes, introducing buses on various routes based on demand, and strategically placing the bus stops. Besides, the rickshaw is the most popular public transportation, particularly for short and medium distances. Due to their convenience, affordability, safety, and security, rickshaws are preferred by women, children, and the elderly. The Bangladeshi government has been gradually phasing out rickshaws from the main traffic arteries in Dhaka over the past few years. These solutions' acceptability, logic, and implications are widely debated in Bangladesh. Many rickshaw drivers lost their jobs. The number of nonmotorized vehicles in Dhaka has decreased in recent decades. According to our survey, people preferred rickshaws more, but the absence of facilities, traffic violations, and regulations banning rickshaws discourage people from using nonmotorized transportation. It is necessary to improve and design the new route for nonmotorized vehicles, and to introduce rickshaws on various routes based on demand. Mix traffic like motorized and non-motorized create traffic congestion, causing more air pollution and causing threats to health and economic loss. Consequently, it is important to encourage non-motorized vehicles to maintain socioeconomic progress, reduce environmental degradation, and consider the limited resources available. Regulations and investments must be based on a thorough review to increase nonmotorized travel and incentivize nonmotorized transport.

Chapter 4
Conclusion

In this research, two low emissions scenarios of Dhaka city are considered. First, a co-benefit assessment of a government policy to convert motor vehicles to CNG policy is estimated. As a result, the benefits resulting from improved local air quality in Dhaka and reduced impact on global warming were determined. The second scenario was an analysis of the impact of willingness to use nonmotorized vehicles and the environmental benefits of nonmotorized vehicles.

Co-benefit assessment of CNG conversion is analyzed for the environmental and public health sector, besides the impact of lower fuel prices on VKT after the implementation of the CNG conversion policy was analyzed. This study concentrated on global emissions (GHG, SO_2, NO_X, PM2.5, CO, HC) before and after the conversion of the vehicles. Among motor vehicle emissions, GHG contributes directly to global warming. $PM_{2.5}$ and NOx have a significant impact on warming. On the other hand, SO_2 occurs the acid rain. It is found that, 12% of GHG emissions are reduced by using CNG fuel-run vehicles. As CNG is low sulfur fuel, 70% of SO_2 can be reduced by this policy. The health benefit is calculated as 5,012 avoided total mortality due to avoided $PM_{2.5}$ concentration. CNG fuel price is lower than petrol and diesel. 2.42% VKT has increased due to CNG conversion.

In the second scenario, the effect of willingness is estimated, and the PKM for nonmotorized vehicles is calculated based on willingness. It was estimated at 37.14 kilometers for each person every month. This significant result for Dhaka city's nonmotorized vehicles offers light on their current state and aids in developing future policies for this preferred mode of public transportation. The current non-motorized vehicles continue to contribute to reducing 21% of $PM_{2.5}$, preventing 6,595 total deaths from averted $PM_{2.5}$ concentration. Based on willingness, until 2035, the PKM of non-motorized vehicles is forecasted, and it is calculated that 12% of $PM_{2.5}$ pollution can be reduced in 2035, taking into account the future rapid population of private cars in this city.

In order to justify sustainable development projects, such as low emissions urban transportation development strategies, it is crucial to look for tangibly beneficial side effects that will further both climate protection and other human development goals. The efforts taken in the transportation industry are typically associated with the use of clean technologies or with changing people's travel habits which are cost-intensive and can be outweighed if the valuing and monetizing of the multiple benefits of such programs are taken into account. The urban population needs access to reasonably priced, comfortable public transportation, especially for low-income communities on the periphery of cities.

This research shows that the transport sector is one of the major contributors to air pollution. For city dwellers in Dhaka, the air quality is unhealthy and contributes to a number of ailments in addition to discomfort. Therefore, the government should increase car emission standards, rules, enforcement, and other related policies to decrease fuel demand and enhance traffic conditions.

The city's transportation and traffic issues, as well as the air quality, might be resolved with improved public transportation facilities. However, the government must have a robust political will or commitment to do this.

The two scenarios can be further studied from more aspects in future studies:

1. Analysis of the impact of different costs (congestion, environmental damages, health cost) and taxes (purchase taxes, fuel taxes, parts taxes).
2. Analyze the present and future travel demand and establish a balanced link between nonmotorized and motorized vehicles.

References

[1] R. Roni and P. Jia, “remote sensing An Optimal Population Modeling Approach Using Geographically Weighted Regression Based on High-Resolution Remote Sensing Data: A Case Study in Dhaka City, Bangladesh”, doi: 10.3390/rs12071184.

[2] S. Engineer, “Sustainable Urban Transport Index (SUTI) for Dhaka, Bangladesh NOOR-E-ALAM,” 2018.

[3] “বাংলাদেশ সড়ক পরিবহন কর্তৃপক্ষ-গণপ্রজাতন্ত্রী বাংলাদেশ সরকার.” https://brta.portal.gov.bd/ (accessed Dec. 21, 2022).

[4] M. M. U. Hasan and J. D. Dávila, “The politics of (im)mobility: Rickshaw bans in Dhaka, Bangladesh,” *J. Transp. Geogr.*, vol. 70, pp. 246–255, 2018, Accessed: Dec. 21, 2022. [Online]. Available: https://www.academia.edu/37259008/The_politics_of_im_mobility_Rickshaw_bans_in_Dhaka_Bangladesh

[5] “Dhaka Air Quality Index (AQI) and Bangladesh Air Pollution | IQAir.” https://www.iqair.com/bangladesh/dhaka (accessed Dec. 21, 2022).

[6] M. Zahangeer *et al.*, “Air Pollutants and their Possible Health Effects at Different Locations in Dhaka City Degradation and Detoxification of Azo dyes by Native Biofilm Forming Bacteria View project Seasonal Variation of Water Quality Constituents in the Turag River View project Air pollutants and their possible health effects at different locations in Dhaka city,” *J. Curr. Chem. Pharm. Sci. Res.* |, vol. 8, no. 1, 2018, doi: 10.21767/2277-2871.1000111.

[7] B. R. Gurjar *et al.*, “Human health risks in megacities due to air pollution,” *Atmos. Environ.*, vol. 44, no. 36, pp. 4606–4613, Nov. 2010, doi: 10.1016/J.ATMOSENV.2010.08.011.

[8] Z. Wadud, “(Unintended) Transport impacts of an energy-environment policy: The case of CNG conversion of vehicles in Dhaka,” *Transp. Res. Part A Policy Pract.*, vol. 66, no. 1, pp. 100–110, Aug. 2014, doi: 10.1016/J.TRA.2014.04.017.

[9] S. A. Iqbal, M. Iqbal, and A. F. M. Salauddin, “Present Scenario of Compressed Natural Gas (CNG) as a Vehicular fuel in Bangladesh”.

[10] M. Sahid Hassan, M. Akther Momin, M. Dutta, M. Kader, and S. Md Iftakher, “Study of LPG (Liquefied Petroleum Gas) And CNG (Compressed Natural Gas) Vehicles And It’s Future Aspects”, Accessed: Dec. 21, 2022. [Online]. Available: https://www.researchgate.net/publication/341450385

[11] Z. Wadud and T. Khan, “Air quality and climate impacts due to CNG conversion of motor vehicles in Dhaka, Bangladesh,” *Environ. Sci. Technol.*, vol. 47, no. 24, pp. 13907–13916, Dec. 2013, doi: 10.1021/ES402338B/SUPPL_FILE/ES402338B_SI_001.PDF.

[12] D. Alam, M. M. Hoque, and A. Roy, “Historical Overview of the Transport System of Dhaka and the Rise of Privately Owned Motor Vehicles,” *UITS J. Sci. Eng.* □, no. 7, p. 1.

[13] M. M. Rahman, G. And D’este, J. M. Bunker, M. M. Rahman, G. D’este, and J. Bunker, “Non-Motorized Public Transport Development Present Scenario & Future Approach in

Developing Cities," 2009, Accessed: Dec. 21, 2022. [Online]. Available: http://eprints.qut.edu.au/

[14] H. Farzaneh, J. A. Puppim de Oliveira, B. McLellan, and H. Ohgaki, "Towards a Low Emission Transport System: Evaluating the Public Health and Environmental Benefits," *Energies 2019, Vol. 12, Page 3747*, vol. 12, no. 19, p. 3747, Sep. 2019, doi: 10.3390/EN12193747.

[15] World bank, "No Title," *world bank Database*, 2020.

[16] "The Co-benefits Evaluation Tool for the Urban Transport Sector", Accessed: Dec. 21, 2022. [Online]. Available: http://tools.ias.unu.edu

[17] T. H. Bhat and H. Farzaneh, "Quantifying the multiple environmental, health, and economic benefits from the electrification of the Delhi public transport bus fleet, estimating a district-wise near roadway avoided PM2.5 exposure," *J. Environ. Manage.*, vol. 321, p. 116027, Nov. 2022, doi: 10.1016/J.JENVMAN.2022.116027.

[18] "Number of Registered Motor Vehicles in Dhaka." http://www.brta.gov.bd/sites/default/files/files/brta.portal.gov.bd/page/5818c2d3_c813_4cdf_8c89_971036fe83b3/2020-10-14-10-49-4993a9d0d4da8dbe5b86c557e12282ae.pdf (accessed Dec. 21, 2022).

[19] J. Dargay and D. Gately, "Income's effect on car and vehicle ownership, worldwide: 1960-2015," *Transp. Res. Part A Policy Pract.*, vol. 33, no. 2, pp. 101–138, 1999, Accessed: Dec. 21, 2022. [Online]. Available: https://ideas.repec.org/a/eee/transa/v33y1999i2p101-138.html

[20] I. Global Inc, "EViews 12 User's Guide II," 1994.

[21] C. Min Lee *et al.*, "Co-Benefit Assessment of Active Transportation in Delhi, Estimating the Willingness to Use Nonmotorized Mode and Near-Roadway-Avoided PM2.5 Exposure," *Int. J. Environ. Res. Public Heal. 2022, Vol. 19, Page 14974*, vol. 19, no. 22, p. 14974, Nov. 2022, doi: 10.3390/IJERPH192214974.

[22] M. M. Hossain, A. Kamruzzaman Majumder, M. Islam, and A. Al Nayeem, "Study on Ambient Particulate Matter (PM 2.5) with Different Mode of Transportation in Dhaka City, Bangladesh", doi: 10.34104/ajpab.019.0191219.

[23] C. Kuranami, B. P. Winston, and P. A. Guitink, "Transportation Research Record No. 1441, Nonmotorized Transportation Around the World".