Assessment of low carbon transport for sustainable development in Bhutan: a general equilibrium approach

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Abstract: Bhutan is dedicated to make its economy carbon neutral and to follow the exemplary path of low carbon development in the coming days. In the process of doing so, Bhutan identified that its transport sector is one of the most important sectors to address. Low carbon technology in transport sector is crucial for Bhutan to combat climate change related impacts. In this paper we have identified four different low carbon interventions possible for Bhutan and analysed their impacts on national economy, social welfare, income status and environment as a whole. The study demonstrates that low carbon transport intervention especially electric cars have highest positive macroeconomic impacts in Bhutan but at the cost of increasing urban rural income disparity. This further draws the attention of policy makers to take preventive measures in the case of introducing the policy for electric cars. In this study we also showed that modal shift (private to public transport) also has positive impacts on economy and environment in Bhutan.

Keywords: electric vehicle; low carbon transport; CGE model; Bhutan.

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1 Introduction

According to a Asian Development Bank study in 2009 (Leather et al., 2009) transport is currently responsible for 13% of all world greenhouse gas (GHG) emissions, and 23% of global carbon dioxide (CO_2) emissions from fuel combustion are transport related. Transport-related CO_2 emissions are expected to increase 57% worldwide in the period of 2005–2030. Solaymani et al. (2015) further argued on reasons of CO_2 emissions increase from transport sector following the decomposition analysis done by Timilsina and Shrestha (2009) with several indicators of transport sector CO_2 emissions in developing Asia, that it depends on three major factors like per capita gross domestic product, transport energy intensity and population growth. The majority of these increased emissions will come from private vehicles, both for passenger and freight transport. Almselati et al. (2011) argued with his analytical findings that CO_2 emissions from transport sector can be significantly reduced by popularising public transport. However, he also cautioned that the success of public transport system depends on quality of services that it provides (UNCSD and SLoCaT, 2012), Rio de Janeiro. Due to lack of long term planning and policy in transport sector and its related emissions reduction, there is a potential threat of transport-related CO_2 emissions lock-in the market for next couple of decades due to irreversible investment in the sector A recent incidence in Delhi city of India regarding banning of diesel based commercial cars running within city opened up a new dimension of low carbon transport planning in developing countries. Due to heavy investment in diesel car segment both by the end users, businesses and by the banks, immediate banning caused huge financial losses to the industry and the government had to come up with an alternative plan of planned phase-out of diesel cars from the market.

It also envisaged that (Leather, 2009) to develop a low carbon sustainable transport system for a developing country should limit GHG emissions from transport and minimise other negative externalities without compromising economic growth and social inclusion. This further deals with the second issue of low carbon transportation of energy intensity. In this context, Michaelis and Davidson (1996) argued that energy use per passenger kilometre or energy use per ton-km of freight movement should be evaluated carefully while developing the low carbon transport policy. For developing countries it is important to have uninterrupted economic growth and transport sector plays a major role in that. Therefore, reduction in emissions from the sector without compromising economic growth can perhaps only be possible by achieving energy efficiency in (less energy unit consumed for same amount of passenger-km or ton-km) transport sector and by fuel switching (high carbon content fuel to low carbon content fuel). Electric vehicle thus can play an important role in creating low carbon transport sector in a country which is capable of delivering required amount of utility to the economy in one hand and can displace fossil fuel use and subsequently reduce GHG emissions.

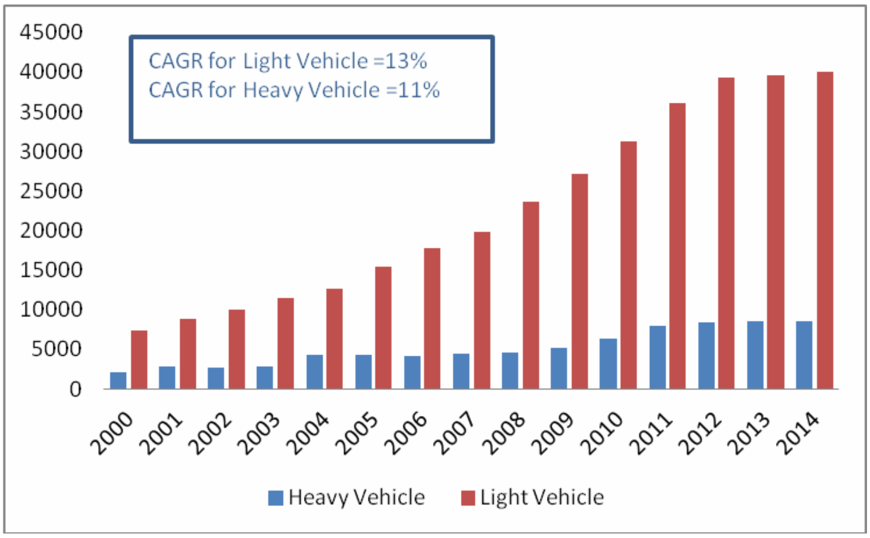
2 Transport sector and GHG emissions in Bhutan

Transport sector plays an important role in Bhutan economy. With 30 GW of potential (MoEFCC, 2012), development of hydro power projects across the country is a major economic activity of the country for next couple of decades. So far export of electricity comprises 80% of the total trade revenue of the country. Hydro power project being considered as major infrastructural project, needs significant amount of heavy vehicular movement. Figure 1 shows that heavy vehicle registration in the country grew at the rate of 11% per annum over last one decade which was happened mainly due to hydro power plant construction work and related activities.

Light vehicle population in Bhutan increased at the rate of 13% per annum between 2004 and 2014 which is a concern for the small country like Bhutan. However, due to increase in export duty since 2012, the growth of light vehicle (mostly the private four wheelers) became relatively stabilised. It has been estimated that between 2000 and 2012 Bhutan economy grew (growth in real GDP at 2000 prices) at an average rate of 8.3% per year (Statistical Yearbook, 2013) fuelled by the growth in energy, construction, industries and services sectors. Energy sector in the country includes transport sector as well. Total greenhouse gas (GHG) emissions in 2000 were 1,559.56 Gg CO_2-equivalent. Out of this 270 Gg CO_2 equivalent were from energy, 237 Gg CO_2 equivalent were from industrial processes, 1,005 Gg CO_2 equivalent were from agriculture/livestock, and 46 Gg CO_2

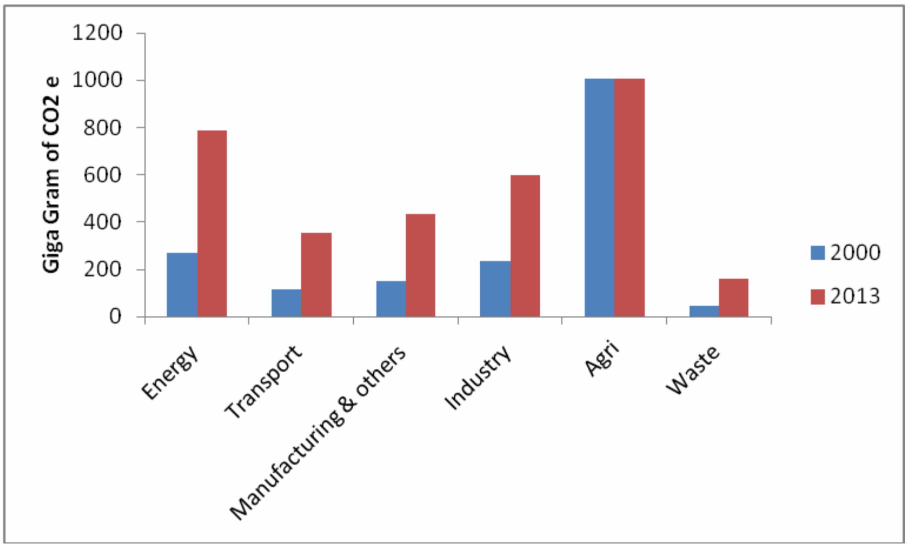
equivalent were from waste. Out of 270 Gg of emissions from energy sector 118 Gg is coming from transport sector only. More than 45% of the energy sector's emissions are attributed to transport related emissions. In the year 2000, transport sector contributed 6% of total GHG emissions in Bhutan which was increased to around 11% by the year 2013. Figure 2 shows the trend in GHG emissions from different sectors in the country.

Figure 1 Trend in vehicular population growth in Bhutan (see online version for colours)



Source: Authors estimated using data from Statistical Year Book 2013

Figure 2 Sectoral GHG emissions trend between 2000 and 2013 in Bhutan (see online version for colours)



Source: Author estimated using information from Bhutan's Second National Communication to UNFCCC (2012)

Future growth in the transport sector in Bhutan is further envisaged to be driven by high economic growth leading to higher vehicle ownership, industrial development, tourism, higher rural connectivity and higher regional connectivity. Among these drivers the rapid increase in vehicle ownership driven by the wealth created by the export of electricity (hydropower) is the most important. The total number of vehicles could be approaching ten times the current level by 2040 and vehicle ownership, especially of private cars, is expected to increase to the levels same as developed countries unless significant measures are taken to improve public transport (ADB, 2011)[1].

According to estimates the number of cars in Thimphu (the country's capital) will be doubled by 2020 and could be six times the present levels by 2040, implying significant deterioration of environmental conditions in the city. The transport sector consumed 38,100 tons of diesel and 17,700 tons of petrol in 2010, emitting 121,000 tons and 56,000 tons of $_{CO2}$ respectively. The imports of fuels lead to considerable outflow of foreign exchange for the economy as well. Transport sector thus has significant impact on Bhutanese economy and its growth and development.

Government of Bhutan has also pledged for emissions reduction from its burgeoning transport sector in the recently published INDCs. It is mentioned that Bhutan is committed to move toward low carbon transport system to keep their nation as net carbon sink. Among various action points improvement of mass transit and demand side management of personal modes of transport, exploring alternative mode of surface transport, promoting non-motorised and non-fossil fuel power transportation like electric vehicles are the important ones.

The paper is divided into seven sections. In the next section (Section 3) we discuss the objectives of this study. In Section 4 we present the model developed for this study. In Section 5 we discuss the different transport sector scenarios (interventions) that we have analysed in this paper. In Section 6 we present and discuss the results, and finally in Section 7 we provide the concluding remarks and recommendations.

3 Objectives of this study

Given Bhutan's rapidly increasing emissions from its transport sector and its increasing level of population growth, it is envisaged that Bhutan needs a long term sustainable transport policy to control its conventional transport sector growth in one hand and but maintain its economic development on the other hand. Bhutan's economic growth is heavily linked to its hydropower development sector and also to its industry sector which are both mobility dependent. It is also important for Bhutan to consider while developing national transport policy its topographic condition which is mostly hilly terrain and not easy for smooth transportation system. In 2015 INDC of Bhutan, it is envisaged that promotion of low carbon transport system in the country would follow up actions in the areas of

- improving mass transit and demand side management of personal modes of transport
- exploring alternative modes of transport to road transport such as rail, water and gravity ropeways
- improving efficiency in freight transport

- promoting non-motorised transport and non-fossil fuel powered transport such as electric and fuel cell vehicles
- improving efficiency and emissions from existing vehicles through standards and capacity building
- promoting use of appropriate intelligent transport systems.

While developing and shaping out the low carbon transport system in Bhutan it is also important to consider the facts that Bhutan does not produce vehicles and it fully depends on fuel imports from India. As a matter of fact, Bhutanese economy is pegged to Indian economy and its currency as well. This is a unique situation for Bhutan compared to other countries in the context of its trade relationship to the rest of the world. It is thus important to have a wider economic benefit estimates of new transport policy promotion in the country like Bhutan where expected benefits can cross over multiple economic sectors in the country (Legaspi et al., 2015).

So far, there is hardly any study available on Bhutan's transport sector which covers the issues related to bilateral trade policies between India and Bhutan, cross sectoral impacts of introducing efficient but expensive vehicles in the Bhutanese market and impacts on national economy due to introduction of low emission vehicles like electric cars. This study will therefore investigate the impacts of introduction of low carbon transport in Bhutan without compromising the desired level of economic growth and social welfare. Thus the objectives of this study are to:

- assess the sustainable development impacts of introducing electric vehicle in heavy, medium and light segments of transport
- assess the economic impacts on conventional energy sector in the country especially on Bhutan's burgeoning petroleum and electricity sector
- demonstrate the benefits of introducing low carbon technologies in the transport sector in terms of achieving INDCs.

4 Model structure

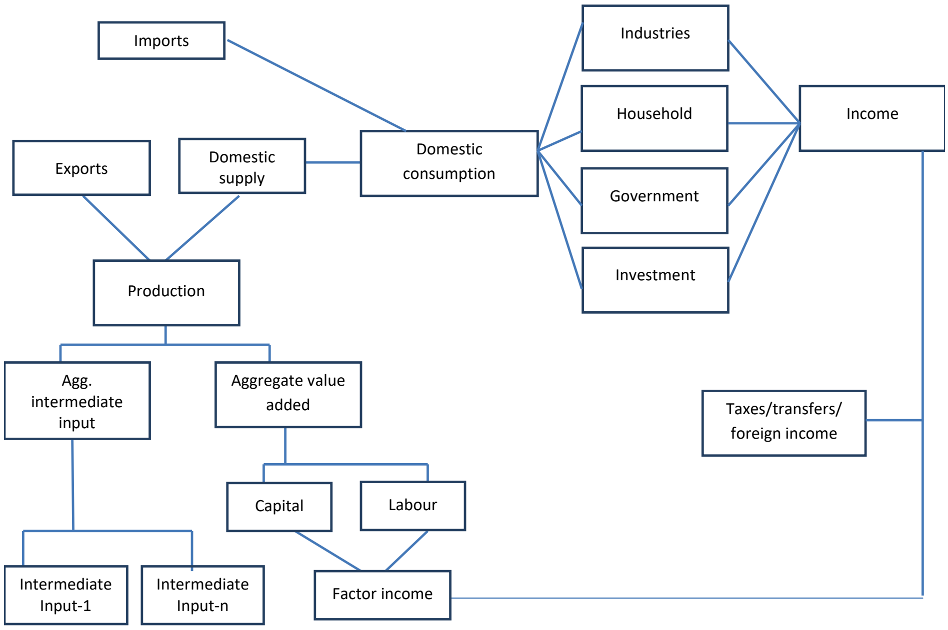
For the purpose of this study, we developed a single country recursive dynamic computable general equilibrium (CGE) model for Bhutan for conducting macroeconomic assessment [impact on gross domestic product (GDP), household income, equity etc.] of the low carbon transport policy intervention. It is envisaged that while achieving the INDCs, Bhutan should also be careful about its economic and social impacts as well. Bhutan also needs to be careful about the trade impact due to low carbon transportation intervention in the country. Bhutanese trade could potentially be affected due to increase in domestic power consumption which is otherwise could be exported, due to changes in indirect tax revenue for differentiated import duties for electric vehicles etc. In this study we opted for a single region recursive dynamic general equilibrium model to analyse the cross sectoral impacts of introducing a particular type of low carbon transport (electric vehicles) and the impacts of modal shift, too.

The model used in this study is based on the structure of general equilibrium economy developed by Lofgren et al. (2002). In the model economy producers are assumed to maximise profits and to operate in a perfectly competitive market condition[2]. Households maximise their utility based on their income and market prices. In this model the household demand for commodities is structured through the linear expenditure system (LES)[3]. Household income comprises of income derived from labour and capital and transfers from the government and the rest of the world. Households also save part of their income and pay taxes to the government.

Government expenditure is on the consumption of goods and services, transfers to households and subsidies. Government income is from taxes (direct and indirect) and from rest of the world in terms of export and import duties. Indirect taxes include production tax, and import and export tariffs. Government savings which is the difference between government expenditure and income is determined residually. Imperfect substitution between domestic and foreign goods is allowed in this model along with imperfect substitution among goods produced within the country as well. The price transmission between domestic and foreign goods is affected by the elasticity of substitution between domestic and foreign goods traded in the market and also the share of traded goods in total supply of those particular goods. The Armington function is used to capture the substitution possibilities between domestic and imported goods. The import demand function, derived from the Armington function, specifies the value of imports based on the ratio of domestic and import prices. The constant elasticity of transformation (CET) function is used to capture substitution possibilities between domestic and foreign sales. The export supply function, derived from the CET function, specifies the value of exports based on the ratio of domestic prices to export prices. The elasticity of substitution determines the relative ease of substitution between domestic and foreign goods in response to changes in relative prices (see Appendix 1 for model detail).

The model is Walrasian in character which means markets for all commodities clear through adjustment in prices, i.e. price is the only factor for market clearing. The consumer price index (CPI) is chosen as the numeraire[4] and is therefore fixed. The model assumes foreign savings to be fixed and the real exchange rate to be flexible. Government consumption expenditure is fixed within a period and government savings is residually determined. Both direct and indirect tax rates are fixed. The household savings rate is also fixed. The Bhutan CGE model is made dynamic in nature until 2035 by solving a series of static equilibriums connected by exogenous evolution of macroeconomic drivers. For each time step, the selected macroeconomic drivers were exogenously 'shocked' (for example, foreign savings which is a fixed variable in the CGE model is increased manually) to update the values of sectoral labour force, sectoral capital stock, sectoral total factor productivity (TFP), and foreign savings (investment) on each time step. Appendix 2 shows the parametric values used in this model. This step wise dynamic movement in the model is called recursive dynamism in the general equilibrium framework. Figure 3 shows the schematic of CGE model structure used in this study. All the linkages among boxes are representative of monitory values.

Figure 3 Schematics of CGE model structure (see online version for colours)



4.1 Data sources

The growth rates of GDP, exogenous drivers like labour force and foreign investment (savings) are adopted from the Government of Bhutan publications including National Accounts Statistics (2013) and Rapten (2014) for data on labour force. The growth rate of TFP was obtained by calibrating the projected GDP growth and other macroeconomic drivers using standard formula. For the conventional transport sectors, the growth rates were derived from time series analysis of nine years of vehicular population data (2004 to 2012) obtained from Statistical Year Books of Bhutan. The baseline GDP growth rate in the CGE model is 9.2% for the period of 2007 to 2035. It might be worth noting that the employed methodology does not use equation of motion of physical capital to update the stock of physical capital. The employed methodology assumes that the evolution of the economy during each time step is represented as the shift of steady-state equilibrium caused by exogenous shocks. This method is consistent with the steady-state equilibrium assumption underpinning static general equilibrium theory.

4.2 Developing social accounting matrix of Bhutan

The database of a CGE model is the social accounting matrix. A social accounting matrix is a systematic method of representing the flows of goods and services and factors and the corresponding payments in an economic system. Once a *balanced SAM*[4] is obtained we can calibrate the CGE model to that SAM for further analysis. The starting point for the construction of the SAM is the input-output (IO) table for Bhutan, developed by ADB (Bhutan Input-Output Tables 2007, ADB). The IO table for Bhutan consists of 15 sectors (industries), apart from the other accounts that include taxes/subsidies, value-added (wage and non-wage income), exports/imports, expenditure by households and government, and investment. The following modifications were done to the IO table for the construction of the balanced SAM:

- *Sectoral mapping*: In the process of developing the SAM, some sectors of the IO table were aggregated while some other sectors were disaggregated. Sectors that have relatively less importance for transport policy from the point of view of this study were aggregated, while sectors that are relatively more important (like the transport sector) have been disaggregated based on data from other sources. Appendix 3 shows the mapping between the sectors of the IO table and the SAM.
- *Disaggregation of the household account*: The household sector in the IO table was disaggregated into urban and rural categories based on data obtained from Bhutan Living Standards Survey 2012 on sources of income (wage/non-wage) and corresponding expenditure patterns of the two household groups. The reason for the disaggregation of the household account in the IO table was to capture the equity (income distribution) aspects of the proposed transport sector interventions on the two different household groups.
- *Construction of petroleum products sector*: Data on imports from Statistical Yearbook of Bhutan (2013) and consumption of petroleum products from Bhutan Energy Data Directory (2005) were used to create the petroleum products sector. Certain adjustments were done in the 'other manufacturing' sector of the IO table to account for the creation of the petroleum products sector. The petroleum products sector was created to track the effects of the interventions on the consumption (imports) of petroleum products, and corresponding CO_2 emissions. It is to be noted that Bhutan is completely dependent on the imports of petroleum products to meet its demand for these commodities.
- *Disaggregation of transport sector by vehicle types*: The transport sector in the IO table is disaggregated into four road transport categories (light transport, bikes, heavy transport and public transport) following the objectives of this paper. Light transport includes cars, taxis and other small four wheelers, bikes are for the two wheelers category, heavy transport includes trucks, public buses, earth movers, tillers etc, and public transport implies public buses. The row and column vectors for the transport sector in the IO table were disaggregated into four road transport categories each, as mentioned above, using data obtained from Road Safety and Transport Authority (RSTA) of Bhutan. Data on vehicle ownership by sector/household group, number of vehicles by type, average fuel costs for the different types of vehicles etc. were used to disaggregate the transport sector in the IO table into the four road transport categories.
- *Introduction of electric vehicles*: Four types of electric vehicles are introduced in the SAM as mitigation options for four different categories of conventional transport

modes. They are: electric light transport, electric bikes, electric heavy transport and electric public transport. The reason behind the introduction of the four different types of electric transport sectors in the SAM is that each type of conventional transport could potentially be replaced by the corresponding electric transport type over the period of time. For example, light transport could be replaced by electric light transport. Data from an earlier project (Capacity Building of the National Environment Commission in Climate Change, May 2011) were used to construct the electric transport sectors. It is assumed that electric transport modes are very small (around 50 vehicles[5] relative to the conventional transport sectors in the baseline scenario (no intervention).

4.3 Closure rules

The current model follows a savings driven closure, that is, aggregate savings is fixed while aggregate investments is flexible. The economy wide wage/rental rate is fixed, and a sectoral wage/rental distortion factor adjusts to clear the factor markets. Both capital and labour are assumed to be fixed for each sector in a given period. Sectoral capital and labour (along with total factor productivity and foreign savings) are changed exogenously over time to create the growth path of the economy. Foreign savings is assumed to be fixed, while the exchange rate is flexible. Finally, government consumption is fixed, and government savings in residually determined in the model.

4.4 Transport sector growth projection for Bhutan

Historical data on the number of vehicles (by type) were collected for the period 2005 to 2012 (Statistical Yearbooks of Bhutan), and these data were used to project the number of vehicles till 2035 using statistical techniques (time series forecasting). The @Risk software was used for this purpose. The model projects that the number of light vehicles (mainly cars and taxis) is likely to increase from about 20,000 in 2005 to more than 110,000 in 2035, an increase of more than 450%. The steep increase in the number of light vehicles is a reflection of current growth trends in the number of light vehicles in Bhutan. Similarly, the model projects that the number of heavy and medium vehicles is likely to increase from about 9,000 in 2005 to about 20,000 in 2035, an increase of 122%. Finally, the number of bikes is projected to increase from about 9,500 in 2005 to about 10,000 in 2035, an increase of about 5% over the entire time period. From the perspective of the construction of the baseline GHG emissions profile the projected increase in the number of vehicles will result in increase in GHG (CO_2) emissions over the time period assuming that parameters like fuel efficiency, vehicle usage etc. remains the same throughout. The growth projections of vehicles are used by the CGE model for the construction of emissions profiles of the different types of vehicles.

5 Scenario building

In this section we discuss the construction of the business as usual (BAU) scenario first (Section 5.1), followed by a discussion of the sustainable transport scenarios (Section 5.2).

5.1 Baseline (BAU) scenario

In this study we have identified the baseline as a scenario which is implementing all the existing Governmental policies in the economy as a whole and in the transport sector in specific. The baseline is the scenario that represents the absence of major mitigation actions in the transport sector in Bhutan but includes the existing implementation plan of various fiscal measures like tax break for electric vehicles, increasing import duties for conventional vehicles coming from India and other countries. A GHG emissions baseline assessment is required for the purpose of understanding how GHG emissions are likely to change over time due to economic growth, structural changes in the economy and also for the assessment of the impact of climate mitigation and adaptation plans, low-emission development strategies, NAMAs, and other mitigation initiatives on environmental, socioeconomic and other indicators. Baseline projections (till 2035) for variables like GDP, CO_2 emissions from the transport sector were obtained from the CGE model.

The model is calibrated to an annual 9% GDP growth trajectory over the entire model period (2007 to 2035). CO_2 emissions from the transport sector increases by about 7% annually (or five times over the entire time period). The highest growth in emissions is observed in the case of light vehicles (8%), followed by heavy vehicles (7%), public transport (6%) and bikes (3%). The number of light vehicles (mainly cars) in Bhutan is growing at a very rapid pace and the growth rate of CO_2 emissions for this mode of transport as projected by the model is a reflection of this trend.

5.1.1 Baseline projection of vehicular population in Bhutan

As per National Statistical Bureau of Bhutan, there are eight different types of vehicle category in the country on which data is recorded on a year to year basis. The categories are:

1 heavy
2 medium
3 light
4 two-wheelers
5 taxi
6 power tiller
7 tractors
8 earth movers.

Table 1 shows the recorded data of these different types of vehicles in terms of number of units registered in the Ministry of Road Transport database.

For the purpose of this study we have further aggregated the vehicle types into four main categories like: light vehicle (containing all public and private four wheelers including taxies), heavy vehicles (containing all medium and heavy trucks, power tillers, tractors and earth movers), two-wheelers (containing all sorts of motorised two-wheelers and bikes) and public transport (containing all sorts of public buses). After aggregating the values we obtain the following time series vehicular population data shown in Table 2.

Table 1 Vehicles by types and units in Bhutan between 2004–2012

Year	*Heavy*	*Medium*	*Light*	*Two-wheeler*	*Taxi*	*Power tiller*	*Tractors*	*Earth mover*
2004	2,964	919	13,359	6,583	1,785	658	0	472
2005	4,352	0	15,374	7,138	2,050	491	0	509
2006	4,184	363	17,712	7,931	2,056	446	0	549
2007	4,494	520	19,792	7,464	2,218	582	0	633
2008	4,627	649	23,929	7,737	2,481	610	149	725
2009	5,198	786	27,208	8,027	2,859	692	183	929
2010	6,634	1,013	31,694	8,958	3,600	794	216	1,277
2011	7,972	1,261	36,220	9,434	4,856	1,030	278	1,716
2012	8,443	1,330	39,324	9,739	5,354	1,128	283	1,918

Source: NSB Statistical Year Book 2009–2013

Table 2 Historic trend of vehicular population growth in Bhutan (no. of units)

Year	*Light transport*	*Two-wheelers*	*Heavy transport*	*Public transport*
2004	15,117	6,583	5,013	NA
2005	17,424	7,138	5,182	170
2006	19,768	7,931	5,367	175
2007	22,010	7,464	6,052	177
2008	26,410	7,737	6,580	180
2009	30,067	8,027	7,604	184
2010	35,294	8,958	9,746	188
2011	41,076	9,434	12,062	195
2012	44,678	9,739	12,893	209

Source: Compiled by the authors using data from NSB Statistical Year Book 2009–2013 of Bhutan

Based on this historic trend we have conducted time series forecasting of each category of vehicle for next two decades until 2035. For forecasting we have used the @RISK software which performs number of statistical techniques simultaneously to best fit the projection methodology based on the distribution pattern of the historic data. Figure 4 shows the forecasting of three different categories of vehicle until 2035 using the best fit method of auto regressive moving average to forecast the available past nine years' data for next two decades until 2035. The black dark line in the figure shows the mean value of the projected vehicular numbers of each category. The figure also shows the confidence intervals of forecasted vehicular numbers under two categories: confidence interval between 25%–75% and 5%–95% respectively. Based on this mean value we further estimated the total number of vehicles until 2035 under four different categories which are shown in Figure 5.

Figure 4 Base line projection of vehicular population in Bhutan (2014–2035) (see online version for colours)

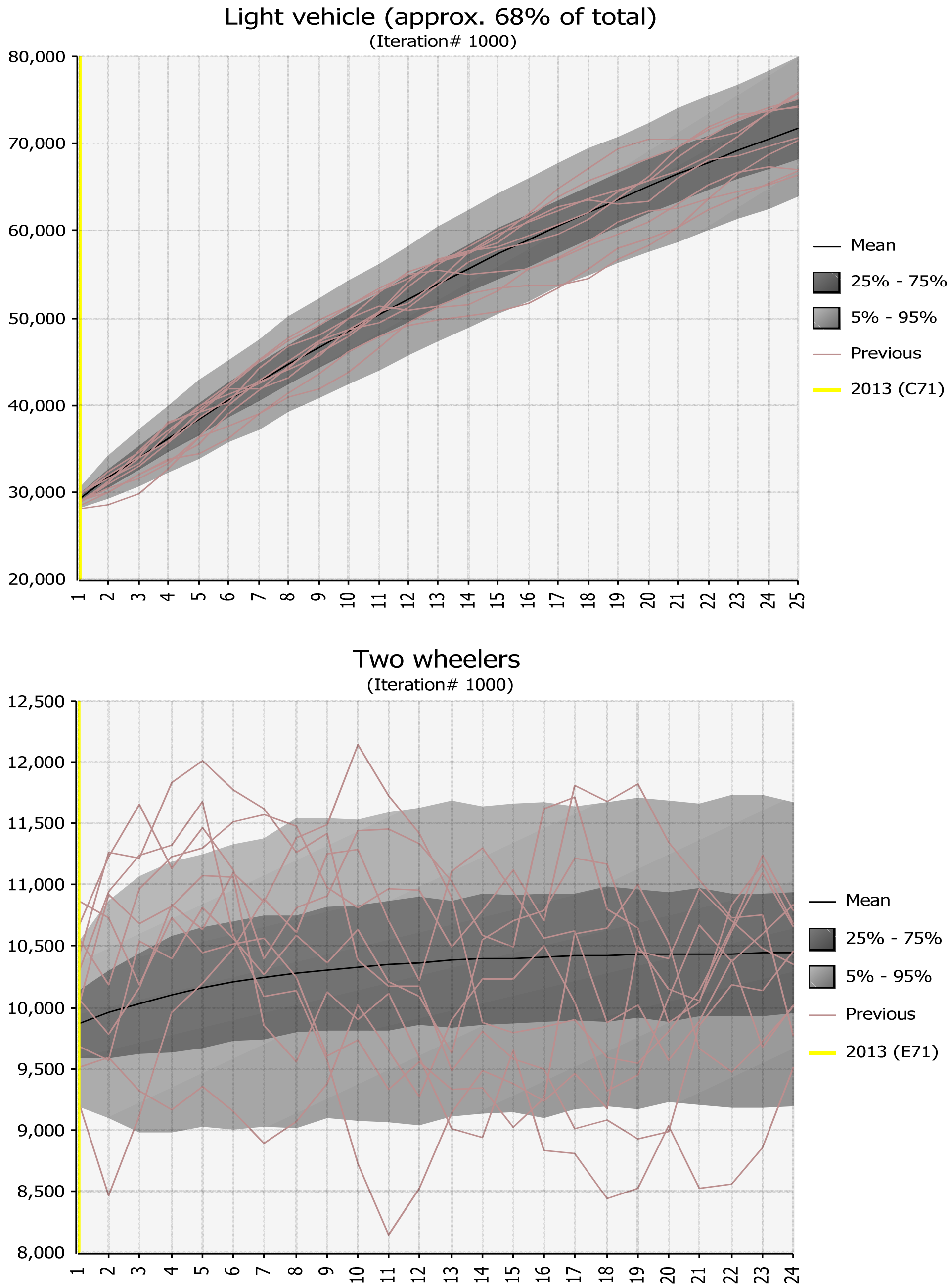


Figure 4 Base line projection of vehicular population in Bhutan (2014–2035) (continued) (see online version for colours)

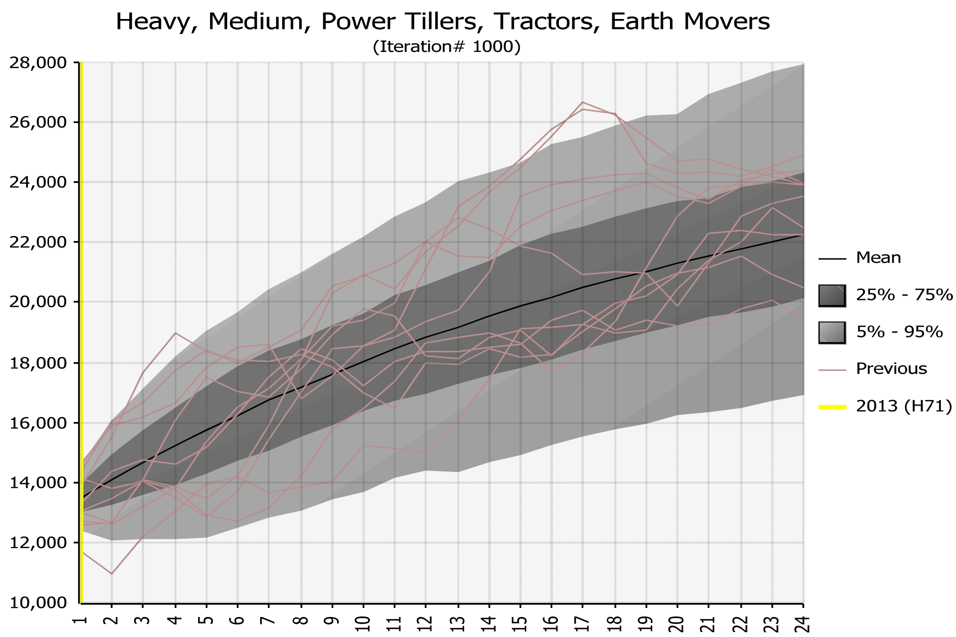


Figure 5 Cumulative baseline projection of total vehicle population in Bhutan (see online version for colours)

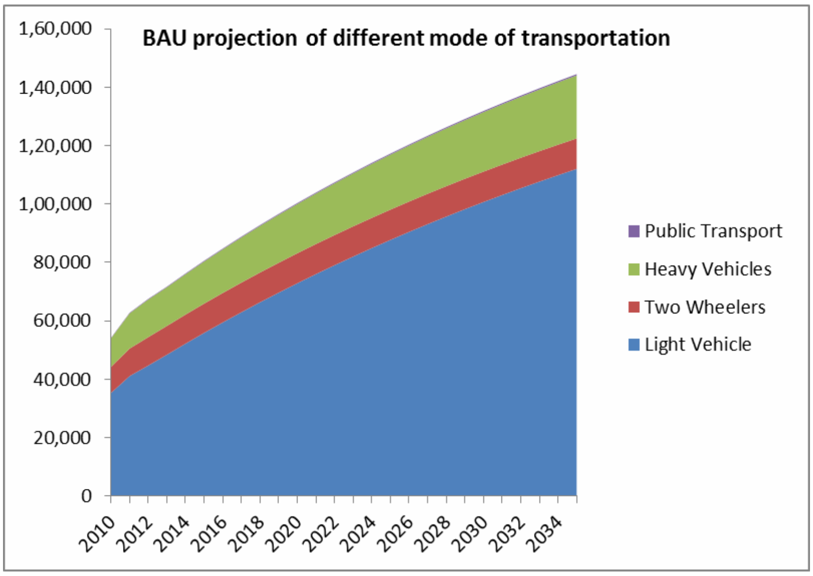


Figure 5 shows the cumulative BAU projection of four different categories of transport in Bhutan until 2035. The light vehicle category includes private four wheeler vehicles and taxies both running on petrol and diesel. It has been recorded that 68% of the light four wheelers are running on petrol and only 32% are running on diesel. Two wheelers are 100% running on petrol while heavy vehicles including trucks, public buses, heavy earth moving equipment, power tillers etc. are all running in diesel (Statistical Year Book 2013).

5.1.2 Baseline projection of vehicular emissions in Bhutan

For conducting the baseline emissions projection from the selected four categories of vehicles in Bhutan, there was hardly any disaggregated data available for transport sector which could be used. Even in the 2nd National Communication to UNFCCC, transport sector information is grossly aggregated. As a result we used an indirect method of attributing GHG emissions to each category of vehicle type based on their respective fuel consumption data which were available at a national level for the period of 2005 until 2012. As per National Statistical Year Book of 2009 and 2013 almost 100% of petrol and diesel imported in the country are consumed by the vehicles only. However, there is an issue of leakage, which is related to vehicles not registered in Bhutan, but coming from India for various commercial purposes and refuelling prior to returning to India. Currently, there are no such records available in Bhutan which can predict the quantity of diesel and petrol being removed in this way. Due to lack of data, we assumed that the entire amounts of diesel and petrol sold in Bhutan were consumed within the country itself and only by the vehicles (Table 3).

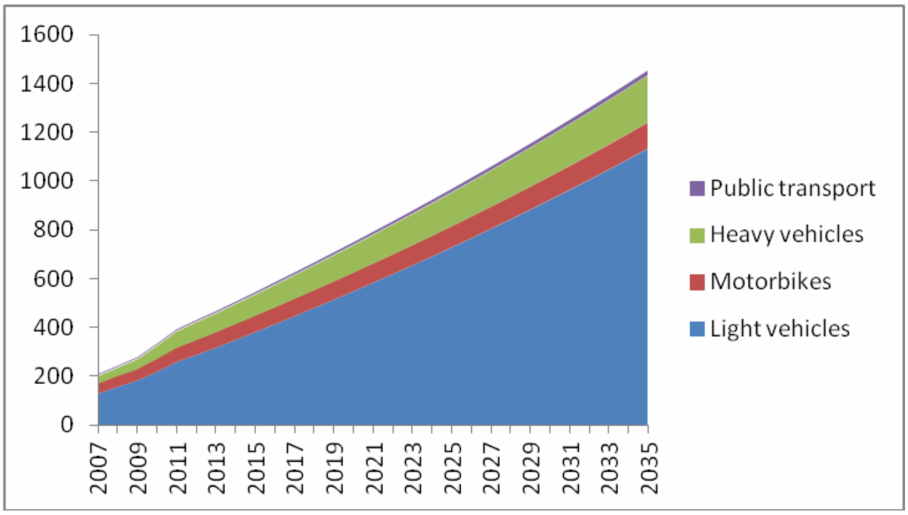
Table 3 Diesel and petrol consumption in Bhutan

Year	*Ton of oil equivalent*	
	Diesel	*Petrol*
2005	43,783	11,311
2006	47,508	12,508
2007	52,988	13,895
2008	54,479	14,326
2009	60,256	16,291
2010	73,176	18,597
2011	87,256	20,884
2012	102,368	22,779

Source: NSB (2013)

CO_2 emissions for each category of vehicle were estimated using the number of vehicles using petrol or diesel, fuel consumption by vehicle category, and the emissions coefficient. The data was further calibrated against the observed CO_2 emissions from the transport sector in Bhutan in 2007, i.e. 220 Giga grams. Figure 6 shows the baseline CO_2 emissions projected by the model.

Figure 6 Transport sector baseline CO_2 emissions (Giga grams) in Bhutan (see online version for colours)



The main conclusion from the baseline scenario is that rapid economic growth in Bhutan is likely to result in a significant increase in CO_2 emissions in the transport sector, with the bulk of the increase due to the increase in the number of light vehicles (particularly cars). From both sustainability and GNH perspectives, the unabated increase in the number of cars is clearly not desirable. Therefore, the introduction of new technologies such as electric vehicles (because of Bhutan's abundant hydropower potential) and modal shift from light vehicles to public transport are possible interventions that Bhutan could consider to lower CO_2 emissions from the transport sector. However, although such interventions could lower CO_2 emissions, trade-offs in terms of other sustainability indicators like household income and welfare are very likely. This paper therefore attempts to quantify the effects of these mitigation interventions on key sustainability indicators. For achieving this objective, different mitigation scenarios related to the development of a sustainable transport sector in Bhutan were run using the CGE model. In this context two different categories of low carbon options have been investigated. First, the low carbon transport option using electric vehicles and, second, by changing the use of transport mode from private vehicle to public vehicle (modal shift).

5.2 Low carbon transport scenario: electric vehicle option

In this section we have described different low emission transport options for Bhutan which have the potential to displace existing conventional mode of transportation like four wheelers, motorised bikes, heavy trucks and public buses and can reduce the GHG emissions from this sector. Following the detailed discussion with the local authorities and considering the inputs from stakeholders we have identified four major mitigating options or alternative mode of transportation for the country which is potentiality to be implemented in the country. In the process of determining the nationally appropriate mitigation action for transport sector this study conducted a detailed investigation of all the selected mitigation options in the context of their economic, social, financial and environmental impacts on Bhutan. There are three categories of electric vehicles finally considered in this study envisaging replacement of conventional cars, motorised bikes and public buses. Replacement of heavy trucks by electric mode is kept out of consideration in this study. Modal shift is also considered as a mitigation option where use of more buses is proposed to reduce number of private cars plying on the road. The following subsections discuss about the details of each scenario tested in this study.

In this study the scenarios are built on three major parameters:

1. corresponding % growth rate of total conventional cars with 10% and 50% annual penetrations of EVs in place of 10% and 50% annual conventional new cars coming in the market
2. total investment growth rate due to additional investment accrued on the country due to introduction of EVs in the given rates
3. corresponding electricity sector output growth rates required to adjust additional power requirement in the country due to introduction of EVs.

Table 4 shows the parameter values estimated exogenously under each scenario of CAR10 and CAR50 which are representing the 10 and 50% penetration of EVs in the market as replacement of new conventional vehicle entries. For example, in the year 2020, for 10% of new cars coming in the market to be electrical, Bhutan's conventional car market growth rate should be 4.2% (in volume term), investment in the conventional car market should be reduced to 7.9% and national electricity consumption should increase by 4.5% compared to the previous year i.e. 2019.

Table 4 Growth rate assumptions for the CAR10 and CAR50 scenarios

	2016	*2020*	*2025*	*2030*	*2035*
10% EV penetration (CAR10)					
Conventional vehicle population growth rate	5.8%	4.2%	3.1%	2.4%	1.9%
Investment growth rate	14.6%	7.9%	5.6%	4.4%	3.6%
Electricity consumption growth rate	4.5%	4.5%	3.5%	1.3%	0.2%
50% EV penetration (CAR50)					
Conventional vehicle growth rate	3.2%	2.6%	2.0%	1.6%	1.3%
Investment growth rate	25.5%	7.2%	5.3%	4.2%	3.5%
Electricity consumption growth rate	4.6%	4.6%	3.5%	1.3%	0.2%

Source: Authors' estimates

In the context of creating simulation scenarios for the CGE framework of this study, we use the above mentioned growth rates to create the same. In the CGE framework all scenarios are required be in value terms and not in absolute number terms. Therefore, in terms of creating the shocks for EV vehicle population growth, we used the same conventional vehicle population growth rates as a representative of corresponding sectoral value output. Transport sectoral output is derived using the Leontief production function where on the isoquants factor inputs are not substitutable. As a result, for 1% output growth, 1% growth for each factor input is required. Since in this model our production function is comprises of labour and capital separately, therefore, each percentage growth in sectoral output can be represented by same % growth in labour and capital. Based on this assumption, we have used the same percentage growth rate of vehicular population as shock for the Bhutan economy to represent the scenario of EV penetration in the model. Following section describes the scenarios in detail.

5.2.1 CAR10 scenario

In this scenario we assume that 10% of the new cars being added in Bhutan from 2016 onwards are electric cars. We simulate this scenario by changing three parameters of the model simultaneously compared to BAU: lowering the growth of conventional cars by 10% relative to the BAU, increasing the growth of the electricity sector corresponding to the higher electricity requirement for running electric cars and by increasing savings in the economy equivalent to the net addition to costs for the purchase of new electric vehicles.

5.2.2 CAR50 scenario

This scenario is same as CAR10 scenario except the percentage of new EV car penetration in the market which is 50%. In this scenario 50% of the new cars being added in Bhutan from 2016 onwards are electric cars compared to 10% in the CAR10 scenario. In other words this scenario reflects relatively stronger actions by stakeholders (consumers, government) to replace the conventional cars by electric cars.

5.2.3 COMB10 scenario

Apart from cars, growth in the number of bikes and buses will also contribute to higher CO_2 emissions in the future (see Figure 6). In this scenario in addition to the replacement of conventional cars by electric cars we also replace conventional bikes and buses as well by electric bikes and buses, respectively. However, it must be kept in mind that the number of bikes and buses is substantially smaller than the number of cars, and this trend is likely to continue in the future.

5.2.4 COMB50 scenario

This scenario is similar to the COMB10 scenario except for the fact that a higher number of new electric cars, bikes and buses are added in the country so the growth rates. In this scenario 50% of the new cars, bikes and buses being added in Bhutan from 2016 onwards are electric compared to 10% in the CAR10 scenario.

In summary, Table 5 shows the assumptions related to each scenario for quick reference and understanding.

Table 5 Average growth rates of each indicator used for scenario building in the study

Scenarios (average growth rates)	*BAU*	*CAR10*	*CAR50*	*COMB10*	*COMB50*
Conventional cars	5.98	5.98	5.96	5.98	5.96
Conventional motorbikes	1.21	1.21	1.21	1.21	1.21
Conventional public transport	3.52	3.52	3.52	3.52	3.50
Electricity	3.23	3.23	3.24	3.23	3.24
Foreign investment	14.75	14.75	14.74	14.75	14.74

Source: Authors estimates

5.3 Low carbon transport scenario: modal shift option

In this section we discuss the creation of different modal shift (from private cars to public transport) scenarios. The Bhutan Transport 2040 Integrated Strategic Vision Report (ADB, 2011) has identified promotion of public transport as one of the mitigation measures that could be pursued by Bhutan. Towards the assessment of promotion of public transport in Bhutan we have run four scenarios related to the shift from a private mode of transport (conventional private cars) to a public mode of transport (conventional buses). The shift from private cars to public buses has been modelled by increasing the tax rate on private cars and simultaneously subsidising public transport. In a CGE framework relative prices play a key role, and substitution between different modes of transport can only take place if relative prices change. Therefore, we model the modal shift scenarios by changing the relative prices of the two different modes of transport through taxes/subsidies. Specifically, we dis-incentivise consumers from using private cars by increasing tax on cars, and simultaneously incentivise them to use public transport by reducing price of public transport through higher subsidies. We analyse four modal shift scenarios in this study as described below:

5.3.1 Modal 1

In this scenario we use the revenues from existing taxes on private cars to subsidise public transport. The objective is to see the effects of such a policy on the public transport sector, as well as other indicators like emissions reduction, GDP etc.

5.3.2 Modal 2

In this scenario the existing tax rate on cars is doubled and the incremental revenue is used to subsidise public transport. Bhutan has increased the tax rate on cars recently and further hikes in tax rates are on the government's agenda.

5.3.3 Modal 3

This scenario is similar to Modal 2 scenario described above, however, in this scenario the existing tax rate on cars is tripled (3X) and the incremental revenue is used to subsidise public transport.

5.3.4 Modal 4

This scenario is similar to Modal 2 scenario described above, however, in this scenario the existing tax rate on cars is increased by four times (4X) and the incremental revenue is used to subsidise public transport.

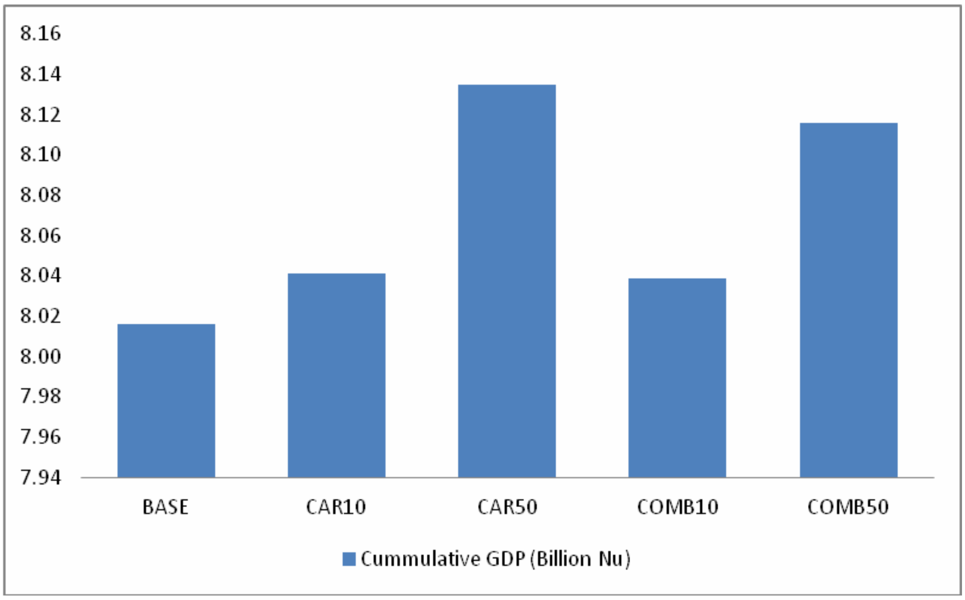
6 Results and discussion

In this section we discuss the results obtained from these scenario based simulations on the selected indicators on like GDP (economic indicator), CO_2 emissions reduction (environmental indicator) and social welfare (social indicator).

6.1 Impact on GDP

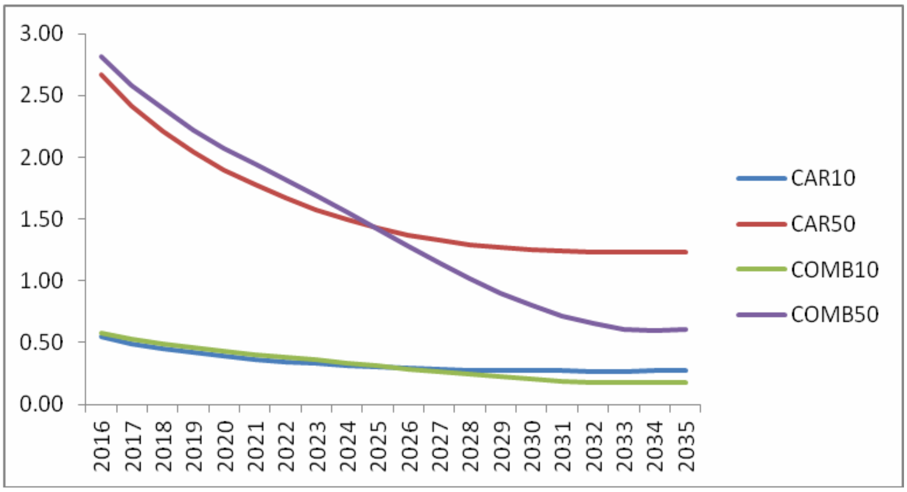
Cumulative real term GDP (sum of GDP over the entire time horizon) is higher in all the scenarios (CAR10, CAR50, COMB10 and COMB50) relative to the BAU. The increase in GDP is driven by higher electricity generation (hydropower) as a result of higher demand for electricity due to the introduction of electric vehicles in the economy. This in turn stimulates growth in other industrial sectors. Hydropower is abundant in Bhutan and the shift from imported fuels (petrol and diesel) to domestically produced hydropower is likely to benefit the Bhutan economy. The shift from conventional vehicles to electric vehicles will significantly reduce the dependence on imported oil and reduce the outflow of valuable foreign exchange. Figure 7 shows the impacts on real GDP due to various levels of electric vehicle penetration in the Bhutanese market.

Figure 7 Cumulative GDP impacts due to EV penetration in the Bhutan (see online version for colours)



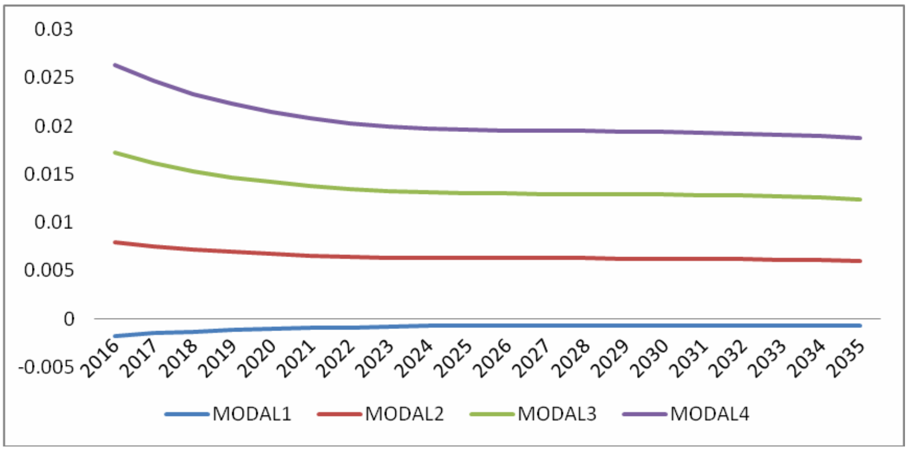
Our analysis suggests that both scale and type of intervention determine the effect on GDP. In general, GDP gains could be much higher if the intervention is on a bigger scale (50% level) than on a smaller scale because it will stimulate the hydro sector to a greater extent resulting in higher income and employment generation in the economy. Percentage change in GDP growth rate compared to the BAU scenario further reveals the importance of electric cars in the market compared to other type of electric vehicles. Simulation result shows that after 2025, a higher level of electric car penetration compared to combined penetration of electric vehicles (electric cars, buses and bikes together) will be less expensive for the economy. Figure 8 shows that the red colour CAR50 line stays above the COMB50 after 2025 whereas before 2025 the situation is reverse. This indicates that in the long run penetration of electric cars in the market will be less costly for the economy and will have bigger economic benefits in terms of GDP gain compared to an effort of introducing electric bikes, buses and cars together.

Figure 8 % change in real GDP growth rate under different scenarios (see online version for colours)



The GDP impact of a modal shift in the transport sector is also having certain positive impacts. However, in the scenario of Modal 1 it is observed that there is certain loss in GDP due to diversion of tax revenue to pay off the public transport system (use of existing tax revenue from conventional car sector to subsidise public transport sector). However, when the tax rate increases, positive impacts on GDP keeps increasing as well. Figure 9 shows the % change in GDP compared to BAU scenario for four different modal scenarios for Bhutan.

Figure 9 Impact on GDP under different modal shift scenarios (see online version for colours)



6.2 *Impact on CO_2 emissions*

The replacement of conventional vehicles by electric vehicles in the future could bring down CO_2 emissions (Figure 10) from the transport sector across all the scenarios.

However, CAR50 and COMB50 have relatively higher potential for CO_2 abatement than CAR10 and COMB10 scenarios. CAR50 and COMB50 scenarios can lower CO_2 emissions by more than 14.2% and 14.6% respectively, compared to the BAU over the time horizon, while the corresponding values for CAR10 and COMB10 scenarios are 2.9% and 3%, respectively. The main reason could be the volume of cars is much higher than any other mode of transportation. Therefore, the scenario with the higher number of cars has higher potential of emissions reduction.

Figure 10 % change is CO_2 emissions reduction compared to BAU scenario (see online version for colours)

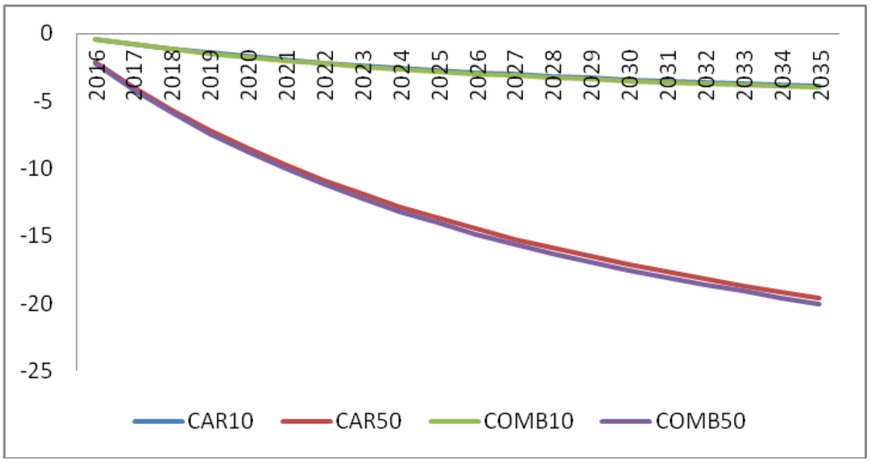
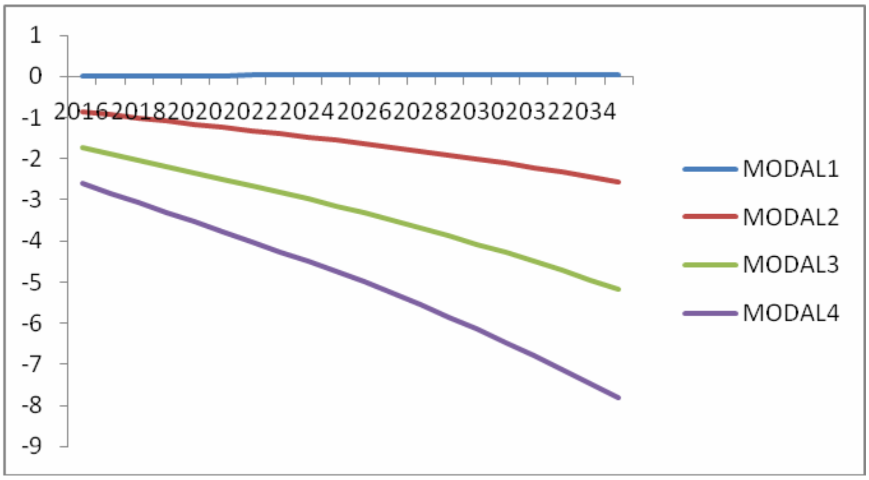


Figure 11 % change in CO_2 emissions reduction compared to BAU scenario (see online version for colours)



In the context of modal shift, percentage of CO_2 emissions reduction compared to BAU scenario is lower than other scenarios described above. It shows that under Modal1 scenario CO_2 emissions is increasing slightly but for other modal scenarios CO_2

emissions are decreasing (Figure 11). The main reason for emissions increase is greater number of public buses added in the fleet using fossil fuels.

Figure 12 Comparison of average MACCs (Nu/ton CO_2)[6] of different interventions (see online version for colours)

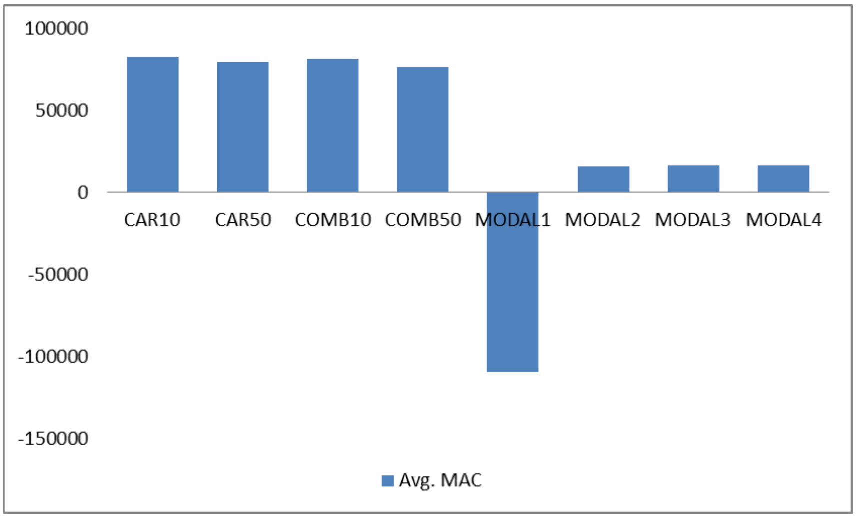
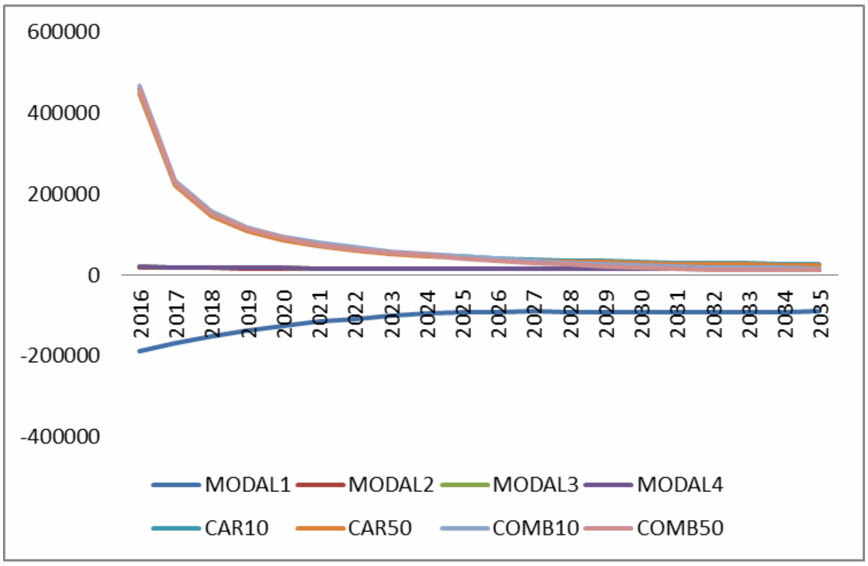


Figure 13 Comparison of MACCs (Nu/ton CO_2) of different interventions over the period of time (see online version for colours)



In this study we have also estimated the marginal abatement costs of the different interventions. Marginal abatement cost curves (MACCs) represent emissions reduction potentials and its corresponding costs. Figures 12 and 13 show the GDP gain/loss per unit of CO_2 emissions reduction. In the case of electric vehicles, we observe that there are gains to the economy (instead of losses which is often the case) due to the interventions. The gains are relatively higher for the interventions involving electric cars only, implying that policy makers should focus on electric cars instead of the other options considered in this study. However, the GDP gains decline over time due to escalation in costs/prices. In the case of the modal shift scenario, there is a marginal cost to the economy which remains almost constant over time.

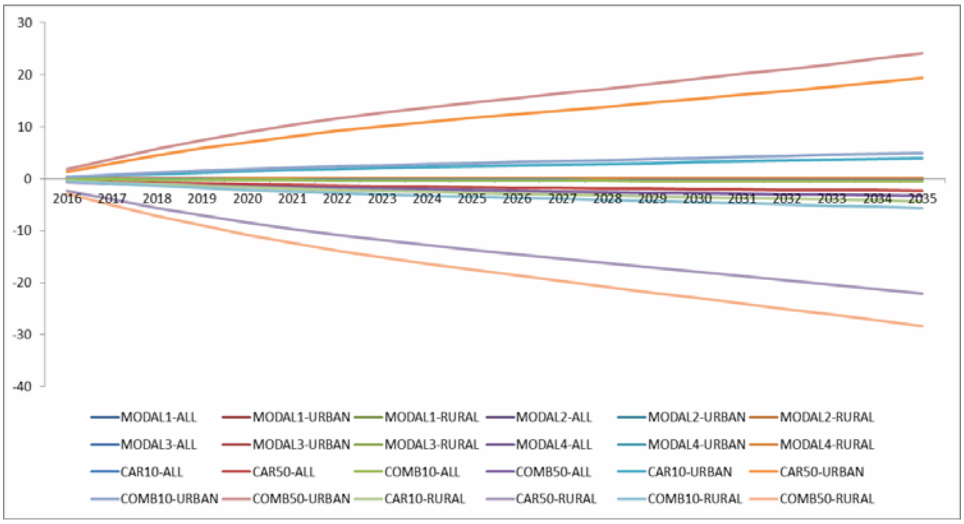
The Modal 1 scenario, though having the biggest loss in the economy as the government plans to use the entire tax revenue for subsidising public transport, further indicates that unless a minimum level of taxation on conventional cars is levied it is not advisable to channel tax revenue for direct subsidisation of public transport system. Figures 12 and 13 show the comparison of average marginal abatement cost of different interventions in the transport sector in Bhutan along with comparison of long term impacts.

6.3 Impact on household income in Bhutan

One of the major social sector indicators that need to be considered for promoting sustainable transport in Bhutan is the societal benefits (welfare and equity) coming out of policy interventions. It is to observe how a particular intervention is likely to affect different categories of households in terms of income generation and their consumptions. The incidence of poverty, particularly in rural areas, is quite high, and policies for the development of sustainable transport in Bhutan must take this aspect into account. For our analysis we have considered the effects of the interventions on two groups of households, rural and urban. Our analysis suggests that the introduction of electric vehicles will have a positive impact on the income of urban households, but will have a negative impact on the income of rural households. This is because urban households derive a higher share of income from the hydropower/industrial sectors, and therefore they gain from the expansion of the electricity and industrial sectors. On the other hand, rural agriculture-dependent households lose out because they do not benefit from the expansion of the power sector as well as industrial sector as much as urban residents. Therefore, the low carbon transport option would likely generate a benefit trade-off among two categories of households in the country.

The results indicates that interventions like CAR50 and COMB50 which strongly promote electric vehicles could lead to higher inequity in income in the country if no corrective measures are put in place beforehand. Figure 14 shows the changes in household incomes due to different interventions proposed in this study. In the modal shift scenarios (Modal 2/3/4) there is loss in income across all household groups because of the higher level of tax rate imposed on cars. However, as discussed earlier there is positive impact on GDP in these scenarios. The positive impact on GDP in these scenarios could be attributed to lower demand for imported cars. In Modal 1 scenario there is gain in household income because of lower price of public transport, as the existing tax revenue from cars is used to subsidise public transport. However, there is GDP loss in this scenario because of lower government savings and investment due to the diversion of government revenue to finance the public transport subsidy. Finally, the magnitude of household income impact is considerably higher in the electric vehicle scenarios compared to the modal shift scenarios suggesting that appropriate measures have to be taken or considered before implementing policies related to the introduction of electric vehicles in Bhutan.

Figure 14 Impact on household income (see online version for colours)



6.4 *Summary of findings*

The model results obtained can be further summarised in three broad categories: macroeconomic, social and environmental. In the context of macroeconomic impacts, it is observed that electric vehicles play a dual role in the economic system. On one hand it creates the intermediate demand for electricity in the market which in turn promotes the production of electricity. Since hydroelectricity is the only source of power generation in Bhutan, introduction of EVs in the market is thus positively correlated to the growth of the hydro power sector in the country. On the other hand, electric vehicles also help the transport sector of the country to grow. Bhutan's conventional transport sector is completely dependent on imported fuel. Introduction of electric vehicles can thus be able to replace the imported fuel with domestically produce electricity and can help saving large amount of fuel import bills and foreign exchange. It was envisaged initially that promotion of electric vehicles in the market which is having zero import duty, would negatively impact upon the revenue of the government and can adversely affect the economy.

However, the study demonstrated that there is no such observed negative impact on the economy in the context of introducing electric vehicles. The study further indicates that higher the level of electric vehicle penetration in the market, more the economic benefits are. This study also finds the importance of tax policy in developing low carbon transport sector in the country. It has been observed that while additional tax is imposed on existing tax of conventional vehicle and subsequently uses the incremental revenue for upgrading the public transport system, it brings the positive impact in the economy in addition to all other environmental and social benefits. This indicates the provision of green tax in the sector as well which can be used for the development of electric mobility, non-motorised transportation and other intelligent transport facilities like advance signalling system, multilayer parking facilities, etc.

In the context of social impacts of electric vehicle introduction in the country, the study reveals the potentiality of increasing income inequality between urban and rural households. The major reason for such inequality is attributed to the variation in income generation from the transport sector. Urban households are more dependent on vehicles than rural households. As a result the household savings are more for the urban sector than rural in case of replacement of conventional vehicles by electric one. Moreover, rural households are yet to be fully connected to power grid and use of electricity is also limited compared to urban households. As a result, rural population are unable to get the benefit of power sector development which is caused by the development of electric vehicle market.

In the context of emissions reduction, introduction of electric vehicle can bring down the emissions up to the level of 20% compared to the baseline condition by 2035. However, under the combined situation (electric vehicle plus modal shift) emission reduction is less because use of a more number of public vehicles using fossil fuels. Thus in terms of achieving the national goals of maintaining carbon neutrality for long, electric vehicle plays an important role.

Another crucial finding of this study is to understand the unambiguous importance of electric private cars in Bhutan in the context of developing low carbon transport sector. This option appears to be a win-win option for the country provided certain precautionary measures are taken to compensate the rural households following the importance of public acceptance of alternative transportation mode in the country for its long term success (Banister, 2008).

7 Conclusions and recommendations

In this paper we have analysed the sustainable development of the transport sector in Bhutan using a CGE framework. The present study addresses all the pillars of sustainable development, namely, economic, environmental and social, using the general equilibrium framework. Baseline and sustainable transport scenarios were constructed and analysed with the help of a recursive dynamic CGE model. In the baseline, CO_2 emissions from the transport sector increase by about 7% annually (or five times over the time period 2007–35). The highest growth in emissions is observed in the case of light vehicles (8%), followed by heavy vehicles (7%), public transport (6%) and bikes (3%). Four different low carbon sustainable transport options have been evaluated in this study which includes electric cars, bikes, public buses and modal shift (people travelling by bus rather than car).

The results show that the promotion of electric vehicles could lead to trade-offs between different sustainability indicators. Large scale roll out of electric vehicles (cars, buses and bikes) lead to reduction in CO_2 emissions (0.1 to 15% relative to BAU) and gains in GDP (maximum 1.4% relative to BAU). The reduction in emissions is quite modest and in order to substantially reduce emissions other approaches must also be considered. Lifestyle change which further encourages people to use more and more public transport than using their own vehicles can bring better result in terms of GDP, carbon emissions and household income. This is rather an easily achievable option for Bhutan. As the study observed certain trade-offs of economic benefits among different sectors in the economy due to low carbon transport intervention, it is therefore, recommending some preventive measures as well to avoid creating long term income disparity in the country. Rural agriculture-dependent households experience income losses because the roll out of electric vehicles does not benefit these households.

Thus, the promotion of electric transport must be accompanied by the development of the rural sector to reduce the adverse impact on rural households either by providing technical knowledge of repairing and maintenance of EVs, or by providing support to set up battery charging stations and its related services, etc. Modal shift from private cars to public transport (through higher taxes on cars and subsidies to public transport) has better potential to bring down CO_2 emissions, along with positive impact on GDP, and this intervention comes at a small cost in household welfare. In terms of marginal abatement cost, electric cars are the best option, but as mentioned earlier it could lead to higher inequality in the country. For the promotion of sustainable transport, Bhutan must look at the options like electric vehicles and shift in transportation model all together to achieve the low carbon pathway of development

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Notes

1 For further reference see Bhutan Transport 2040 Integrated Strategic Vision Final Report.

2 Perfect competitive market is referred to such conditions where all firms in the market sell identical products, firms cannot control the price in the market, buyers in the market are completely informed about the product and the sellers can enter and exit the market at any time.

3 Linear expenditure system (LES) assumes that the total income of household is equal to their total expenditure in the market.

4 An item or commodity acting as a measure of value or as a standard for currency exchange.

5 Because every payment by an agent in the economic system represents a receipt to some other agent in the system, the row and column sums of the SAM must be equal at equilibrium.

6 For further detail please go to this link: http://www.reuters.com/article/2015/06/09/us-bhutan-climate-change-autosales-idUSKBN0OP0W720150609.

7 Nu is the Bhutanese currency unit.

Appendix 1

CGE model structure, equations and variables

CGE model description

Sets

- C – set of commodities
- CE – set of exported commodities
- CM – set of imported commodities
- A – set of sectors/activities
- F – set of factors
- H – set of households
- INSD – set of domestic institutions (households and government)
- ETRNS – set of electric transport sectors

Parameters

- alphaq(c) – Armington function shift parameter for commodity c
- alphat(c) – CET function shift parameter for commodity c
- alphava(a) – shift parameter for CES activity production function
- betam(c, h) – marginal share of household consumption spending on commodity c
- corprat0 –share of retained earnings in capital (non wage) income
- ctax(c) –sales tax
- ctaxh(h) – tax on household consumption
- ctaxg – tax on government consumption
- ctaxs –tax on savings investment
- cwts(c) – weight of commodity c in the consumer price index
- deltaq(c) – Armington function share parameter for commodity c
- deltat(c) – CET function share parameter for commodity c
- deltava(f, a) –share parameter for CES activity production function
- emmfactorbikes – CO_2 emission factor for bikes
- emmfactorlighttrns – CO_2 emission factor for light transport
- emmfactorheavytrns – CO_2 emission factor for heavy transport
- emmfactorpubtrns – CO_2 emission factor for public transport
- gammam(c, h) – per capita subsistence consumption of marketed commodity c for household h

- ica(c, a) – quantity of c as intermediate input per unit of aggregate intermediate
- inta(a) – intermediate aggregate coefficient of Leontief production function
- iva(a) – aggregate value added coefficient of Leontief production function
- modshift – government spending on public transport
- mps0(h) – base year marginal (and average) propensity to save for household h
- ptax(a) – producer tax
- pwm(c) – world price of imports
- pwe(c) – world price of exports
- qbarinv(c) – base-year quantity of investment demand for commodity c
- rhoq(c) – Armington function exponent for commodity c
- rhot(c) – CET function exponent for commodity c
- rhova(a) – CES activity production function exponent
- shif(insd, f) – share of institution INS in the income of factor f
- tm(c) – import tariff
- te(c) –export tariff

Variables

- CPI – consumer price index
- EG – government expenditure
- EH(H) – household consumption expenditure
- EXR – exchange rate (domestic currency per unit of foreign currency)
- GSAV – government savings
- IADJ – investment adjustment factor
- MPS(H) – marginal (and average) propensity to save for household h (fixed)
- PDD(C) – demand price of output produced & sold domestically
- PDS(C) – supply price of output produced & sold domestically
- PINTA(A) – price of intermediate aggregate
- PE(C) – export price
- PM(C) – import price
- PQ(C) – composite commodity price for c
- PVA(A) – value-added price for activity a
- PX(A) – producer price for commodity c
- QD(C) – quantity sold domestically of domestic output c

- QE(C) – export quantity
- QF(F,A) – quantity demanded of factor f from activity a
- QVA(A) – quantity of aggregate value added
- QH(C, H) – quantity consumed of commodity c by household h
- QINT(C, A) – quantity of commodity c as intermediate input to activity a
- QINTA(A) – quantity of aggregate intermediate input for activity a
- QINV(C) – quantity of investment demand for commodity c
- QM(C) – import quantity
- QQ(C) – quantity of goods supplied domestically (composite supply)
- QX(A) – quantity of domestic output of commodity c
- TABS – total absorption
- TINS(H) – direct tax rate on households (fixed)
- WF(F) – wage rate (fixed)
- WFDIST(F, A) – wage distortion factor for factor f in activity a
- YF(F) – factor income
- YG – government income
- YIF(INSD, F) – income of institution INSD from factor f
- YI(INSD) – income of institution INSD
- CORPSAV – corporate saving
- QFS(F) – factor supply
- QG(C, INSD) – government consumption
- WALRAS – saving investment adjustment variable (should be zero in equilibrium)
- TOTSAV – aggregate savings
- GADJ – government consumption adjustment factor (fixed)
- TOTINV(C) – investment demand for commodity
- CO_2LIGHTTRNS – CO_2 emissions of light transport sector (private cars, taxis)
- CO_2BIKES – CO_2 emissions of motorbikes sector
- CO_2HEAVYTRNS – CO_2 emissions of heavy transport sector (trucks, private buses)
- CO_2PUBTRNS – CO_2 emissions of public transport sector (public buses)

Equations

Price block

$$PM(cm) = (1 + tm(cm)) * EXR * pwm(cm) \quad (1)$$

$$PE(ce) = (1 - te(ce)) * EXR * pwe(ce) \quad (2)$$

$$PDD(c) = PDS(c) \quad (3)$$

$$PQ('PETPROD') = PM('PETPROD') \quad (4)$$

Non-public transport

$$PQ(C) * (1 - ctax(c)) * QQ(C) = PDD(C) * QD(C) + PM(C) * QM(C) \quad (5)$$

Public transport

$$PQ('PUBTRNS') * (1 - ctax('PUBTRNS')) * QQ('PUBTRNS') + modshift \quad (6)$$

Petroleum products (imports only; no domestic production)

$$PQ('PETPROD') * QQ('PETPROD') = PM('PETPROD') * QM('PETPROD') \quad (7)$$

$$PX(c) * QX(c) = PDS(c) * QD(c) + PE(c) * QE(c) \quad (8)$$

$$PINTA(a) = \Sigma_c PQ(c) * ica(c, a) \quad (9)$$

$$PX(a) * QX(a) * (1 - ptax(a)) = PVA(a) * QVA(a) + PINTA(a) * QINTA(a) \quad (10)$$

$$CPI = \Sigma_c cwts(c) * PQ(c) \quad (11)$$

Electric transport

$$PINTA(ETRNS) = PQ(ETRNS) \quad (12)$$

Production block

$$QINTA(a) = inta(a) * QX(a) \quad (13)$$

$$QVA(a) = iva(a) * QX(a) \quad (14)$$

$$QVA(a) = alphava(a) * (deltava('CAP', a) * QF('CAP', a)^{-rhova(a)} + \left(1 - deltava('CAP', a)) * QF('LAB', a)^{-rhova(a)}\right)^{-\frac{1}{rhova(a)}} \quad (15)$$

$$QF('CAP', a) = QF('LAB', a) * ((WF('LAB') * WFDIST('LAB', a) / (WF('CAP') * WFDIST('CAP', a))) * \left(deltava('CAP', a) / (1 - deltava('CAP', a))\right))^{\frac{1}{1+rhova(a)}} \quad (16)$$

$$QVA(a) * PVA(a) = QF('CAP, a) * WF('CAP') * WFDIST('CAP', a) + QF('LAB', a) * WF('LAB') * WFDIST('LAB', a) \quad (17)$$

$$QINT(c, a) = ica(c, a) * QINTA(a) \quad (18)$$

$$QQ(c) = alphaq(c) * \left(deltaq(c) * QM(c)^{-rhoq(c)} + (1 - deltaq(c) * QD(c)^{-rhoq(c)}\right)^{-\frac{1}{rhoq(c)}} \quad (19)$$

$$QM(c) = QD(c) * \left(PDD(c) / PM(c) * (deltaq(c) / (1 - deltaq(c))\right)^{\frac{1}{1+rhoq(C)}} \tag{20}$$

$$QX(c) = alphat(c) * \left(deltat(c) * QE(c)^{rhot(c)} + (1 - deltat(c)) * QD(c)^{rhot(c)}\right)^{\frac{1}{rhot(C)}} \tag{21}$$

$$QE9c) = QD9c) * \left(PE(c) / PDS(c) * (1 - deltat(c)) / deltat(c)\right)^{\frac{1}{rhot(c)-1}} \tag{22}$$

Non-imported commodities

$$QQ(c) = QD(c) \tag{23}$$

Non-exported commodities

$$QX(c) = QD(c) \tag{24}$$

$$QG('othserv', 'GOVT') = GADJ * QG0('othserv', 'GOVT') \tag{25}$$

$$QINTA(ETRNS) = QINT('ELECTRICITY', ETRNS) \tag{26}$$

Institution block

$$YF(F) = SUM(A, WF(F) * WFDIST(F, A) * QF(F, A)) \tag{27}$$

$$YIF(INSD, 'LAB') = shif(INSD, 'LAB') * (YF('LAB')) \tag{28}$$

$$YIF(INSD, 'CAP') = shif(INSD, 'CAP') * \left(YF('CAP') - CORPSAV\right) \tag{29}$$

$$YI(H) = SUM\left(F, YIF(H, F)\right) \tag{30}$$

$$EH(H) = \left(1 - MPS(H)\right) * \left(1 - TINS(H)\right) * \left(1 - ctaxh(h)\right) * YI(H) \tag{31}$$

Household demand (linear expenditure system)

$$\begin{aligned} PQ(C) * QH(C, H) \ &= PQ(C) * gammam(C, H) + betam(C, H) * \\ &\quad \left(EH(H) - SUM\left(CP, PQ(CP) * gammam(CP, H)\right)\right) \end{aligned} \tag{32}$$

$$QINV(C) = qbarinv(C) * IADJ \tag{33}$$

Government block

$$\begin{aligned} YG = \ & SUM(H, TINS0(H) * YI(H)) + SUM(A\$(NOTETRNS(A)), ptax(A) * PX(A) * QX(A)) + \\ & SUM(ETRNS, ptax(ETRNS) * PX(ETRNS) * QX(ETRNS)) + \\ & SUM(C, tm(C) * pwm0(C) * QM(C) * EXR) + SUM(C, ctax(C) * PQ(C) * QQ(C)) + \\ & SUM(C, te(C) * pwe0(C) * QE(C) * EXR) + YIF('GOVT', 'CAP') + \\ & ctaxs * sum(C, QINV(C) * PQ(C)) + ctaxg * EG + sum(H, ctaxh(H) * EH(H)) \end{aligned} \tag{34}$$

$$EG = SUM\left(C, PQ(C) * QG\left(C, 'GOVT'\right)\right) + ctaxg * EG + modshift \tag{35}$$

$$GSAV = YG - EG \tag{36}$$

Factor supply

$$QFS('LAB') = SUM\left(A,\ QF('LAB', A)\right) \tag{37}$$

$$QFS('CAP') = SUM\left(A,\ QF('CAP', A)\right) \tag{38}$$

Market equilibrium condition

$$\begin{aligned} QQ(CINT) = SUM\left(ANF,\ QINT(CINT, ANF)\right) \\ + SUM\left(H, QH(CINT, H)\right) \\ + QG(CINT, 'GOVT') + QINV(CINT) \end{aligned} \tag{39}$$

Retained earnings

$$CORPSAV = corprat0 * YF('CAP') \tag{40}$$

Total savings

$$\begin{aligned} TOTSAV = GSAV + SUM\left(H, MPS(H) * YI(H) * (1 - TINS(H)) * (1 - ctaxh(h))\right) \\ + CORPSAV + FSAV0 * EXR + SUM\left(C, ctaxs * TOTINV(C)\right) \end{aligned} \tag{41}$$

Total investments

$$TOTINV(C) = PQ(C) * QINV(C) \tag{42}$$

Saving investment balance

$$SUM\left(C,\ TOTINV(C) * (1 + ctaxs)\right) = TOTSAV + WALRAS \tag{43}$$

Current account balance

$$SUM\left(C\$CE(C),\ pwe0(C) * QE(C)\right) + FSAV0 = SUM\left(C\$CM(C),\ pwm0(C) * QM(C)\right) \tag{44}$$

Total absorption

$$TABS = SUM\left((C, H), PQ(C) * QH(C, H)\right) + SUM\left(C, PQ(C) * QG(C, 'GOVT')\right) \tag{45}$$

Marginal propensity to save of household

$$MPS(H) = MPS0(H) \tag{46}$$

Transport sector emissions block

$${}_{CO2}LIGHTTRNS = QINT('PETPROD', 'LIGHTTRNS') * emmfactorlighttrns \tag{47}$$

$${}_{CO2}BIKES = QINT('PETPROD', 'BIKES') * emmfactorbikes \tag{48}$$

$${}_{CO2}HEAVYTRNS = QINT('PETPROD', 'HEAVYTRNS') * emmfactorheavytrns \tag{49}$$

$${}_{CO2}PUBTRNS = QINT('PETPROD', 'PUBTRNS') * emmfactorpubtrns \tag{50}$$

Appendix 2

Parametric values

Table 1 Armington elasticities

Agriculture	2.28
Mining	0.65
Metals	0.65
Manufacturing	0.91
Petroleum product	0.61
Electricity	0.99
Consumer and retail	0.99
Light vehicle	0.99
Two wheelers	0.99
Heavy trucks	0.99
Public transport	0.99
Alternative transport	0.99
Other services	0.99

Table 2 Production elasticities (labour and capital factor substitution)

Agriculture	0.78
Mining	0.96
Metal	0.96
Manufacturing	0.96
Petroleum product	0.96
Electricity	0.91
Consumer retail	0.39
Light vehicle	0.59
Two wheelers	0.59
Heavy trucks	0.59
Public transport	0.59
Elec. cars	0.59
Elec. bikes	0.59
Elec. trucks	0.59
Elec. buses	0.59
Other services	0.59

Appendix 3

Social accounting matrix of Bhutan

Column1	*AGRIC*	*MINING*	*METALS*	*MANU*	*PETPROD*	*ELECTRICITY*
AGRIC	354			283		
MINING			515	1302		
METALS			330	419		
MANU	421	30	339	2183		35
PETPROD	21			39		
ELECTRICITY	7	8	750	233		2645
CONSRETAIL	80	5	47	229		7
LIGHTTRNS	34	41	153	202		14
BIKES	1	3	8	108		3
HEAVYTRNS	23	417	293	601		18
PUBTRNS						
ELIGHTTRNS	1	1	1	1		1
EBIKES	1	1	1	1		1
EHEAVYTRNS	2	2	2	2		2
EPUBTRNS						
OTHSERV	61	55	139	490		33
LAB	3562	204	491	1282		3890
CAP	6096	420	339	2158		6466
URBANHH						
RURALHH						
NETCONSTAX	29	11	47	134		12
NETPRODTAX		291	35	72		7
GOVT						
SAVINV						
ROW	620	2018	11997	8201	2248	1729
TOT	11314	3507	15486	17941	2248	14863

Social accounting matrix of Bhutan (continued)

Column1	*CONSRETAIL*	*LIGHTTRNS*	*BIKES*	*HEAVYTRNS*	*PUBTRNS*
AGRIC	491				
MINING	1046	53	11	76	11
METALS	2335	63	12	91	12
MANU	3729				
PETPROD		736	81	1103	98
ELECTRICITY	29	13	7	16	6
CONSRETAIL	368	39	10	56	9
LIGHTTRNS	76	79	12	116	13
BIKES	5				
HEAVYTRNS	887	155	24	228	26
PUBTRNS					
ELIGHTTRNS	1				
EBIKES	1				
EHEAVYTRNS	2				
EPUBTRNS					
OTHSERV	754	268	33	400	38
LAB	3042	464	53	694	63
CAP	4667	1054	114	1582	138
URBANHH					
RURALHH					
NETCONSTAX	142	22	8	30	7
NETPRODTAX	1515	28	8	39	8
GOVT					
SAVINV					
ROW	878	286	35	427	41
TOT	19968	3261	408	4859	471

Social accounting matrix of Bhutan (continued)

Column1	*ELIGHTTRNS*	*EBIKES*	*EHEAVYTRNS*	*EPUBTRNS*	*OTHSERV*
AGRIC					264
MINING					
METALS					24
MANU					765
PETPROD					45
ELECTRICITY	4	3	5	2	96
CONSRETAIL					282
LIGHTTRNS					545
BIKES					151
HEAVYTRNS					633
PUBTRNS					
ELIGHTTRNS					2
EBIKES					1
EHEAVYTRNS					2
EPUBTRNS					
OTHSERV					1689
LAB	5	4	4	2	6769
CAP	5	3	9	2	3769
URBANHH					
RURALHH					
NETCONSTAX					65
NETPRODTAX					158
GOVT					
SAVINV					
ROW					3523
TOT	14	11	18	6	18783

Social accounting matrix of Bhutan (continued)

Column1	*LAB*	*CAP*	*URBANHH*	*RURALHH*	*NETCONSTAX*
AGRIC			2205	3521	
MINING			61	54	
METALS			575	499	
MANU			2231	1933	
PETPROD			89	37	
ELECTRICITY			276	289	
CONSRETAIL			745	781	
LIGHTTRNS			812	478	
BIKES			81	48	
HEAVYTRNS					
PUBTRNS			296	175	
ELIGHTTRNS			2	2	
EBIKES			1	1	
EHEAVYTRNS					
EPUBTRNS			3	3	
OTHSERV			2319	2483	
LAB					
CAP					
URBANHH	12891	7968			
RURALHH	7640	9886			
NETCONSTAX			494		
NETPRODTAX					
GOVT		4671			1532
SAVINV		4297	10668	7222	
ROW					
TOT	20531	26822	20859	17526	1532

Social accounting matrix of Bhutan (continued)

Column1	*NETPRODTAX*	*GOVT*	*SAVINV*	*ROW*	*TOT*
AGRIC			3328	868	11314
MINING			–572	950	3507
METALS			828	10299	15486
MANU			1109	5165	17941
PETPROD					2248
ELECTRICITY			5	10470	14863
CONSRETAIL			16129	1182	19968
LIGHTTRNS				686	3261
BIKES					408
HEAVYTRNS			198	1355	4859
PUBTRNS					471
ELIGHTTRNS				2	14
EBIKES					11
EHEAVYTRNS			2	3	18
EPUBTRNS					6
OTHSERV		9331	7	681	18783
LAB					20531
CAP					26822
URBANHH					20859
RURALHH					17526
NETCONSTAX		113	74	343	1532
NETPRODTAX					2162
GOVT	2162				8366
SAVINV		–1079			21107
ROW					32003
TOT	2162	8366	21107	32003	