Implication of Sustainable Low Carbon Transportation Development Strategy in Emerging City: A case of Kathmandu Valley

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Abstract: This study consists of developing the future energy demand and emission scenarios for the road transport subsector of Kathmandu valley for 2012-2050 by using Long range Energy Alternative Planning (LEAP) modelling framework. It mainly consists of analyzing three policy intervention strategies namely, electric vehicle penetration, electric mass transportation (Trolley Bus) and combine scenario (electric vehicle and electric mass transportation).

The passenger travel demand of 18.8 billion passenger-km in 2012 is expected to reach over 240 billion passenger-km by 2050. Similarly, the freight transport demand is expected to increase from 3.2 billion ton-km in 2012 to 22 billion ton-km by 2050. To fulfil this transport end use demands, the total final energy consumption (TFES) has to be increased from 12 PJ to 120 PJ (an average growth rate of 5.54%) mostly consisting of imported fossil fuel during 2012-2050 under business as usual scenario. During that period the emission of GHGs is expected to rise from 1,903 MT in 2012 to 12,232 MT by 2050 (5.4% growth rate). Under electric vehicle scenario the cumulative TFES decreases by .97% and cumulative GHGs emission decreases by 1.19% during 2012-2050. Similarly under electric mass transportation scenario TFES decreases by 1.27% and cumulative GHGs emission decreases by 1.61% during 2012-2050. In addition, under the combine scenario, TFES and GHGs emission decreases by 1.68% and 2.26% respectively.

Keywords: Sustainable transport, Low carbon strategy, Kathmandu, energy security, GHGs mitigation, LEAP

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1. Introduction

Kathmandu, the capital city of Nepal, is one of the fastest growing cities in the South Asia. With an estimated population of 2.5 million and urban growth rate of 6.6% it is facing a rapid growth in urbanization over the last decade (Shrestha, Ahmed, Suphachalasai, & Lasco, 2012). Transport sector consume around 22% of the total energy consumption in Kathmandu valley and contribute the 44% PM10 emission in Kathmandu (Shrestha & Rajbhandari, 2010) the number of vehicle in Kathmandu is increasing rapidly as the urban population of Nepal is mostly concentrated in the valley.

The Kathmandu Valley is the largest urban area of Nepal, where the capital city of the country is located. With rapid population growth and increasing economic activities, the demand for energy (especially fossil fuels) has been growing faster in the Valley than in the rest of the country. The vehicle activity of year 2003 will triple at the end of the year 2025, if no intervention is made and in which ninety six percent share of fuel consumption is gasoline and diesel (Pradhana, Ale, & Amatya, 2005).In the recent year's air pollution has been emerging as a major environmental concern in the Kathmandu Valley. As reported by the permanent air quality monitoring stations in the Valley, the concentrations of the particulate matters in the Valley are found to exceed the National Ambient Air Quality Standards (NAAQS). Even though the concentrations of SO2, NOX, CO and HC in the Valley are presently well below the NAAQS values, they are found to have been increasing over the recent years (Gautam, 2006).

The rapidly increasing vehicular traffic in the valley is a major contributor to air pollution in Kathmandu valley. It is mainly because of the large number of vehicles on congested streets, poor quality fuel and weakness in the emission controlling system. Department of Transport Management (DoTM, 2012) estimated that around 688097 vehicles were registered in Bagamati Zone. Most vehicles in Kathmandu have old engines, (more than 15 years old); are not well maintained.

It is essential to develop a system now so that the public is encouraged to use public transport. From user's perspective, four factors are vital in determining public satisfaction from transport services: Time, cost, dependability or predictability, and comfortable service. In order to address public demand of reliable public transport, The key urban transport requirements for planners perspective in Kathmandu valley are management of travel demand by modes of transport along with fair allocation of road space, in favor of pedestrians and public transport; an upgraded public transport network and facilities with improved operations and enhance traffic management. However it is essential to follow low carbon development path while fulfilling and managing the transport demand. So, the promotion of low-carbon vehicles needs to be under priority for sustainable transport development (Udas, 2012).

Low carbon city is the concept of strategically and effective reduction carbon emissions without compromising the need of urban economic growth. Every sector in city has the role to reduce emission especially in transport sector and industry sector. Transport sector in Nepal is one sector that release more greenhouse gas (GHGs) and local pollutant emission (CO_2, CO, SOx, N_2O, dust, etc.)

In the last century, the level of carbon dioxide in the atmosphere has increased by more than 30% as a result of human activities. The effects of climate change are becoming more pronounced and they include droughts, floods, heat waves and changes in the weather patterns. Global temperatures have increased by almost 0.8°C over the past 150 years. Without any global action, it is expected that temperatures will increase further by 1.8-4°C by 2100 (Beuthe, Gasca, Greene, Lee, & Muromachi, 2007). It is anticipated that this rise will result in sea level increment of 15 to 95 centimeters. While the transportation sector is crucial to a nation's economy and personal mobility, it is also a significant source of GHGs. According to the Kent and colleague of China, the contribution of the transport sector to total CO_2 emissions in developed nations is forecast to increase from 20% in 1997 to 30% in 2020. The world transportation oil demand has continuously risen with increasing GDP. World forecasts show that transport oil demand in developing nations will increase three times more than in developed nations. Increasing income will cause a tremendous increase in car ownership in developing countries, where the vehicle stock is expected to triple (IEA, 2006). Developing countries account for about 10% of the global automobile population and a little over 20% of the global transport energy consumption. In comparison, the United States alone consumes about 35% of the World's transport energy (Shrestha S. , 2006).

2. Overview of Energy and Transport Policy in Nepal and Kathmandu

Nepal has a population of about 26.6 million, of which 17% lived in the urban area (CBS, 2011). The urban population of the country is growing at a rate of 3.97%, which is over 3 times that of the national population growth rate during (CBS, 2011). This has caused a high growth in the stock of transport vehicles operating in the country. Because of rapid development of transport infrastructure, especially road transport, during the past three decades, nowadays, Nepal heavily relies on energy-inefficient transport modes. Passenger transport, both in urban area and inter-city, is mostly made by private passenger vehicles. The urban passenger transport share by private vehicles, including private cars, pick-up trucks and motorcycles, around 90%, while less than 10% are made by public transport (DoTM, 2012).The average annual growth rate of passenger transport vehicles in the country is found to be above 13.7 % during 1990–2012, while that of freight transport vehicles is found to be 7.3% (DoTM, 2012).

Kathmandu, the capital of Nepal has a population of 2.6 million and over 60% vehicle resides in valley. Thus it is major demand side of fossil fuel and major source of GHGs emission. A low carbon city has the same concept with the concept of sustainable development. Through the adoption of sustainability as the driving planning objective, and the integration of ecological and resources management principles into the urban planning decision making process, carbon emissions can strategically and effectively reduced without compromising the need of urban economic growth (Jaroenkhasemmeesuk, 2010). Thus it is necessary to address the issue of climate in very high fossil energy demanding sector for sustainable development.

The Government of Nepal (GoN) has issued the National Transport Policy 2001/02, which emphasized the promotion of electricity based transport system throughout the country with private sector participation (Shakya, 2011). Three year interim plan (2011-2014) gave an emphasis on is to develop the transport system so as to make it less expensive, safe, non-polluting, and equipped with facilities, competitive and self-dependent and to make the transport sector efficient, transparent, service-oriented and effective. The policies of 3 year plan have special priority on public transport along with focus institutional strengthening and coordination among different agencies ((NPC), 2012).

Similarly, the country's Hydropower Development Plan of 1992 emphasized the use of electricity in the transport sector to reduce fossil fuel consumption and diversify the use of electricity. Furthermore, the GoN has adopted the 25-year National Water Resources Strategy 2002, one of the objectives was to increase the total demand for electricity through diversification of electricity usage and to promote indigenous hydropower development (S.R Shakya, 2011). Recently, the GoN has also developed a plan to develop hydropower plants of capacity over 10,000MW by 2030 that would be dedicated to both domestic and export markets. But, there was lots of gap in systematic analysis of policy and target set by GoN in transport and hydro sector with proper interrelation to address the issue of sustainability by fulfilling the energy demand in transport sector by hydroelectricity.

3. Methodology

Quantitative approach is pursued for the collection and analysis of data collected from field visit, regarding the vehicle mileage and passenger kilometer and energy consumption in transportation sector.

Basic methodology of the study as follows:

3.1 Data collection

In this study primary and secondary data from various sources are required for modelling, calibrating and validating the model. Primary and secondary data had been collected in this section. Primary data is obtained from survey of vehicle running in Kathmandu valley which includes vehicle type, mileage, occupancy rate, no of trip, type of fuel, capacity of transporting load and age of vehicle etc. Secondary data is obtained from different source like (DoTM, 2012) and other various relevant literature related to the study.

Data on oil consumption was taken from Nepal Oil Corporation and electricity data was taken from report of NEA and according to this report total installation of hydro power in Nepal is 648MW (NEA, 2012).The Corporation provided the sales of petroleum products from various depot in the country. Similarly, population of valley was taken from national census report of Central Bureau of Statistics (CBS). The population of Kathmandu was assumed to be sum of Bhaktapur, Lalitpur and Kathmandu districts. The share of Kathmandu valley's GDP on national GDP was obtained from Nepal Rastra Bank's recent survey. Older values for GDP were obtained from various literatures.

3.2 Major parameter calculation

3.2.1 Travel Demand

In our study we have considered only road transport. In LEAP model total travel demand was stated in terms of passenger-km in case of passenger transport and tonne-km for freight. So the total travel demand is calculated as,

Travel demand (Passenger-km) $=\sum V_i$ (t) $\times VKT_i$ (t) ×vehicle occupancy rate (in no. of people) ……… (1)

Travel demand freight (Tonne-km) $=\sum V_i$ (t) $\times VKT_i$ (t) ×vehicle weight rate (in tonne) ……… (2)

Where Vi (t) is the number of vehicles of type i in street and VKTi (t) is the average annual vehicle-km travelled by vehicle of type I in year t. Vehicles registered after FY 2055/56 are considered to be currently operating. The travel demand for base and earlier year had been calculated and then develops a regression model for future demand calculation as a function of GDP and urban population. Passenger travel demand and freight travel demand is forecasted based on the regression model shown below. For developing regression model past travel demand is used as a dependent variables with economic factor such as GDP and demographic parameter such as population is used as an independent variables. Different combination of regression model is used such as log linear, semi log linear and linear model with both population and GDP used and only used single parameter then among the different model having high value of R^2 and t_{stat} and with best fitted model is selected for future travel demand forecasting.

Travel demand pass (Billion Pass-km) = -49.25+ 15.1* POP (in million) t_{stat}= 17.87……… (3)

Demand freight (Billion Tonne-km) = -0.91+0.38* GDP (In billion U.S. Dollar t_{stat}= 11.78……… (4)

The population and GDP is forecasted for future with the rate provided by Central Bureau Statistics and NRB respectively. Then the equation mention above gives the value for future travel demand.

3.2.2 Energy Intensity

The energy intensity is given in terms of Gigajoule (GJ) of fuel consumed per unit activity level. In this case, it is given as GJ per passenger-km.

3.2.3 Energy demand

The energy demand will be calculated based on the result of the regression model. The energy demand will be entered as the function of GDP per capita and urban population. The energy demand will be forecasted for high, medium and low growth rate.

Major parameters are as follows:

Table 1: Major Parameter of Passenger and freight

Passenger Vehicle Type									
Vehicle type		Number[1] (a)	Annular km [2](b)	Occupancy [2](c)	o.f[3](d)	Pass-km (a*b*c*d) mill.	Fuel economy[2](km/l ; km/kWh[4]	Final energy intensity (GJ/Pass-km)	Final demand(TJ)
Car/jeep/van	Gasoline	31931	10890	2.6	0.8	723	9.6	1.328	960.7
	HSD	4131	10890	2.6	0.8	94	8.6	1.686	157.8
Taxi	Gasoline	7564	37125	2.6	0.97	708	10.6	1.203	851.9
Bus	HSD	12743	53746	38	0.31	8068	4.89	0.203	1636.8
Minibus	HSD	5849	42240	26	0.68	4368	3.685	0.393	1718.7
Microbus	HSD	899	53460	18	0.97	839	8.5	0.246	206.7
	LPG	735	53460	12	0.88	415	9.31	0.229	94.6
Tempoo	ELEC.	460	43890	10	0.91	202	3.34	0.108	35.1
	LPG	460	43890	10	0.72	202	14.7	0.174	21.8
2-wheeler	Gasoline	396489	6501	1.68	0.7	3031	46.68	0.423	1281.4
Freight Vehicle type									
Truck/tank	HSD	12233	35617	6 T	1	2.61	3.33	1.89	4932.3
Pick-up	HSD	3723	14650	3.875 T	1	0.55	5.59	1.74	954.6
Tractor	HSD	72	38020	2 T	1	0.0021		2.68	5.7

Source:
[1] Department of Transportation management (DoTM, 2012)
[2] Author's calculation from survey data
[3] Dhakal, 2006; Dhakal, 2003 (Dhakal, 2003);Shabbir and Ahmad 2010
[4] Consume 2 sets of batteries with full charging capacity of 184 ampere hours

3.2.4 Emission

The emission from vehicles is the energy demand of each type of vehicle and its efficiency factors. The estimation procedure for emission factor in LEAP is,

$$E_j (t) = \sum V_i (t) \times VTK_i (t) \times EF_{ij} (t) \times F_i (t) \quad \text{………(5)}$$

Where Ej (t) is the total emission by type j in year t, EF_{ij} (t) is the emission factor of pollutant j by vehicle i in year t and F_i (t) is the fuel economy of vehicle i in km/l.

3.3 Scenario Construction

Forecasting the future is a challenging task. One method widely used to foresee the future consists of setting a baseline, usually a business-as-usual scenario, and then evaluating alternative strategies by comparing them to that baseline. This study also followed this strategy in which four scenarios were considered to study the impact of different urban transport policy initiatives that would reduce total energy requirement in the transport sector of Kathmandu and also reduce emissions. These scenarios are defined below:

3.3.1 Scenario 1: Business-as-usual (BAU)

In this scenario, 2012 was selected as the base year and this scenario was selected as base scenario. This scenario was based on a continuation of recent trends. By extrapolating these trends, values were projected to 2050 without any change.

3.3.2 Scenario 2: Electric mass transport (Trolley bus) transport

It is important to promote electric mass transportation as it can reduce emissions, congestion, and energy use. If this measure is complemented with policies to restrain private transport means such as cars and motorcycles, a significant modal shift from private to public transport, especially buses as they have high occupancy rate, is possible and desirable. Thus in scenario 2, it was assumed that if change was brought at minimum rate in Kathmandu, there would be a significant effect. It was assumed that the growth rate of private vehicles would be decreased by 0.8 % and that of public transport especially buses would be increased by1 %.

Table 2: Share of travel demand

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Two wheeler	16.3	15.9	15.4	14.9	14.4	13.9	13.4	12.8	12.3
Three wheeler	2.17	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Micro bus	6.72	6.3	5.7	5.1	4.5	3.9	3.2	2.6	2
Minibus	23.4	21.6	18.5	15.4	12.3	9.2	6.2	3.1	0
Bus	43.3	46.2	51	55.8	60.7	65.5	70.3	75.2	80
Taxi	3.8	3.6	3.3	3	2.7	2.4	2.1	1.8	1.5
Car/Jeep/Van	4.38	4.2	3.9	3.6	3.3	2.9	2.6	2.3	2

3.3.3 Scenario 3: Electric vehicle (EV)

The growth in the growth of hydropower sector is impressive and Nepal has become the leading country in hydro resources. The hydroelectricity can be used in both small and large vehicle with introduction of new technology famous in world. The EV scenario considered the substitution for gasoline and diesel engine in urban taxi, cars, jeeps and station wagons in the Kathmandu valley. This substitution rate of EV for above mentioned vehicles was assumed to be 2% per annum.

3.3.4 Scenario 4: Combined scenario

The scenario consists of implementing both strategy as describe earlier at the same time and its effect comparison with individual strategy.

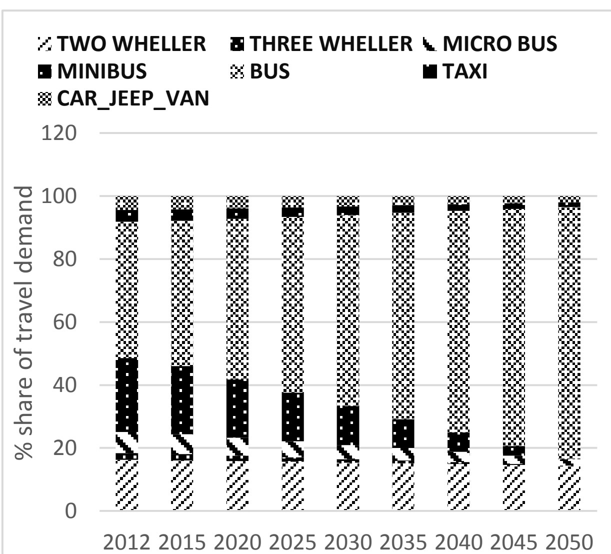

Figure 1: Transport demand share in combined share

3.4 Structure for LEAP modeling

LEAP was originally created in 1980 for the Beijer Institute's Kenya Fuel wood Project, to provide a flexible tool for long-range integrated energy planning. LEAP provided a platform for structuring data, creating energy balances, projecting demand and supply scenarios, and evaluating alternative policies, the same basic goals as the current version of LEAP (SEI, 2011). LEAP is usually used to analyses national energy-systems. It functions using an annual time-step, and the time horizon can extend for an unlimited number of years (typically between 20 and 50). Top-Down and Bottom-up methods are the two basic approaches for analysis. "Top-down" approach analyses in a wider scope to incorporate the bigger picture. Some major characteristics of this approach are the macroeconomic approach, looking at the aggregate and also factors that may not be immediately measured (Wilson, 1993). A bottom up energy system model (based on Long Range Energy Alternative (LEAP) model framework has been developed for the purpose of the study. The overall energy demand has been divided into passenger and freight demand. Passenger transportation is further sub divided into different vehicle technology like car, bus, tempo, two wheelers etc. Truck, tractor and pickup are the vehicle technologies used here for the analysis of freight transport.

4. Result and discussion

4.1 Base case

4.1.1 Travel demand

The travel demand for the base year is around 18.8 billion passenger-km and 3.2 billion tonne-km respectively. Figure below shows the share of travel demand of different vehicles in Kathmandu.

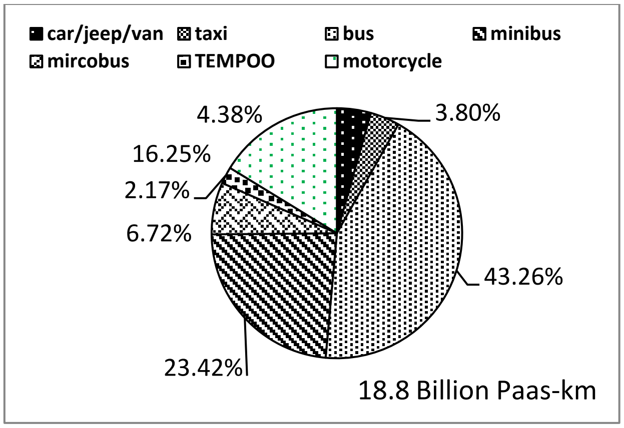

Figure 2: Passenger travel demand in base year

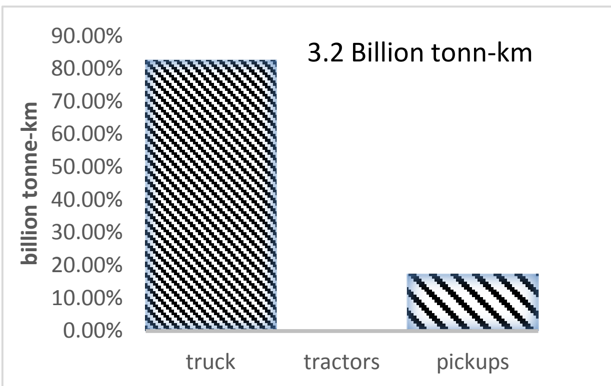

Figure 3: Freight travel demand in base year

4.1.2 Future travel demand

The travel demand of Kathmandu is forecasted based on the regression model with the help of past data and forecasted parameter such as population and GDP. The passenger travel demand of Kathmandu is expected to reach over 240 billion pass-km by 2050 whereas freight demand is expected to reach over 21 tonne-km.

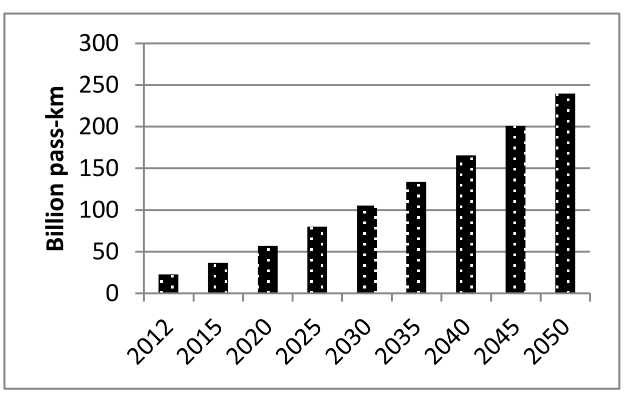

Figure 4: Passenger travel demand based on model

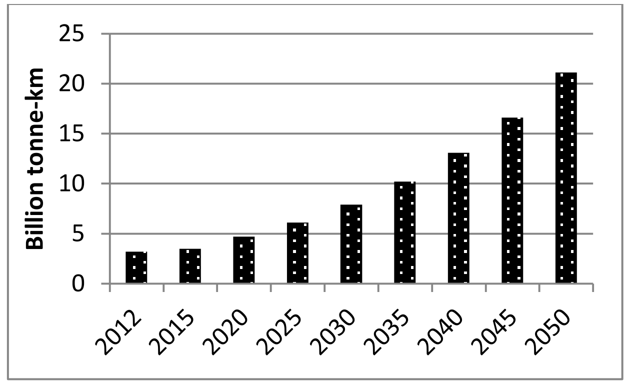

Figure 5: Freight travel demand based on model

4.1.3 Energy demand and emission in BAU

The energy demand under business as usual scenario is shown in figure 6 below and shows the increasing trend of energy demand in future and expected to reach over 128PJ by 2050.

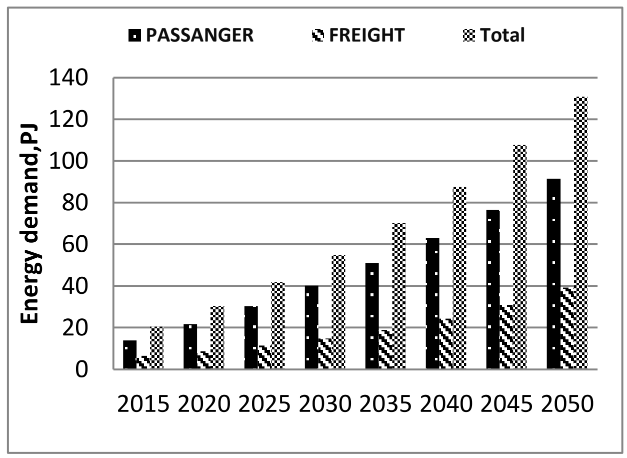

Figure 6: Energy demand in BAU

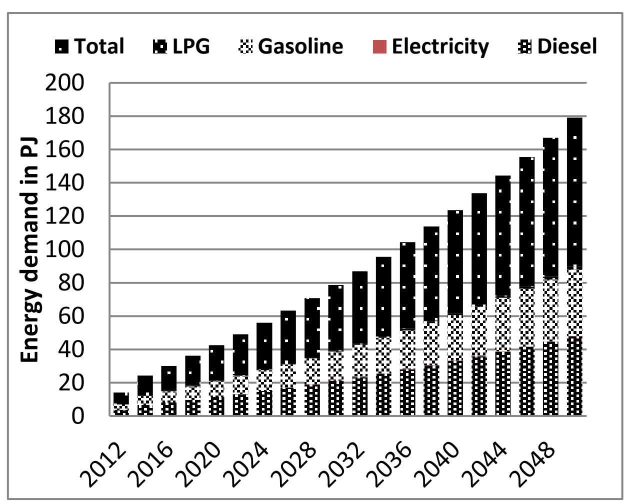

Figure 7: Energy demand by fuel type in BAU

The figure 7 indicate the energy demand by fuel type under business as usual scenario and indicate the very high demand of diesel and gasoline which is imported fossil fuel also major source of carbon emission. Thus this scenario raises the concern of energy security in Nepal and climate related problem. Hydro electricity and its implication in transport sector is only sustainable a proper solution for our country.

4.2 Energy demand analysis based on scenario

The energy demand of transport sector under different scenario is shown in figure 8 which shows that energy demand under business as usual scenario is expected to reach over 128.57 PJ by 2050 which is only 12.96PJ for base year. The value of energy demand under different scenario and their change with BAU scenario is shown in table 3 below.

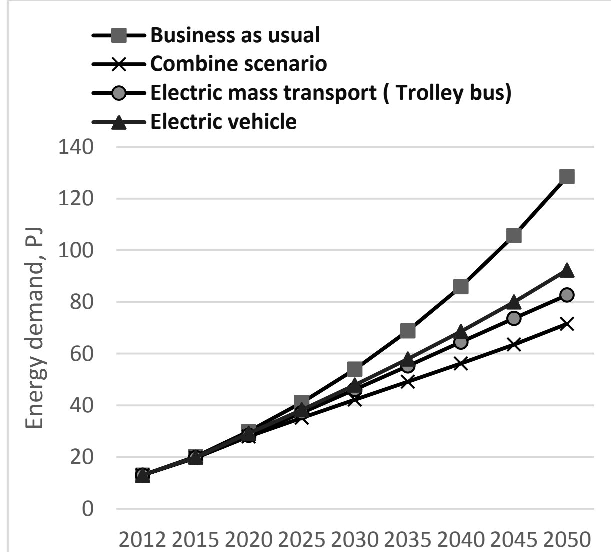

Figure 8: Energy Demand under different scenario

Table 3: Energy demand and % change in different scenario

Year	2012	2015	2020	2025	2030	2035	2040	2045	2050
Business as usual	12.96	20.14	29.91	41.12	54.01	68.84	85.94	105.7	128.57
Electric vehicle	12.96	19.98	29.22	38.31	47.86	57.93	68.61	80.03	92.35
% change	0.000%	0.794%	2.307%	6.834%	11.387%	15.848%	20.165%	24.286%	28.171%
Electric mass transport (Trolley bus)	12.96	19.79	28.42	37.16	46.14	55.27	64.47	73.65	82.72
% change	0.000%	1.738%	4.982%	9.630%	14.571%	19.712%	24.983%	30.322%	35.662%
Combine scenario	12.96	19.68	27.99	35.22	42.24	49.18	56.21	63.56	71.58
% change	0.000%	2.284%	6.419%	14.348%	21.792%	28.559%	34.594%	39.868%	44.326%

4.2.1 Fuel consumption scenario

Demand of different fuel under different scenario is analyzed in this section. The demand of fossil fuel under business as usual scenario is very high and that is reduced in case of other policy scenario in which the penetration of electricity increases accordingly.

Figure 9 indicate the rapid demand of diesel in BAU scenario that is around 90PJ by 2050 but in case of other scenario will be just about 60PJ in EV, 52PJ in EM and 58PJ in combine scenario.

Figure 10 is the result of gasoline demand under different scenario in Kathmandu valley. In this figure the demand under BAU is around 40PJ by 2050 and that for other scenario like electric vehicle (EV) is 25.17PJ, Electric mass transportation is 22.46 PJ and for combine scenario it is just around 8.19PJ.

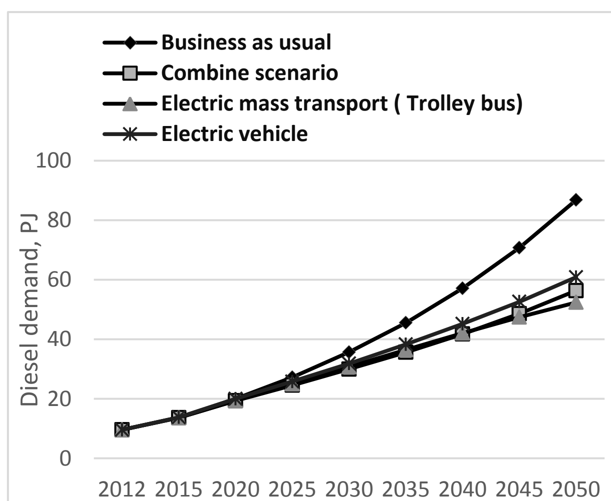

Figure 9: Diesel demand in scenario

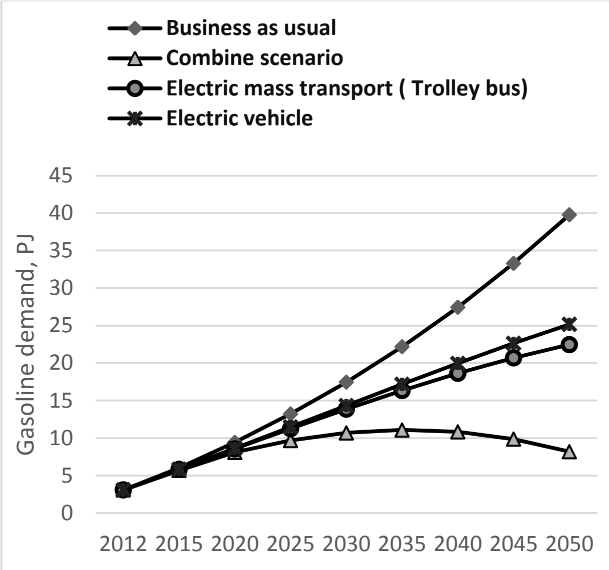

Figure 10: Gasoline consumption scenario

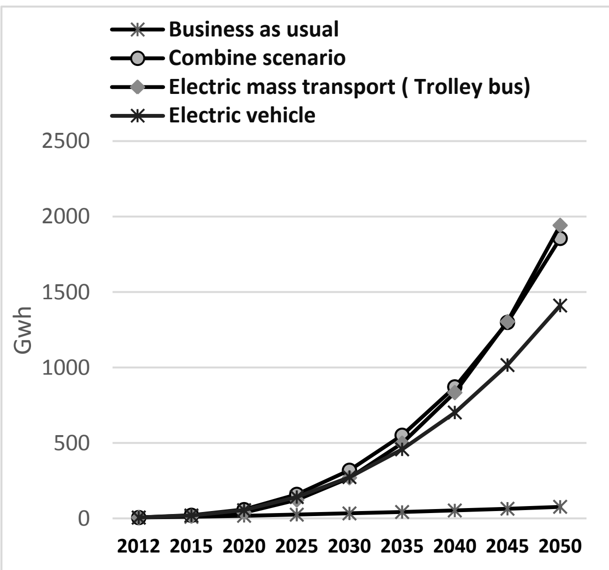

Figure 11: Electricity demand

The figure 11 indicates the demand of electricity as the penetration of electric vehicle increases in Kathmandu valley. The demand of electricity in Kathmandu for the base in transport sector is just around 6.7 GWh while that is around 78GWh by 2050 in BAU but in the case of electric vehicle scenario it is 1410 GWh, for electric mass transportation scenario it is 1856 GWh and for combine scenario it is about 1942 GWh.

4.3 Emission Analysis for all scenarios

The emission of GHGs and their share for all the scenarios is analyzed in this section.

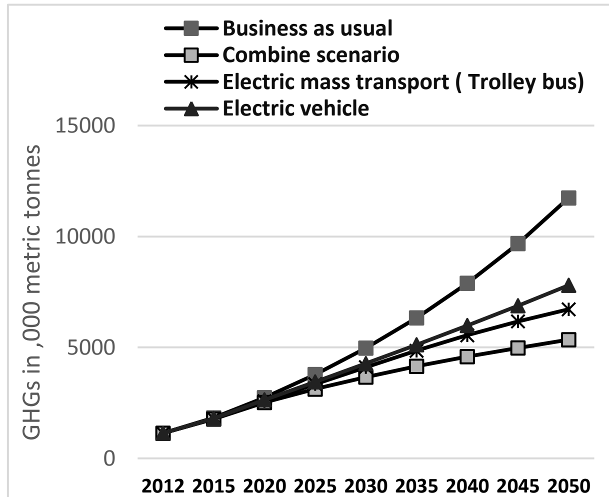

Figure 12: Emission scenario

The emission of GHGs increases as the consumption of fossil fuel increase. Figure 12 illustrates the emission of GHGs in different scenario. The emission for BAU scenario is very high and increased by ten folds than base year by 2050(Emission for 2012 is 1132 thousand metric tonne and that for 2050 is 117700 thousand metric tonne). The value of energy demand under different scenario and their change with BAU scenario is shown in table 4.

Table 4: Value of GHGs and % change under different scenario

	2012	2015	2020	2025	2030	2035	2040	2045	2050
Business as usual	1133.52	20.14	29.91	41.12	54.01	68.84	85.94	105.7	128.57
Electric vehicle	1133.52	1799.01	2634.72	3439.56	4263.44	5106.76	5971.8	6860.25	7780.15
% change	0.00%	1.27%	3.52%	8.74%	13.97%	19.11%	24.11%	28.92%	33.5%
Electric mass transport (Trolley bus)	1133.52	1784.8	2570.19	3339.4	4099.76	4835.11	5527.01	6154.74	6695.33
% change	0.00%	2.09%	5.88%	11.4%	17.27%	23.41%	29.75%	36.23%	42.78%
Combine scenario	1133.52	1769.07	2512.19	3114.6	3656.82	4141.55	4575.27	4969.04	5339.82
% change	0.00%	2.91%	8.01%	17.36%	26.21%	34.4%	41.85%	48.51%	54.36%

5. Conclusion

This study has examined various effects of the transport sector electrification in Nepal using the hydropower resource of the country under three different scenarios during 2013–2050 using a Long Range Energy Alternative Planning (LEAP) modelling framework. The BAU scenario, in which present trends were assumed to continue, has shown a dramatic increase in energy demand and the resultant emissions. The alternative scenarios have shown how the increase in energy consumption and pollutant levels can be limited through measures such as encouraging a shift to buses, reducing the population and substitution of electricity for diesel and gasoline vehicles. The study strengthens the advantages of implementation of hydroelectricity in transport sector to reduce the fossil fuel dependency and GHGs emissions, which addresses the issue of energy security. The studied scenarios demonstrated that plausible alternative pathways do exist. They did not predict what the future would be or even what it should be like or whatever would be the hurdles. Rather they opened the doorway to possibilities. The method, tool, and examples presented were a starting framework for beginning an opportunity for creative engagement with the future.

The study shows cumulative imported energy during 2012–2050 is estimated to decline in the transport electrification scenarios by 26% in electric vehicle scenario (EV) (i.e., for meeting 40% of the road transport service demand through electrified transport modes) to 34.9% in electric mass transportation (trolley bus) scenario as compared to the base case. On the other hand energy demand is decrease to 43% by 2050 as the both scenario is used in combine. The study also examined the emission of transport sector in which GHGs emission would increase more than twelve fold during 2012-2050. As a climate related benefit, there would be a reduction of about 46 thousand metric tonne CO_2e (21.9%) of GHG emissions in cumulative terms during 2013–2050 under electric vehicle scenario and that for electric mass transportation scenario is about 60 thousand metric tonnes (27.3%) and for combine scenario it is about 80 thousand metric tonnes(37%).

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