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Energy Demand and Emissions Mitigation Potential of Mass Transportation Vehicle: A Case Study of Ring Road Kathmandu Valley

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Abstract

The public transportation mode in Nepal mainly consists of bus, minibus, microbus and three wheeler. The existing Public Transport System is complex, inefficient and provides a low level of service to users. The objective of this study is to improve public transportation system by using mass transportation vehicles in Ring Road of Kathmandu valley. The modelling tool Long Range Energy Alternative Planning Software (LEAP) been used to develop a bottom up model to estimate energy demand and environmental emissions in the Kathmandu valley for the period 2017-2035. The survival profile of the vehicle has been identified which has not been done in Nepal till now.Big bus and electric bus has been penetrated as an option to reduce the energy demand and emissions.The energy consumption increases by 123.81 percent in year 2035 as compared to base year in BAU scenario. The energy consumption by buses in 2035 will be 287.6 TJ.There is 30 percent energy reduction in large bus penetration scenario and 34 percent energy saving using electric bus scenario.

Keywords

Public transportation – LEAP – Energy demand – Ring road

Introduction

The public transportation mode in Nepal mainly consists of bus, minibus, microbus and three wheeler.The seat capacity is 25-35 for minibus and 35-55 for large bus [1]. More than 70 percent of the total vehicles registered in Nepal are in Kathmandu valley [2]. Similarly, the number of registered vehicles is also increasing annually at the rate of 17 percentin 2008-2012 [3]. The maximum number of registered vehicles is motorcycles followed by private cars. The composition of motorcycle is highest with 73.2 percent among registered vehicles in Kathmandu valley followed by cars/jeep/vans with the share of 18.5 percent. Public transportation constitutes only 5 percent of the total registered vehicles in the Bagmati zone except four wheelers [4]. Maintaining and enhancing public transit service in Kathmandu Valley is important, to meet rapidly growing mass mobility needs, and curb personal motor vehicle activity and its impact at low cost. However, the public bus transit service is inadequate for the urban poor. The existing public transport system is complex, inefficient and provides a low level of service to users.With the use of electricity in transport sector, dependency on import of POL can be cut to a wide value, the benefits being the reduction of GHG emission and use and opportunity to develop the indigenous resources of the nation.

The main reason behind the increase in the number of personal vehicles like motorcycles and light duty vehicles in the Kathmandu valley is due to the poor public transportation. Small vehicles like microbus, minibus and three wheelers are the means of basic public transportation in the valley and the quality of the services provided by these public vehicles is extremely poor and therefore, people are attracted towards the use of personal vehicles. Promoting the use of public transportation, especially in urban cities, has been taken as a mitigation option in number of studies. For instance by increasing the share of travel demand of public transport (bus) from 42 percent in 2000 to 70 percent by

2020 reduces the energy demand of Kathmandu valley by 28 percent while promoting a reasonably comfortable condition on overcrowded public transportation could increase energy demand by 10 percent [5]. A case study in Delhi (Bose, 1996) has estimated the reduction of energy demand by 9 percent by increasing the share of bus, a means of public transport, from 72 percent to 78 percent. The Kathmandu Sustainable Urban Transport Project (KSUTP) is an initiative of the Ministry of Physical Infrastructure and Transport Management, with loan and grant funding from the Asian Development Bank (ADB),and grant funding from Global Environment Facility. This policy on restructuring public bus services in Kathmandu Valley was based upon evaluation current conditions and recommends a set of interventions aimed at improving bus services in Kathmandu valley. The policies should be formulated to encourage the use of buses for the public transportation and discourage the use of personal and small vehicles by various means such as exercise duty, tax, parking charge, pollution tax and fuel cost discrimination. There are some studies in the past related to energy demand and environmental emissions from the transportation sector in Kathmandu valley. Ale etal studied the extension of trolley bus in Kathmandu valley and its impact on the reduction of petroleum fuel consumption and greenhouse gas emission upto year 2025 [6]. This study has no relevance since trolley bus service was shut down in 2009. Shrestha and Rajbhandari analyzed the sectoral energy consumption including transport sector and emissions in Kathmandu valley for the period 2015-2050 [7]. KSUTP ongoing its project for restructuring public bus services in Kathmandu valley but energy demand and emissions issues are not studied. This study has been undertaken to estimate the energy demand reduction by improving public transportation system by using mass transportation vehicles in Ring Road of Kathmandu valley. This study has also calculated the life cycle profile of bus and micro bus running in the Kathmandu valley.

1. Methodology

For the analysis of transportation demand, bottom up methodology has been used. The demand analysis for transportation sector has been implemented through a number of spreadsheet models and Long Range Energy Alternative Planning Software (LEAP). The flowchart for the model development is as follows:

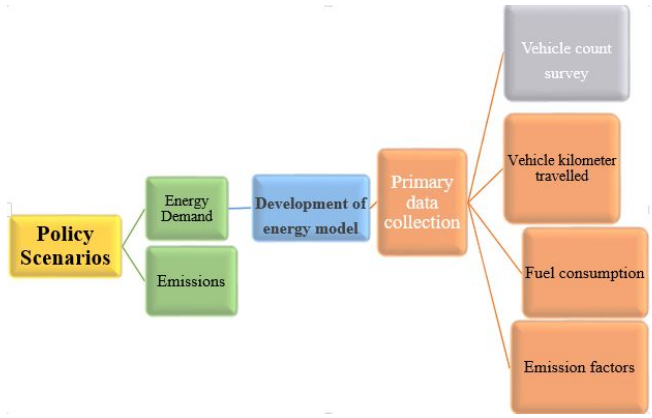

Figure 1: flowchart for the model development

Evolution of vehicle stock

To model the energy demand and emissions made by the vehicles, the actual vehicle fleet plying on the road has to be calculated. The statistics of data provided by DOTM is only the cumulative number of vehicle since their first registration and therefore do not represent the actual fleet existing and plying on the road each year. Each year large number of vehicles are scrapped due to their age. If the annual scrapping rate is known, the actual vehicle fleet plying on the road can be estimated by subtracting the scrapped vehicles from the annually registered vehicles numbers. The survey has been done for 50 number of buses and 32 number of buses to find the survival probability of the vehicle. The first step in the modeling of transportation energy demand is to estimate the evolution of existing vehicle in each year can be estimated by using the following equation[8].

$$N = 0.5D_i,y + \sum_{x=2001}^{y-1} D_i,yF_i(y-x) \quad (1)$$

Where Di,y is the number of vehicles of type i registered in year y, F(y-x) is the survival probability of vehicle type I of age (y-x). Registered vehicle data since 2001 to 2016 have been taken into account to model the vehicle stock. The survival probability has been calculated by doing survey. The value b and T can be calculated using Weibull equation.

$$F_i(k) = e - \left[\left(\frac{k+b_i}{T_i}\right)^{b_i}\right] \text{ and } F_i(0) = 1$$

Where F(y-x) is the survival probability of vehicle of type i having age k, k is the age of vehicles expressed in years, bi is the failure steepness for vehicle of type i (bi¿ 1, i.e, the failure rate increases with age and Ti is the service life for the vehicle of type i.

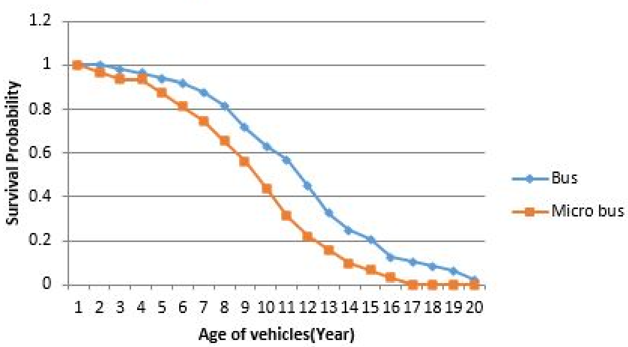

Figure 2: Vehicle survival profile

Vehicle Use Intensity

The average distance travelled by a vehicle in kilometer in a year also called Annual Vehicle Kilometer Travelled (VKT), which is one of the most important parameter in modeling the energy demand in transportation sector. Very few studies have been done in Nepal about the vehicle use intensity. Therefore the author conducted a primary survey to estimate annual VKT in Ring road of Kathmandu valley. Table 1 shows the estimated average annual VKT for different vehicle categories.

Table 1: Average annual kilometer travel in Ring road of Kathmandu valley

Vehicle	Fuel Type	Annual vehicle Km travel
Mini Bus	Diesel	50450
Micro Bus	Diesel	53743

The surveyed data is very close to that of Bhattarai (2016) as 43,307 for mini bus, 38,520 for microbus .

Estimation of fuel consumption

The average fuel consumed per kilometer distance travelled by a vehicle is required to model the energy demand in transportation sector. This data is based on the author's survey which is as follows:

Table 2: Average fuel economy of vehicles in Ring road of Kathmandu valley

Vehicle	Fuel Type	Fuel consumption(km/l)
Mini Bus	Diesel	4.5
Micro Bus	Diesel	6.8
Large Bus	Diesel	3.0

The fuel consumption was collected by asking with the drivers of bus and micro bus. The average mileage was found as 4.92km/l for bus and 6.59 km/l for micro bus. The total number of mini buses and microbuses taken for sample has been 50 for both. For large buses value has been taken from past data from Sajha Yatayat office. The surveyed data is very close to that of Bhattarai (2016) as 4 for mini bus, 6.8 for microbus and 3 for large bus.

Estimation of energy demand and emission

LEAP calculates the total energy demand using the following expression:

$$TEM = \sum Veh - km_i FE_i \tag{2}$$

Where TE is the total energy demand in the respective scenario, Veh-km is the total activity of the vehicle type i and FE is the fuel economy of the vehicle type i. The total emission is calculated using the following expression:

$$TEM = \sum Veh - km_i * FE_i EF_i \tag{3}$$

As the published emission data are not available in Nepal, these data are taken from existing literatures[9]. The average emission factors are presented in Table 3.

Table 3: Emissions factors by vehicle type

Vehicle	CO2(KG/GJ)	CO(g/km)	NOx(g/km)
Large Bus	79.7	4.9	6.8
Micro Bus	75.66	3.16	0.28

2. Results and Discussions

Survival Profile

The first step in the calculation of energy demand is to calculate the evolution of vehicle stock which can be obtained only by using the survival probability of the vehicle.. The value of b(steepness) and T (survival life) has been calculated using Weibull equation using iteration.The survival profile result for the vehicle is obtained as follow:

Table 4: Parameters obtained from survival probability

Parameter	Bus	Micro bus(km/l)
b	3.87	3.4
T (Years)	15	13

Stock of vehicles in fleet

Figure below illustrates the percentage value of the vehicle from previous years to till now. It shows that 5,6,7 years old micro buses accounts 49 percent which are running in base year. It means that almost half of the micro buses are of more than 5 years old. There are 16 percent of mini buses age 1 year and 10 pecent ofmini buses are of 10 years old.

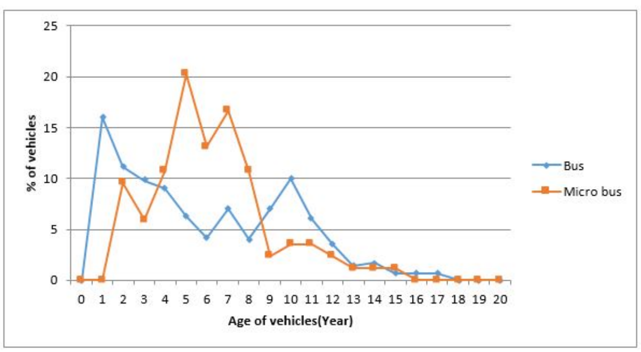

Figure 3: Percentage of vehicles in base year

Energy consumption

In the study, 2016 has been taken as a base case. The total number of vehicles in stock has been calculated as 248 and the vehicles sales as 27 which is of mini bus and there is no sale of microbus in base year. The total annual energy demand in litres can be estimated if the total number of existing vehicles in certain year their average annual mileage in kilometer and average fuel economy in liters per kilometer are known. The total energy consumption by bus in base year is 105.1 TJ and by micro bus is 23.4 TJ.

Business as Usual Scenario

The figure shows that the micro bus will be phase out from 2027 whereas the number of buses reaches 500 in 2035. The whole passenger demand will be fulfilled by buses only.

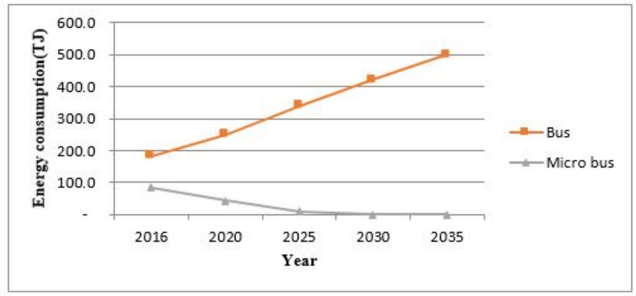

Figure 4: Energy consumption by different vehicles

The energy consumption increases by 123.81 percent in end year as compared to base year. The energy consumption by buses in 2035 will be 287.6 TJ.The total diesel demand was calculated as 2625 kilolitres in 2016 . For the data to be considered good, the parameters should be validated to establish authenticity. According to Bhattarai etal the total diesel demand by passenger vehicle was 28 thousand kilolitres in 2016 in Kathmandu valley. Around 12 percent of vehicles operating in Kathmandu valley runs in ring road only (Acharya, 2016). There is slight difference of 2.6percent it is because only operating vehicles are taken into account in this study. Table below shows the emissions in tones of Co2 equivalent

Table 5: Emissions in tones of Co2 equivalent

Vehicle Type	Bus	Micro bus
2016	8.4	1.8
2020	11.3	0.9
2025	15.4	0.2
2030	19.2	0
2035	22.9	0

Mass Transporting Vehicle Scenario

Following measures are taken for the construction of Mass transporting vehicle scenario. This scenario encourages the use of large 55 seater bus for transportation instead of small size buses and microbuses .It has been assumed that the registration of public vehicles which run in the rin road i.e. existing buses and microbuses will be decreased linearly by 2 percent in 2017 and accordingly the number of large buses will increase and replace all vehicles by large buses in 2035.

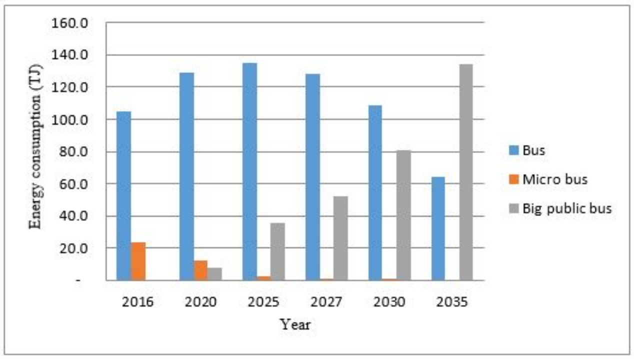

Figure 5: Energy consumption in mass transporting vehicle scenario

This scenario includes increasing the share of large buses with cutting off the mini buses and micro buses. The share and growth of other modes are untouched by this scenario. The energy consumption of buses decrease by 92 percent at the end year as compare to total energy demand in base year. The energy consumption by big public bus is 134 TJ. The total energy consumption at end year has been calculated as 198 TJ. The emissions result in this scenario is presented as shown in Table.

Table 6: Emission in tonnes of CO2 equivalent in mass transporting scenario

Vehicle Type	Bus	Micro bus	Large Bus
2016	8.4	1.8	0
2020	10.3	0.9	0.6
2025	10.8	0.2	2.8
2030	8.7	0	6
2035	5.1	0	10.7

Electric Vehicle Scenario

This scenario encourages the use of electric bus in place of existing diesel bus. Therefore it has been assumed that the sales of electric bus increase by 1percent in 2017 to 75 percent by 2035 as compared to reference scenario and the use of conventional buses will be decrease accordingly.

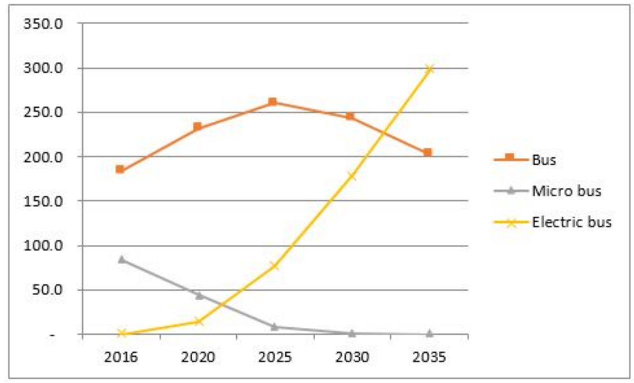

Figure 6: Vehicle stock in electrified scenario

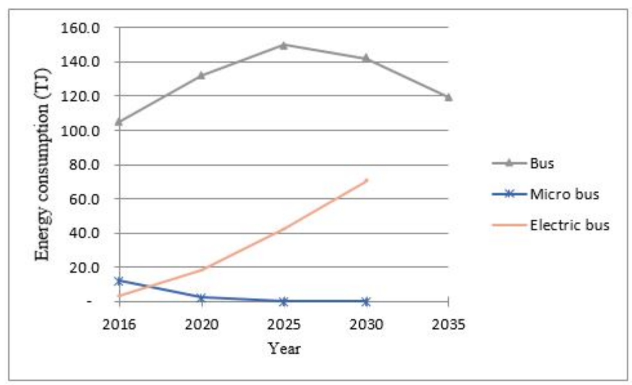

Figure 7: Comparison of energy demand in electric vehicle scenario

The above figure shows that the total energy consumption by the end of year is 189.5 in electric bus scenario. There will be 98.1 percent reduction in energy demand in 2035 by using electric bus in place of conventional buses. Figure shows the comparison of energy demand in different scenarios. It has been calculated that the energy demand in BAU scenario is 287 TJ, in large vehicle scenario 198 TJ and 189 TJ in electric bus scenario at the end year.

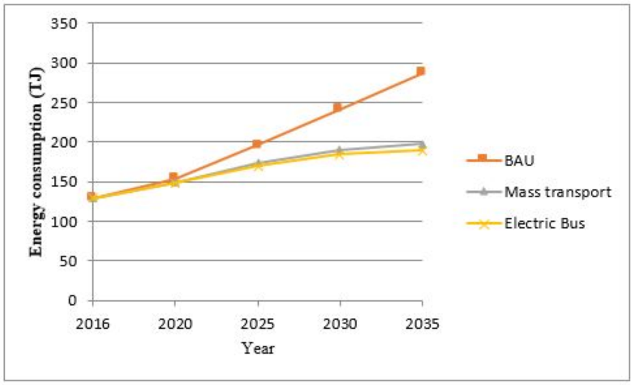

Figure 8: Comparison of energy demand in different scenarios

3. Conclusions

This research is very important in the context of Kathmandu valley due to the severe crisis of energy supply and increasing number of private vehicles resulting traffic congestion. This study has presented the growth trend in the evolution of vehicles, their survival life, energy demand and emissions in the Ring road of Kathmandu valley from year 2016-2035. The survival profile and life cycle profile of the vehicles has been calculated. Big bus and electric bus has been penetrated as an option to reduce the energy demand and emissions. The energy demand in BAU scenario increases by 2.24 times in the end year as compared to base year. There is 30 percent energy reduction in large bus penetration scenario and 34 percent energy saving using electric bus scenario.

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