ANALYSIS OF LOW CARBON DEVELOPMENT STRATEGIES: ROLE OF TRANSPORT SECTOR ELECTRIFICATION AND CARBON TAX IN NEPAL

by

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Abstract

The main objective of this study is to analyze the energy, environmental and economy-wide implications of selected low carbon development strategies in Nepal with huge untapped hydropower potential but still relying heavily on the imported fossil fuels. The study developed and used soft linked integrated energy-environment-economic modeling tools to examine the mid and long term effects of a sectoral low carbon strategy, i.e., transport sector electrification and an economy-wide carbon tax strategy. The bottom up energy system model (Nepal-ESM) was used to study the effects of selected low carbon strategies on the hydropower development, energy supply mix, energy system cost and global and local environmental emissions, while the overall macroeconomic and welfare implications of the low carbon strategies were assessed by hybrid top-down type Computable General Equilibrium (Nepal-CGE) model.

In order to analyze implications of transport sector electrification, a base case scenario without any policy resulting transport electrification and five counterfactual scenarios with different levels of electrification of the transport system during 2015-2050 were developed. The analysis based on the bottom up Nepal-ESM model shows that the transport sector electrification would promote development of indigenous hydropower resource in the country with additional hydropower capacity requirement for various transport electrification scenarios compared to the base case scenario. The hydropower capacity addition would increase by up to 538 MW under high (35%) transport electrification scenario EMT20+EV15 (20% modal shifts to electric mass transport (EMT) and 15% penetration of the electric vehicles (EV) by 2050). With the electrification of the transport system, there would be a noticeable improvement in the energy security of the country with decline in the cumulative imported energy (in the range of 6.3% to 14.6%) and improvement in diversification of the primary energy supply system. There would be a decrease in the discounted total energy system cost under the transport electrification scenarios (in the range of 1.0% to 2.0%) as compared to the base case. As a climate related co-benefit, there would be a reduction of 13% greenhouse gas (GHG) emissions in cumulative terms under the 35% transport sector electrification (EMT20+EV15). In addition, there would be a reduction in the emissions of local pollutants (CO, NO_X, SO_2, NMVOC and PM_{10}). The study also shows that there would be additional employment generation during 2015-2050 associated purely with the additional hydropower development and recharging stations serving electric vehicles required under the transport electrification scenarios.

The economy-wide effects of the transport sector electrification were studied using the Nepal-CGE model. The main finding of the study indicates that Nepal would benefit economically from the implementation of the transport sector electrification process in the long run with an increase in the cumulative undiscounted real GDP (in the range of 2.5% to 3.1%) and household welfare under all the transport electrification scenarios. Besides, transport electrification would promote energy efficiency improvement and green economy with a significant reduction in the average energy intensity (in the range of 2.7% to 4.1%) and average GHG emission intensity of GDP (in the range of 4.7% to 7.7%) under different transport electrification scenarios. This highlights the importance of the transport sector electrification as one of the desirable

options for a low carbon development path in the country. It also indicates that the transport sector electrification would result in the appreciation of the national currency triggering reduction in the export of the other non-transport and non-electricity related commodities produced in the country in the long run (i.e., the presence of Dutch disease kind of effect). Introducing foreign direct investment would reduce such effects to some level.

The effects of the carbon tax were studied by developing a base case scenario without any environmental policy and three counterfactual scenarios with introduction of carbon tax under different GHG stabilization targets of 450 ppmv (CT-HIG), 550 ppmv (CT-MED) and 650 ppmv (CT-LOW) during 2015-2050. The analysis using Nepal-ESM model reveals that there would be a need to install additional hydropower capacity of 614 MW in CT-MED to 945 MW in CT-HIG by 2050. It indicates an improvement in the efficiency of the cumulative total final energy consumption (in the range of 0.03% under CT-HIG to 0.5% under CT-MED) in all the carbon tax scenarios compared to the base case. The study also shows the co-benefits in terms of employment generation associated with additional hydropower development under the carbon tax scenarios and that through the establishment of more electric recharging stations under CT-MED and CT-HIG. It reveals that there would be a reduction in the emission of short-lived local pollutants. The adoption of the carbon tax would decrease the discounted net fuel import cost (in the range of 2.2% under CT-LOW to 5.5% under CT-HIG) but increases the discounted total energy system cost including carbon tax (in the range of 0.6% under CT-LOW to 4.7% under CT-HIG). However, if recycling of 100% of the carbon tax revenue back to the economy is considered, the discounted total energy system cost excluding carbon tax is expected to decrease under CT-HIG.

Nepal-CGE model was also used to examine the economy-wide consequences of the carbon tax. It indicates that if the carbon tax is implemented in Nepal, there would be significant decrease in average energy intensity (in the range of 5.0% under CT-LOW to 2.4% under CT-HIG) and average GHG emission intensity of GDP (in the range of 6.2% under CT-LOW to 13.7% under CT-HIG) but at the cost of moderate loss in the cumulative undiscounted real GDP (in the range of 2.3% under CT-LOW to 8.1% under CT-HIG) and household welfare as compared to the base case. Under CT-HIG there would be a significant increase in the electricity consumption. However, carbon tax revenue recycling scheme would help to reduce GDP loss and improve household welfare. There would be an additional benefit related to the reduction in average energy intensity if carbon tax revenue is recycled above 50%.

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List of Abbreviations

ADB	Asian Development Bank
AEEI	Annual Energy Efficiency Improvement
AEPC	Alternative Energy Promotion Centre
APERC	Asia Pacific Energy Research Centre
ATF	Aviation Turbine Fuel
CBS	Central Bureau of Statistics
CES	Centre for Energy Studies
CGE	Computable General Equilibrium
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COP	Conferences of the Parties
C-Tax	Carbon Tax
EEA	European Environment Agency
EIA	Energy Information Administration
EREC	European Renewable Energy Council
ETSAP	Energy Technology Systems Analysis Programme
FNCCI	Federation of Nepalese Chambers of Commerce and Industry
FOSTCA	Federal Office for Scientific, Technical and Cultural Affairs
GAMS	General Algebraic Modeling System
GDP	Gross Domestic Product
GoN	Government of Nepal
GHG	Greenhouse Gas
ICIMOD	International Centre for Integrated Mountain Development
ICS	Improved Cooking Stoves
IEA	International Energy Agency
IFEU	Institute for Energy and Environmental Research Heidelberg
IPCC	Intergovernmental Panel on Climate Change
IRPAD	Institute for Policy Research and Development
JBIC	Japan Bank for International Cooperation
JICA	Japan International Corporation Agency

LCD	low carbon development
LED	light emitting diode
MARKAL	MARKel ALlocation
MOE	Ministry of Energy
MOEV	Ministry of Environment
MOF	Ministry of Finance
MOI	Ministry of Industry
MOPE	Ministry of Population and Environment
MOPPW	Ministry of Physical Planning and Works
MOWR	Ministry of Water Resource
Mtoe	Million Tonnes of Oil Equivalent
N_2O	Nitrous Oxide
NEA	Nepal Electricity Authority
NESS	National Environmental and Scientific Services
NMVOC	Non-methane Volatile Organic Compound
NO_X	Nitric Oxide
NRB	Nepal Rastra Bank
NRs	Nepalese Rupees
PJ	Peta Joules
PM_{10}	Particulate Matter of less than 10 Micrometers in diameter
PREGA	Promotion of Renewable Energy, Energy Efficiency and GHG Abatement Nepal
SO_2	Sulphur Dioxide
TERI	The Energy and Resources Institute
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
USEPA	U.S. Environmental Protection Agency
USEPA	United States Environmental Protection Agency
WECS	Water and Energy Commission Secretariat
3Es	Energy-Environment-Economic Modeling

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Chapter 1

Introduction

1.1 Background

An ever increasing concern for the escalating effects of global climate change has brought together national and global policy makers in the development and implementation of various policy options to mitigate the emission of greenhouse gas (GHG) on the long term basis. Recent studies have shown that to restrict to the so called 2-degree temperature rise from 1750 by end of this century, meaningful contribution from present developing and emerging countries is inevitable, though there is a moral but not legal obligation for them to cut back their business as usual GHG emission (Blanford et al. 2009; IPCC 2007b; UNEP, 2010). Reducing the present trend of GHG emission are proving to be hard to implement by developing countries due to lack of adequate resources and knowledge about its socio-economic effects in the long run. To achieve meaningful reduction in GHG emissions in the stipulated time frame, there has to be paradigm shift from conventional carbon intensive economic development path to low carbon development (LCD) path (Kainuma et al., 2012). However, such changes in the economic development path raises many questions for the policy makers in the developing countries related to its implications on the national energy security, environmental emissions, domestic economy, household welfare, and so on. It is crucial to answer these questions before adopting any new national and international policies if successful and objective oriented implementations of such policies are to be expected.

Nepal represents a small economy developing country which possess a huge untapped hydropower potential. However, it depends excessively on imported fossil fuels for her major economic activities. The country's increasing dependence on fossil fuels has resulted in the degredation of the local environment, increased the energy import dependency and amplified the economic vulnerability. The Government of Nepal (GoN) has recently introduced the Climate Change Policy 2010, which states the main objectives as (i) promotion of the use of clean and renewable energy resources in the country and (ii) adoption of climate friendly socio-economic development by following a low carbon development path (MOEV, 2010). It also envisages formulating the national low carbon development plan by 2013. The GoN had introduced national hydropower development policy in 1992 which emphasized the use of hydropower to reduce fossil fuel consumption and reduce dependency on imported energy resources (WECS, 2005a). GoN had adopted 25-year National Water Resources Strategy 2002, and one of its objectives was to optimize the use of indigenous hydropower resource by diversifying the use of electricity (WECS, 2005a). The GoN had introduced a medium term plan to develop 10,000 MW hydropower by 2020 dedicated to domestic market and export (MOWR, 2009). Later, it was revised to develop 25,000 MW of hydropower by 2030 and also mentioned the potential to develop up to 37,628 MW by that year (MOE, 2010). The GoN has issued the National Transport Policy 2001/02 which emphasized the reduction of harmful environmental emissions from the transport sector by promoting hydro-electricity based transportation system throughout the country (NESS, 2003). Recently, the GoN has come up with the long term plan to introduce electric railway system joining east to west of the country and also connecting the major cities (Kathmandu and Pokhara) (RITES/SILT, 2010).

1.2 Problem Statement

An increasing trend of anthropogenic GHG emissions and resulting negative impacts of climate change has forced both the developed and developing countries to rethink on the formulation and implementation of measures towards adopting a LCD path that would reduce GHG emissions and promote sustainability of the society simultaneously. Since energy is the main indegrient for economic development and also the main source of anthropogenic GHG emissions, the only way of achieving sustainable development is through switching to the low carbon energy resources and technologies. There exist an important and a complex relationship between economic development, energy, and the environment, usually referred to as the 3Es (Nakata et al., 2011). As such, policies based on the LCD pathway have to be studied from 3Es perspective for complete insight in a holistic manner (Kainuma et al., 2012; Nakata et al., 2011). There are limited studies at present that focus on the long term implications of LCD based policies from 3Es perspective especially in case of developing countries (Kainuma et al., 2012; Nakata et al., 2011). The present study attempts to contribute to the literature related to the long term implications of selected LCD based policies, namely transport electrification policy and Carbon tax (C-tax) policy in the developing country framework.

Energy (supply) security has been a matter of serious concern, especially for the energy importing developing countries. The rising prices of fossil fuels and the growing dependence of such countries on imported fuels have increased their economic vulnerability. The case of Nepal is a good example. The country is one of the low income developing countries and has to spend more than its total merchandise export earnings just for importing fossil fuels in 2007/08 (MOF, 2009). The transport sector accounts for above 35% of the imported fossil fuel consumption in 2005 and its share is growing (MOF, 2009; WECS, 2006a). If this trend continues, there would be a big question regarding the sustainable supply of the energy in future. As the country has to meet its entire demand for petroleum products through import, one of the long term national strategies to reduce the dependence on oil is to diversify the energy mix through greater use of its indigenous resources like hydropower. Thus, formulation and implementation of policies focused on substantial utilization of indigenous hydropower emerge as an important national strategic option. In addition, increasing air pollution (mainly due to the vehicular emissions) is creating acute environmental and health problems mostly in the urban areas of the country (ADB/ICIMOD, 2006; Shrestha and Rajbhandari, 2010). This indicates the need for the formulation and implementation of the national climate policy focused on the effective mitigation of environmental emissions in the long term for the country.

Studies have shown that developing countries are more vulnerable to the impacts of climate change (Maplecroft, 2011). Recently, published climate change vulnerability index (CCVI) by Maplecroft ranked Nepal among the countries with extreme risk of environmental, economic and social impacts due to the climate change in the next 30 years (Maplecroft, 2011). Though, developing countries (non-Annex I) are not obliged to reduce GHG emissions in absolute term at present, recent studies have shown that their participation is a must for the substantial reduction of GHG emission in order to stabilize long term GHG concentrations at 450 ppm CO_2e or lower by end of this century (corresponding to global average temperature limit between 2.0 and 2.4°C) (Blanford et al., 2009; den Elzen and Höhne, 2010; IPCC, 2007b; UNEP, 2010). Under these circumstances, there is a need to study the potential of the medium and long term GHG emissions mitigation in the developing countries. In the face of the rapidly growing fossil fuel consumption and their associated negative implications for national energy security, environmental quality and health in most developing countries, some of the climate change related policies can be attractive to the policy makers of these countries more for their local and national level benefits rather than for climate change mitigation per se.

Policies on the promotion of a transport sector electrification based on indigenous cleaner energy resource and introduction of emission tax on the GHG emitting fuels can be promising strategic options to promote hydropower development, enhance national energy security and reduce the country's macroeconomic vulnerability. Such policies are also expected to reduce emissions of GHG and local air pollutants as well as create employment. However, introduction of these policies is expected to bring distortions in the (existing) national economy in terms of change in the structure of the production sectors, national welfare, energy intensity, emission intensity and other economic impacts. These macroeconomic implications need to be studied and properly addressed for minimizing the negative effects of such policy on the national economy.

a) Transport electrification policy

There are only a limited number of studies that considered the effects of transport sector electrification on the national energy system development, environment, energy security and energy system costs (Kazim, 2003; Kim and Moon, 2008; Nakata, 2003; Sadeghi and Hosseini, 2008; Shrestha et al., 2008). Most of the studies were conducted at the sectoral level and failed to capture the overall implications for the entire national energy system and the environment. Sadeghi and Hosseini (2008) studied only the energy mix and cost implication of the modal shift to mass transport system (intra city mass rapid transport (MRT), railway) for Iran. Shrestha et al. (2008) examined the effects on CO_2 reduction through the modal shift in passenger transport supply to one based on electrified MRT for Thailand, while Kim and Moon (2008) studied the effects on energy mix and CO_2 emission by introducing hydrogen vehicles in Korea. The effect on CO_2 emission of introducing hybrid and fuel cell vehicles in the passenger transport system in the case of Japan has been studied by Nakata (2003). However, these studies neither considered emissions of non-CO_2 GHG (CH_4 and N_2O) and local environment pollutants nor did they rigorously analyze the effects on the entire national energy system. Kazim (2003) examined the changes in the technology cost and local air pollutant emission by the introduction of fuel cell vehicles in the case of United Arab Emirates. However, the study did not consider cost optimization as an objective.

There exist only a few studies that assessed the potential for GHG mitigation of electric railway and trolley bus options in the case of Nepal (ADB, 2004; Pradhan et al., 2006; PREGA, 2006a) and hydrogen vehicles (Ale and Shrestha, 2009; UNEP/CES, 2005), and the effects of reducing the cost of electric vehicles on electricity demand and CO_2 reduction (Shrestha, 2007). There is a research gap on a comprehensive analysis of the implications of the transport sector electrification for hydropower development, emissions of GHG and local pollutants, energy security, employment benefit and energy system costs from a long term integrated energy sector planning perspective in the context of a developing country.

Apart from energy and environmental issues, there exist economic issues relating to structural change in the domestic production sectors, national welfare, energy intensity and emission intensity due to the flow of investment and other intermediate inputs to transport and electricity sectors from other sectors under transport electrification policy. This is a peculiar problem especially for small economy country like Nepal with limited domestic investment capacity to finance large-scale hydropower and transport electrification projects. As such it is likely to be invested with large share of foreign direct investment (FDI). When introducing large scale of FDI, there is the possibility of detrimental impacts on the other sectors, especially export oriented manufacturing sector (Dutch disease effect), of the economy. Besides, there is also likelihood of significant effect on the national welfare of the country.

There are few studies on macroeconomic effects of investment flow in the transport and hydropower sectors of developing countries. Effect of investment in energy sector in developing country context has been studied (Barry, 2009; Benjamin et al., 1989; Chuanyi, 2009; Chuanyi et al., 2010; Dhungel, 1996; Kojo, 2005; Kyophilavong and Toyoda, 2008; Osmani et al., 2007; Warr, 2006). Kyophilavong and Toyoda (2008) and Warr (2006) have studied macroeconomic effects of investment flow in the hydropower sector of Loa PDR. Macroeconomic effects of hydropower development in Paraguay have been studied by Dhungel (1996). Kojo (2005) and Osmani et al. (2007) have studied macroeconomic implications of investment flow in hydropower sector of Bhutan. However, studies of Dhungel (1996), Kojo (2005), Kyophilavong and Toyoda (2008) and Osmani et al. (2007) are based on partial equilibrium models. At the same time the study by Warr (2006) is based on very much aggregated one consumer and two sectors based “1-2-3” general equilibrium model framework (Devarajan et al., 1993). Similarly, Chuanyi et al. (2010) used static computable general equilibrium (CGE) model and Chuanyi (2009) used recursive dynamic CGE model to analyze effect of investment increase in energy sector of Shaanxi province of China on the sectoral GDP distribution and export. Benjamin et al. (1989) used static CGE model to study impact of oil boom on the other traded and non-traded sectors of the Cameroon economy. Barry (2009) used static CGE model to investigate implication of FDI flow in the energy sector on the trade balance of Central Asia (Turkmenistan, Uzbekistan and Kazakhstan). However, most these studies did not use energy as a separate factor of production and did not disaggregate the electricity sector.

Several studies have analyzed the effects on the national and regional economy due to the investment flow in the transport sector. Siddiqui (2007) used dynamic CGE model to study the effect of tax financed public investment in the transport service sector and transport infrastructure in Pakistan. Gilbert and Banik (2010) analysed the impact of investment in international land transport infrastructure in India, Sri Lanka, Bangladesh, Nepal and Pakistan using static CGE model. Estache et al. (2008) used static CGE model to study the effects of investment in the infrastructure related to road, electricity and telecommunication in Tanzania, Uganda, Senegal, Mali, Benin and Cameroon. Similarly, Kim and Hekings (2003) have analysed effects of investment in highway construction on the regional GDP and welfare in Korea using transport network-multiregional CGE model. These studies did not disaggregate the transport sector elaborately representing electic and non-electric modes of transportation and the power supply sector was not disaggregated.

There is a gap in the studies related to the macroeconomic implications of transport sector electrification resulting in investment flow in power sector and transport sector in the context of developing country. In case of Nepal, no such study has been done. In this context, it would be useful for policy makers in the country and abroad to get acquainted with the implications of LCD options such as transport sector electrification in the context of the small economy country with large hydropower resources. The results of the study can be useful in devising appropriate measures to avoid or mitigate negative effects of the policies considered here.

b) Carbon tax policy

Economic instruments, such as C-tax, for reducing emissions have been widely adopted in Denmark, Finland, Italy, Netherlands, Norway, Sweden and Switzerland, but are rare in developing countries. Studies on the effects of C-tax on indigenous energy resource development, energy security, local pollutants emission and energy system cost with reference to developing countries are limited. Most of the studies are conducted at the sectoral level and fail to capture the overall implications on the entire national energy system, environment and economy. IIM (2009) and Shukla et al. (2008) studied the effect of C-tax on energy system for India, but did not analyze the effect on energy system costs, non-CO_2 emissions (CH_4 and N_2O) and local pollutants co-benefits beside sulphur dioxide (SO_2). Jegarl et al. (2009), Mathur et al. (2003), Limmeechokchai and Hieu (2003), Santisirisomboon et al. (2001), Shrestha and Marpaung (1999) and Shrestha et al. (1998) have examined the effect of C-tax on the power sector only but not on the overall national energy system. Shrestha et al. (2008) have studied the effect of C-tax policy on national GHG mitigation in Thailand but did not highlight the extent of the energy system costs and broader local pollutants emission (except SO_2 and Nitrogen oxides (NO_X)). No study so far has analyzed the implications of a C-tax on the national energy system, environment and economy for Nepal. There is research gap on the implications of the C-tax in the context of a developing country, in particular a hydropower resourceful one.

The literature on impacts of C-tax on the overall economy of European countries and other industrialized countries are extensive (see e.g., Andre et al., 2003; Drouet et al., 2006; Palatnik and Shechter, 2010; Siriwardana et al., 2011, Wissema and Dellink, 2007). There are also a number of studies on economic implications of introducing C-tax in developing countries (Devarajan et al., 2009; Quasem et al., 2008; Timilsina and

Shrestha 2002, 2007; Van Heerden et al., 2006; Winkler and Marquard, 2009; Xu, 2010; Yusuf and Resosudarmo, 2007; Zhong, 1998; Zhou et al., 2011).

Van Heerden et al. (2006) have used static CGE approach to study the economic and environmental implication of different environmental tax, namely, C-tax, fuel tax, electricity tax and energy tax for South Africa. Another study on the effects of C-tax on the CO_2 emission and welfare was carried out for South Africa by Devarajan et al. (2009) following static approach. Timilsina and Shrestha (2002, 2007) have used the static CGE model of Thailand to study the economic and environmental effects of C-tax along with sulphur tax, energy tax and output tax for reducing CO_2 emission by 10% from the base case. Yusuf and Resosudarmo (2007) used the static CGE model of Indonesia to determine the economic effects of C-tax in the country. Macroeconomic effects of limiting CO_2 emissions by introducing different level of C-tax have been studied by Quasem et al. (2008) for Malaysia by using static CGE model.

Recursive dynamic CGE approach has been used by Zhong (1998), Xu (2010) and Zhou et al. (2011) to study the economic effects of different levels of C-tax in case of China. Zhong (1998) analysed the change in the Gross National Production (GNP), aggregate gross output and household welfare under the C-tax application. Xu (2010) studied the structural change of the production sector and resulting carbon emissions under the application of C-tax during 2008 to 2020. Similarly, Zhou et al. (2011) analysed the impacts on energy production, energy intensive sectors, and on household income under C- tax policy.

The main limitation of these studies on C-tax policy for developing countries is the lack of extensive representation of emission and technology details in selected sectors. None of the studies considered the non-CO_2 GHG emissions which is expected to have significant share in case of developing countries as most of the developing countries depends on the biomass predominantly. They have not used technology specific disaggregation in any production sectors and consumption. Details on the main results of the study mentioned in this section are given in Chapter 2. This study has attempted to fill the gap in these issues by adopting hybrid CGE model with detail technology level disaggregation in the electricity and transport sectors. It also includes non-CO_2 GHG emissions consisting of CH_4 and N_2O with their technology specific and sector specific emission factors calibrated with the help of Nepal-ESM model.

1.3 Objectives of the Study

General Objective

To study the energy, environmental and economy-wide implications of selected low carbon development strategies (transport sector electrification and carbon tax) in Nepal under the small economy and developing country frame work.

Specific Objectives

1. To investigate the effects of transport sector electrification on hydropower development, energy supply mix, energy system cost, energy security and environmental emissions.
2. To examine the economy-wide effects of transport sector electrification and study the role of foreign direct investment under the policy.
3. To analyze the effect of carbon tax under different stabilization targets on the hydropower development, energy supply mix, energy system cost, energy security and environmental emissions.
4. To examine the economy-wide consequences of carbon tax and study the effects of transferring (recycling) carbon tax revenue to the household.

1.4 Scope and Limitations

Nepal-ESM model has been developed focusing on the national energy system of the country as representative as possible under available data and information of the country. The outcome of the analysis based on results of the model can be helpful to policy makers and related stakeholders in understanding the energy, environment and economy-wide implications of the selected LCD strategies related to transport sector electrification and C-tax. The policy makers can use the information from this study to adopt additional mechanisms to avoid any negative implications of these LCD strategies. Nepal-ESM model can be used for analyzing the policy related to imposing energy tax, renewable energy portfolio standards, specific technology penetration in supply and demand side, implications of price and demand shock etc.

This study has used emission factors as well as some technology and cost data from various international sources in the absence of country specific database. There is a need to establish a comprehensive energy and environmental database of the country in order to improve the assessment of similar nature.

Similarly, Nepal-CGE model has been developed using a multi-sectors social accounting matrix (SAM) focusing on the detailed representation of the electricity sector and transport sector. Here it is only used to analyze economy-wide implications interms of sectoral distribution of the national economy, household welfare, energy and GHG emissions intensities under selected LCD policies in Nepal. The model can be further upgraded to analyze other issues like implications of investment in other sectors, welfare distribution among different households, effects of change in tariff and tax structure etc. These issues are left for further study.

The SAM for the base year 2005 has been developed for the purpose of this study based on the 2000/01 input-output table (IRPAD, 2007) which did not contain disaggregated electricity and transport sectors. The specific procedure was adopted for disaggregation of those sectors (as discussed in Chapter 7). Being a single country model, Nepal-CGE model cannot represent the change in the international prices of factors and commodities under the policies considered. As such, result of Nepal-CGE model has to be interpretated under these limitations.

1.5 Organization of the Report

This report is comprised of ten chapters. Chapter 1 presents a background, problem statements and research gaps, objectives as well as scope and limitations of the study. Chapter 2 deals with the literature reviews on energy-environment-economic (3Es) modeling and 3Es implications of transport electrification policy and C-tax policies in the context of developing countries.

Chapter 3 describes the methodology used in the study. Formulation of a Nepal-ESM model is discussed in Chapter 4. Implications of transport sector electrification on hydropower development, energy security, environmental emissions and employment generation are presented in Chapter 5. This is followed by the discussion on the implications of C-tax on the hydropower development, energy security, local pollutants emission and employment generation in Chapter 6.

The formulation and calibration of Nepal-CGE model is described in Chapter 7. Next, Chapter 8 presents the potential macroeconomic consequences of the transport electrification policy in Nepal. The macroeconomic effects of C-tax policy are discussed in Chapter 9. Finally, Chapter 10 summarizes the results and provides recommendations for policy makers and relevant stakeholders. Further research work is also highlighted.

Chapter 2

Literature Review of Transport Electrification and carbon tax policy in the context of developing country

This chapter presents a review of existing development in the field of integrated energy-environment-economic modeling in the first part. It discuss the different types of modeling approaches used for studying issues related to low carbon development (LCD) and its implications in terms of energy, environment and economy with a special focus on transport electrification policy and carbon tax policy in the developing country framework.

2.1 Reviews on Energy-Environment-Economic Modeling for analyzing LCD policies

An increasing trend of anthropogenic greenhouse gas emission and resulting negative impacts of climate change has brought together both the developed and developing countries in the international forum to formulate and implement measures and policies towards adopting the climate friendly economic development path that would reduce GHG emission and promote sustainability of the society in the short, medium and long terms. Since energy is the main component for economic development and also the main source of anthropogenic GHG emissions, one way of achieving sustainable development of the society is through switching to the low carbon energy resources and technologies. The process of economic development considering de-carbonization of the energy is termed as low carbon development (LCD) and also referred to as low carbon society (LCS) (Nakata et al., 2011). There exists important and complex relationship between economic development, energy, and the environment, usually referred to as the 3Es or trilemma concept (Nakata et al., 2011). The 3Es concept brings together three goals, namely, economic development, supply of energy sources, and environmental protection. Policies based on the LCD path have to be studied from 3Es concept for complete insight in holistic manner as they have medium and long term effects on the economic development, energy system, and environment.

In order to device effective plans and policies as well as implement them in an efficient and sustainable manner it is very important to understand and know the possible outcomes, so that appropriate actions can be taken to maximize benefits and minimize losses during implementation. This is carried out by developing a virtual replica of the system through models. Modeling of a system is an approximate representation of the reality that is manageable in yielding certain insights or conclusions not obtainable from direct observations of the actual system due to its complexity (Nakata et al., 2011).

An energy system related model can be characterized mainly by two analytical approaches. The first approach consist of the top-down approach, which is based on the broader economic framework, use of aggregated economic variables and a simplified representation of production and consumption technologies. It uses aggregated data to examine interactions between the energy sector and other sectors in the economy and the overall macro-economic performance of the economy in terms of economic responsiveness to the policies, for example input substitution, structural change, output adjustment, trade effects, national welfare, emission and energy intensity, etc.

Its main disadvantages are poor representation of specific technologies and other physical parameters which may be relevant for an appropriate assessment of energy or climate policies (Schumacher, 2007; van Vuuren et.al, 2009). In addition, it considers different substitution elasticities which are calibrated to base year information or, in the case of econometric models, estimated based on historical data. These parameters, however, may change in the future in response to the availability of new technologies with their inherent characteristics and in response to new policies. Most top-down models are not able to cope with such radical or even incremental changes, and their simulations into the future (baselines) remain bound to the behavioral and technical structure of the base year or past trends (Schumacher, 2007).

The next approach is the bottom-up approach (also referred as the engineering approach), which is based on an extensive representation of the energy sector and selection of the supply side and demand side technologies are based on their performance (least cost option). In contrast to the top-down models, the bottom-up models use highly disaggregated data for describing energy end-uses and technological options in the model. In the bottom-up models, it is usually assumed that consumers' decisions are based on cost-effectiveness and disregard the behavior of markets (Nakata et al., 2011). In other words, bottom up models operate in partial equilibrium condition of energy sector only. It's main disadvantage is the lack of macro-economic feedbacks between the energy and other economic sectors, such as energy price-induced changes of production and consumption patterns, trade and other market behaviors (van Vuuren et.al, 2009). Discussion of the specific features, advantages, weaknesses and caveats of each of these two approaches can be found in several studies e.g. Bataille et al. (2006), Hourcade et al. (2006), Loschel (2004), Nakata et al. (2011) and van Vuuren et al. (2009). Table 2.1 shows the main features of top-down and bottom-up modeling approaches. The comparision of these two types of models are made in the table based on level of disaggregation, representation of behavior and technologies, consideration of technological change, methodological approach, efficiency gap, hidden costs and market barriers of new technologies, and transaction costs associated with removal of market barriers.

Recently, efforts have been made to compensate the limitations of these two approaches by the development of hybrid type of models that incorporate features from one model type into the other and aim at combining features of both model types (Schumacher, 2007). The bottom-up models are extended by adding macro-economic feedbacks into the model or include micro-economic decision-making characteristics (Schumacher, 2007). Following, the above approach, MARKAL-MACRO (Manne and Wene, 1992) adds a growth model and economy-wide production functions to the partial equilibrium optimization MARKAL model. Likewise, MARKAL-ED (Loulou and Lavigne, 1996) incorporates demand elasticities for some key products in the MARKAL model. A similar approach is adopted in MERGE (Manne et al., 1995). An energy system model is solved in an iterative process with an economy model allowing for feedbacks between the two models in case of MESSAGEMAKRO model, (Rao et al., 2006). In the CIMS model, hybrid approach includes provision for feedbacks between energy demand, energy supply, and macroeconomic modules through iteration process (Bataille et al., 2006; Jaccard et al., 2003).

Table 2.1: Main features of top-down and bottom-up modeling approaches (Nakata et al., 2011)

Criteria	Bottom-up	Top-down
Level of disaggregation	High: a range of energy end-uses	Low: 1 - 10 sector represented
Behavior representation	Detailed at end-use level but not comprehensive	Comprehensive, but few energy relevant details
Representation of technologies	Based on engineering and cost data Description of physical flows	Based on macro input-output/econometrics analysis Production functions determine substitution possibilities
Technological change	Assumptions on market share or optimization Projections of technological efficiency	Price and income effects Mostly based on exogenous technological change
Methodological approach	Spreadsheet-based analysis Simulation/optimization models	Econometrics or calibration based on a single year Economic growth estimated or exogenous
Efficiency gap	Energy markets are not efficient Potential for cost effective energy savings	No energy efficiency gap except in case of energy subsidies All markets are fully competitive
Market barriers and hidden costs of new technologies	Prevent adoption of new technologies	Cost of adopting new technologies are reflected in observed behavior
Transaction costs of removing market barriers	Low	High

Top-down models on the other hand are extended by adding explicit technological modules to the models and allowing a choice between these technologies over time (Edenhofer et al., 2006; McFarland et al., 2004; Sands, 2004; Schumacher, 2007; Schumacher and Sands, 2006; Welsch, 1998). Schafer and Jacoby (2006a, 2006b) and

Proost and van Regemorter (2000) devoted their effort to coupling detailed energy models, such as MARKAL, with CGE frameworks for transport technologies and energy services respectively. Bohringer (1998) and Bohringer and Loschel (2006) used advanced mathematical techniques to link a CGE model with bottom up activity analysis for electricity generation while other sectors are represented by conventional functional forms used in top-down analysis. There exist various theoretical, analytical, computational complexities of combining the two approaches. One of the main challenges is the construction of an integrated database (Schumacher, 2007). Engineering and economic data are most often not consistent and calibration of a model based on both types of datasets remains a challenge (Sue Wing, 2006a, 2006b).

2.2 Environmental and Energy Security Implications of Transport Sector Electrification

Decreasing the petroleum fuel consumption in the transport sector has multifaceted benefits for a country, especially for those developing countries that depends entirely on imported petroleum products. Electrification of the transport sector is seen as one of the promising strategy to improve energy supply security and reduce harmful environmental emissions for those countries with sufficient renewable energy resource for clean electricity generation. Several country level studies have been done to analyze the effects of transport sector electrification on the national energy system development, environment, energy security and energy system costs (Kazim, 2003; Kim and Moon, 2008; Nakata, 2003; Sadeghi and Hosseini, 2008; Shrestha et al., 2008). Most of the studies were conducted only at the sectoral level and failed to capture the overall implications for the entire national energy system and the environment.

A summary of the national level studies related to implications of transport electrification policy on energy, environment and energy system cost is given in Table 2.2. Sadeghi and Hosseini (2008) studied only the energy mix and cost implication of the modal shift to mass transport system (intra city mass rapid transport (MRT), railway) for Iran. They have found that there is a decrease in fuel consumption and reduction in system cost of transport system under modal shift compared to the reference case. Shrestha et al. (2008) examined the effects on CO_2 reduction through the modal shift in passenger transport supply to the one based on electrified MRT for Thailand and found significant reduction in CO_2 emissions. The study has reported decrease in CO_2 emissions under modal shift. Kim and Moon (2008) studied the effects on energy mix and CO_2 emissions of introducing hydrogen vehicles in Korea and have reported a decrease in CO_2 emissions, improvement in energy efficiency and energy security in addition to decrease in CO_2 emission. The effect on CO_2 emission of introducing hybrid and fuel cell vehicles under energy tax policy in the passenger transport system in Japan was studied by Nakata (2003). However, these studies did not consider emissions of non-CO_2 GHG (CH_4 and N_2O) and local environment pollutants nor did they rigorously analyze the effects on the entire national energy system. Kazim (2003) examined the changes in the technology cost and local air pollutant emission from the introduction of fuel cell vehicles in the case of United Arab Emirates. The result shows decrease in the local pollutants emissions and costs associated with vehicle and pollutants cleanup cost. However, their study did not consider cost optimization as an objective.

Most of these studies do not have a comprehensive analysis of the implications of the transport sector electrification in terms of energy security, hydropower development, emissions of GHG and local pollutants, employment benefit and energy system costs from a long-term integrated energy sector planning perspective in the context of a developing country.

2.3 Environmental and Energy Security Implications of Carbon Tax in Developing Country

Effects of C tax have been thoroughly studied in the developed countries (Endo, 2007; Levin et al., 2011; Martinsen et al., 2007; Nakata and Lamont, 2001; Schmidt et al., 2011). There are only a few studies that analyze the effects of carbon tax on indigenous energy resource development, energy security, local pollutants emission and energy system cost with reference to developing countries. Most of the studies are conducted at the sectoral level and fail to capture the overall implications on the entire national energy system, the environment and the economy.

National level studies related to implications of carbon tax policy on energy, environment and energy system cost in developing countries is presented in Table2.3. Shukla et al. (2008) and IIM (2009) have studied the implications of introducing C tax corresponding to the global carbon price trajectory for carbon dioxide equivalent (CO_2e) stabilization targets of 550 and 450 ppmv CO2e concentrations respectively for India during 2000-2050. Shukla et al. (2008) mentioned 38.6% decrease in the cumulative CO_2 emission during 2010-2050 under C-tax (with carbon price for 550 ppmv CO_2e stabilization target) scenario compared to the base case scenario. Shukla et al. (2008) found that the power sector dominates with over 64% share in the total CO_2 emissions mitigated under the C-tax scheme compared to base case and there would be significant increase in nuclear and carbon capture and storage (CCS) based power generation. Similarly, IIM (2009) mentioned 48.1% decrease in the cumulative CO_2 emission and increase in the final energy consumption (due to increase in biomass) during 2010-2050 under C-tax (with carbon price for 450 ppmv CO_2e stabilization target) scenario compared to the base case scenario. It mentioned power sector consititutes over 67% of the total CO_2 emissions mitigation with significant increase in nuclear and CCS based power generation. In addition, both Shukla et al. (2008) and IIM (2009) found the adverse impact on the national energy security with higher import of uranium under C-tax. However, neither study considered the effect on non-CO_2 GHG emissions (CH_4 and N_2O), energy system costs and emission of local pollutants except sulphur dioxide (SO_2).

Shrestha et al., (2008) have studied the effect of carbon tax policy on national GHG mitigation in Thailand. They mentioned 6.0% decrease in the cumulative CO_2 emissions during 2000-2050 and power sector plays dominant role with 70% share in total CO_2 emission reduction under C-tax (with carbon price for 550 ppmv CO_2e stabilization target) policy as compared to the base case. There was no significant improvement in energy import dependency under C-tax scenario. The nuclear and CCS based power generation plays the dominant role in CO_2 emissions reduction under C-tax. But it did not highlight the extent of change in the energy system costs and did not consider non-CO_2 GHG emissions and broader local pollutants emission.

Shrestha et al. (1998), Shrestha and Marpaung (1999), Santisirisomboon et al. (2001), Limmeechokchai and Hieu (2003), Mathur et al. (2003), Karki et al. (2007) and Jegarl et al. (2009) have examined the effect of carbon tax on the power sector only but not on the overall national energy system.

2.4 Macroeconomic Effect of Transport based Policies

Introduction of electrified transportation system is expected to results changes in the macro economy of the country in terms of GDP distribution, household welfare, energy and emission intensities of the GDP. Change in the overall economy mostly comes from the transfer of factors of production (capital and labor) and intermediate inputs among different sectors as transport electrification takes place. There would be major changes in the transport and electricity production sector under transport electrification. It would be followed by the change in the income level of the household due to the change in the returned on factor (capital and labor) investment and other financial transfers.

National level studies related to economy-wide effects of investment in transport and electricity sectors is presented in Table 2.4. Siddiqui (2007) have studied effects of public investment in the transport infrastructure by using dynamic CGE model and found that transport cost increase in the short run but decrease in the long run. Gilbert and Banik (2010) have used static CGE model to study the impact of invesrtment in the international land transport infrastructure and found that household wellfare and GDP increase in all five South Asian countries (India, Sri Lanka, Bangladesh, Nepal and Pakistan). Macroeconomic implications of investment in infrastructure (road , electricity and telecommunication) in six Sub Saharan African countries (Tanzania, Uganda, Senegal, Mali, Benin and Cameroon) were studied based on static CGE model by Estache et al. (2008). They have found decrease in the nominal exchange rate resulting slight Dutch disease effect when investment was increased in the infrastructure. Haddad and Hewings (2004) have found a positive gain in real GDP and household wellfare when transporttation costs were reduced in Brazil. Economic implications of highway projects were studied by Kim and Hekings (2003) using transport network-multiregional CGE model for Korea and have found an improvement in the regional GDP and household welfare under the projects. All these studies have not used energy as separate intermediate input of production.

Effect of investment in energy sector shows mixed effect among different developing countries. Different studies shows investment flow in hydropower sector results negative effect on export oriented sectors in case of Loa PDR (Kyophilavong and Toyoda, 2008; Warr 2006) and Paraguay (Dhungel, 1996), where as in case of Bhutan, the investment flow in hydropower sector results positive effect on the export oriented sectors (Kojo, 2005; Osmani et al., 2007). However, studies of Dhungel (1996), Kojo (2005), Kyophilavong and Toyoda (2008) and Osmani et al. (2007) are based on partial equilibrium models. At the same time study by Warr (2006) is based on very much aggregated general equilibrium model with one consumer and two production sectors framework (Devarajan et al., 1993).

Similarly, Chuanyi et al. (2010) used static computable general equilibrium (CGE) model and Chuanyi (2009) used recursive dynamic CGE model to analyze effect of investment increase in energy sectors of Shaanxi province of China on the sectoral GDP distribution and export. They have mentioned increase in GDP, household consumption and CO_2 emission when investment is increased in the energy sectors.

Benjamin et al. (1989) used static CGE model to study impact of oil boom on the other traded and non-traded sectors of the Cameroon economy. They have found positive effects on the export of manufacturing based commodities and negative effects on the export of agriculture based commodities. Barry (2009) used static CGE model to investigate implication of FDI flow in the energy sector on the trade balance of Central Asia (Turkmenistan, Uzbekistan and Kazakhstan). They have found positive effects on the export of energy commodities while decrease in the export of non-energy related commodities. However, these studies did not use energy as one of the production factors, and did not disaggregate the power sector.

2.5 Macroeconomic Effects of Carbon Tax Policy

Economic instruments, such as emission tax or energy tax, for reducing emissions have been widely adopted in most of the developed countries but are rare in case of developing countries. Many countries in Europe, for example, Denmark, Finland, Italy, Netherlands, Norway, Sweden and Switzerland have introduced carbon tax. The literature on impacts of carbon taxes on overall economy of European countries and other industrialized countries are extensive (see e.g., Andre et al., 2003; Drouet et al., 2006; Palatnik and Shechter, 2010; Siriwardana et al., 2011, Wissema and Dellink, 2007). There are also numbers of studies on carbon tax in the case of developing countries (Devarajan et al., 2009; Quasem et al., 2008; Timilsina and Shrestha 2002, 2007; Winkler and Marquard, 2009; Xu, 2010; Yusuf and Resosudarmo, 2007; Zhong, 1998; Zhou et al., 2011). National level studies related to macroeconomic effects of C-tax policy is presented in Table2.5.

Van Heerden et al. (2006) have used static CGE approach to study the economic and environmental implication of different environmental tax namely: carbon tax, fuel tax, electricity tax and energy tax for South Africa. They have found that real GDP and real consumption decreases in all cases of environmental tax compared to the reference case. If environmental tax revenue is recycled through a food tax handback, they all increase GDP and reduce poverty as well yielding triple dividends. Another study on the effects of C-tax on the CO_2 emission and welfare was carried out for South Africa by Devarajan et al.(2009) following static approach, where they have found fairly small welfare loss while achieving significant reduction in CO_2 emissions. They mentioned that the results hold true irrespective of elasticity of substitution in production.

Timilsina and Shrestha (2002, 2007) have developed the static CGE model of Thailand to study the economic and environmental effects of C-tax along with sulphur tax, energy tax and output tax for reducing CO_2 emissions by 10% from the base case. They have found that economic impacts of the C-tax such as, reductions in household welfare, GDP and gross output are significantly affected by revenue recycling scheme but the environmental impacts are not.

Yusuf and Resosudarmo (2007) have used the static CGE model to determine the economic effects of C-tax in Indonesia and have found that C-tax results contraction of energy intensive industry and expansion of agriculture and service sectors. C-tax also favors the lower income households due to the expansion of labor intensive agriculture sectors. Macroeconomic effects of limiting carbon emissions by introducing different level of C-tax has been carried out by Quasem et al. (2008) for Malaysia by using static CGE model. Thay have reported contraction in GDP and export under the C-tax introduction. Fixed capital investment increase under lower C-tax case but decrease under higher C-tax cases as compared to base case.

Recursive dynamic CGE approach has been used by Zhong (1998), Xu (2010) and Zhou et al. (2011) to study the economic effects of different levels of C-tax in case of China. Zhong (1998) reported the decrease in the GNP and welfare under the C-tax application. It mentions the aggregate gross output tends to decrease at an increasing rate of C-tax. Xu (2010) have found that C-tax increase the share of service sector in national production (due to less energy intensive compared to other sectors). It results smaller reduction in carbon emissions in 2020 terminal year, but greater accumulated reduction for the total simulation years (2008-2020). Similarly, Zhou et al.(2011) reported that imposing carbon tax will have adverse impacts on energy production, energy intensive sectors, and on household income.

The main limitation of these studies on C-tax policy for developing countries is the lack of an extensive representation of emission and technology details in selected sectors. None of the study considered the non-CO_2 GHG emissions which is expected to have significant share in case of developing countries as most of the developing countries depends on the biomass predominantly. They have not used technology specific disaggregation in any production sectors and consumption. This study has attempted to fill the gap of these issues by adopting hybrid CGE model with detail technology level disaggregation in the electricity and transport sectors. It also includes non-CO_2 GHG emissions, namely, CH_4 and N_2O with their technology specific and sector specific emission factors calibrated with the help of Nepal-ESM model.

Table 2.2: National level studies related to implication of transport electrification policy on environment and energy system cost

Reference	Country	Approach/ Model Name	Analysis details	Main Findings/Limitations
Sadeghi and Hosseini (2008)	Iran	EFOM-ENV	- Studied the energy mix and cost implication of the modal shift to mass transport system (MRT, train) by allowing the vehicle share to change in the fixed share of the base year in the base case	- Total discounted transport cost decreases under modal shift - Decrease in the fuel consumption - No consideration of GHG and local pollutant emissions, energy security
Shrestha et al. (2008)	Thailand	Partial equilibrium least cost optimization/AIM Thailand	- Examined the effects on CO_2 reduction from modal shift in passenger transport to electrified MRT	- Reduction in CO2 emission - No consideration of broader GHG and local pollutant emissions, no consideration of total energy system cost
Kim and Moon (2008)	Korea	Accounting scenario based/ LEAP model	- Studied the effects on energy mix and CO_2 emission from introducing hydrogen vehicles	- Decrease in CO2 emission, improvement in energy efficiency and energy security - Use non-optimization model - No consideration of broader GHG and local pollutant emissions, no mention of total energy system cost
Nakata (2003)	Japan	Bottom up, partial equilibrium/METANet	- The effect Btu (energy) tax on selection of cleaner and fuel cell passenger vehicles, on CO_2 emission, technology and fuel mix	- Energy tax help to introduce fuel cell vehicle, decrease CO2 emission - It does not analyze the impact on the supply side and over all energy system as well as effect on other pollutants

Reference	Country	Approach/ Model Name	Analysis details	Main Findings/Limitations
Ichinohe and Endo (2006)	Japan	Bottom up, partial equilibrium/MARKAL	- Effects of CO_2 reduction target (8% from 1990 levels by 2030) on passenger transport technology mix - Carbon tax (USD31/t-CO_2) and subsidize the hybrid vehicles	- Gasoline hybrid electric vehicles would be selected (62% by 2030) under the CO_2 emission reduction target - Carbon tax revenue collected at the carbon price of USD31/t-CO_2 is sufficient to finance required subsidy for penetration of the same level of the hybrid vehicle if CO_2 reduction target is not applied - It does not analyze the impact on the energy security, supply side options and over all energy system - It does not consider non-CO_2 GHG emission and other pollutants
Kazim (2003)	United Arab Emirates	Accounting method	- Examined the change in the technology cost and local air pollutant emission from the introduction of light duty fuel cells vehicles	- Decrease in the local pollutants emissions and cost associated with vehicle and pollutants cleanup cost - It does not use optimization model and consider GHG emission
Andress et al.(2011)	USA	Accounting method/VISION model	- Examined the change in the GHG emission under different level of penetration of plug-in hybrid and fuel-cell vehicles	- Reduction in GHG emission depends on the source of electricity supply and hydrogen production (coal, natural gas or renewable) - It does not use optimization model

Table 2.3: National level studies related to implications of carbon tax policy on energy, environment and energy system cost

Reference	Country	Approach/ Model Name	Analysis details	Main Findings/Limitations
IIM (2009) and Shukla et al. (2008)	India	MARKAL/AIM-CGE/AIM-SNAPSHOT/End-use demand soft linked hybrid model	- Studied the effect of carbon tax on energy system for India	- Reduction in cumulative CO_2 emissions by 38.6% under C-tax for 550 ppmv CO_2e stabilization target and 48.1% reduction under 450 ppmv CO2e target - Power sector dominates (above 60%) in the cumulative CO_2 emissions mitigation - Major penetration of nuclear and CCS technologies in power sector - Adverse impact on energy security - Did not consider effect on non-CO_2 GHG emissions (CH_4 and N_2O), energy system costs and local pollutants emission beside SO_2
Jegarl et al. (2009)	Korea	Power sector bottom up least cost optimization/ Korean Energy Strategy Project (KESP) MARKAL	- Examined the effect of carbon tax, carbon emission cap on the power sector	- Significant decrease in CO2 emission when new technologies including Pressurized Fluidized (PF) bed, carbon capture and storage (CCS) are introduced - Have not examined the effect of carbon tax on the overall national energy system
Mathur et al. (2003)	India	Power sector bottom up least cost optimization/ KESP MARKAL	- Examined the effect of carbon tax on the power sector fuel and technology mix, GHG emission	- More hydropower and wind becomes feasible under moderate and higher carbon tax - Have not examined the effect of carbon tax on the overall national energy system
Santisirisomboon et al. (2001)	Thailand	Least cost generation planning/ Wein Automatic system Planning (WASP IV) model	- Examined the effect of carbon tax on the power sector especially focusing on biomass based power plants	- Carbon tax results CO2 mitigation and promote biomass based power plants - Have not examined the effect of carbon tax on the overall national energy system

Reference	Country	Approach/ Model Name	Analysis details	Main Findings/Limitations
Limmeechokchai and Hieu (2003)	Vietnam	Least cost generation planning/ Wein Automatic system Planning (WASP IV) model	- Examined the supply side and demand side effects of carbon tax on the power generation expansion and CO2 emission from power sector	- At higher tax fuel switch from coal to gas and nuclear resulting reduction of CO_2 emission - Contribution of demand side not considerable under carbon tax due to low price eleasticity - Have not examined the effect of carbon tax on overall national energy system
Shrestha and Marpaung (1999)	Indonesia	Least cost generation planning/ Integrated Resource Planning (IRP) model	- Examined the effect of carbon tax on the power sector only	- At lower tax mitigation of CO2 mostly due to change in electricity price and at medium and higher prices it is due to technology and fuel switching - Have not examined the effect of carbon tax on the overall national energy system
Shrestha et al. (1998)	Pakistan	Least cost generation planning/ Wein Automatic system Planning (WASP III+) model	- Examined the CO2 emission reduction due to carbon tax on the power sector	- Lower carbon tax may not be effective to reduce CO2 emission from power sector - Have not examined the effect of carbon tax on the overall national energy system
Shrestha et al., (2008)	Thailand	Partial equilibrium least cost optimization/AIM Thailand	- Studied the effect of carbon tax policy on national GHG mitigation in Thailand	- Reduction in cumulative CO2 emission by 6% under C-tax for 550 ppmv CO2e stabilization target - Power sector dominates (70%) in the cumulative CO_2 emissions mitigation - Major penetration of nuclear and CCS technologies in power sector - No significant effect on energy security - Did not consider effect on non-CO2 GHG emissions (CH4 and N2O) and broader local pollutants emission

Table 2.4: National level studies related to macroeconomic effects of investment in transport and energy sectors

Reference	Country	Approach/ Model Name	Analysis details	Main Findings/Limitations
Siddiqui (2007)	Pakistan	Dynamic CGE model	- 18 production sectors, 2 factors, 2 consumer group - Growth in labor force and total factor productivity used as dynamic features - Transport sector disaggregated into land, water, air and other - Effects of taxed financed public investment in transport infrastructure and transport service studied	- Export increase - Wage rate increase on short run but decrease in the long run - Freight land transport and rural passenger land transport cost increase in the short run but decrease in the long run - Urban passenger transport decreases in short and long run - No energy factor used
Gilbert and Banik (2010)	5 South Asian countries (India, Sri Lanka, Bangladesh, Nepal and Pakistan)	Multi-country, regional, static CGE model	- 16 production sectors, 47 regional households - Studied impact of investment in international land transport infrastructure - Equivalent Variation (EV) approach used for measuring household welfare change	- Household welfare increase in all countries with largest gain for India - GDP increases in all countries with largest gain for Nepal - No energy factor used, no dynamic effect considered
Haddad and Hewings (2004)	Brazil	CGE/ B-MARIA-27 Model	- 27 Brazilian states, 8 sectors in each state, 8 commodities, one representative household, two factors - Effects of reductions in transportation costs	- Positive gain in real GDP growth and welfare (EV) and gain would magnify in the long-run - No energy factor used

Reference	Country	Approach/ Model Name	Analysis details	Main Findings/Limitations
Estache et al. (2008)	6 Sub Saharan African countries (Tanzania, Uganda, Senegal, Mali, Benin and Cameroon)	Static CGE model	- Studied effects of investment in the infrastructure funded by different fiscal tools (foreign aid, import duties, VAT funding, Income tax, transfer from other public sectors) - Only two scheme of investment is analyzed for each infrastructure investment - Infrastructure considered are road , electricity and telecommunication	- Increase in infrastructure investment produces slight Dutch disease effect with the level of negative impacts depending on the financing scheme used. - Investment in road increases GDP and house hold welfare. - Investment in road increases wage rate and decrease in nominal exchange rate with more negative impact under foreign aid funding than under transfer from public expenditure. - Investment in electricity increases wage rate and decrease in nominal exchange rate with more negative impact under income tax funding than under VAT funding. - Investment in electricity increases GDP and house hold welfare. - No energy factor used, no dynamic effect considered
Benjamin et al. (1989)	Cameroon	Static CGE model	- Study the impact of an oil boom on the economy of the country - Imperfect substitution between domestic and imported goods (Armington effect) assumed - 11 production sectors	- Not all traded sector gets negative effects - Agriculture trade sector get most hurt - Some manufacturing traded sectors get benefited. - No dynamic nature

Reference	Country	Approach/ Model Name	Analysis details	Main Findings/Limitations
Kim and Hewings (2003)	Korea	Transport network-multiregional CGE model	- Economic effects of highway projects - Network effects of set of highway projects on the economy	- Improves regional GDP and welfare due to highway construction - No energy factor used
Chuanyi et al. (2010)	Shaanxi Province of China	Static CGE/ THCGE-MRS model	- Two-regions, six agents, two factors (capital and labor), ten sectors recursive dynamic model - Investment in the energy sector is exogenous (Keynesian closure) - Analyzed short term effects on local economy growth, industrial structure and emission of CO_2 - Fixed assets investment in the energy sectors increased by 20%, 40%, 60% as compared to the base case investment	- GDP, household disposable income, employment, household consumption and CO_2 emission increases with respect to the increase in the scale of investment in energy sectors. - Scale of increment of the total export and transfer outward is higher than the total import and transfer inwards. - Growth of production is highest in the oil and gas sector followed by coal sector and electricity sector. - Static nature of the model and no energy factor used
Chuanyi (2009)	Shaanxi Province of China	Recursive Dynamic CGE/ MRDR model	- Total investment determined by total saving endogenously - analyzed long term effects on local economy growth, industrial structure and emission of CO2 - Fixed assets investment in the energy sectors increased by 20%, 40%, 60% as compared to the base case investment - Use of dynamic module for fixed capital investment, labor growth and technology progress	- GDP and CO2 emission increases with respect to the increase in the scale of investment in energy sectors in base year. - The percentage increased on the eighth year as compared to the base year under the increased level of investment in the base year for GDP is higher than the CO2 emission. - No energy factor used

Reference	Country	Approach/ Model Name	Analysis details	Main Findings/Limitations
Levy (2007)	Chad	CGE model	- Effect of oil revenue on the public investment (road and irrigation infrastructure) - 6 sectors, 2 factors used	- Dutch disease is not an unavoidable consequence of oil booms in Chad - Diversion of oil revenue to the public sector results GDP increase, improve rural household welfare - No dynamic nature and no energy factor used
Kyophilavong and Toyoda (2008)	Lao PDR	Macro-econometric model	- Impact of foreign capital inflow in the mining and hydropower sectors	- The foreign capital inflows in resource sectors stimulate the economic (GDP) growth - It results increase in price, appreciation of real exchange rate and decline in export - partial equilibrium model not CGE
Warr (2006)	Lao PDR	1-2-3 CGE model	- One consumer, Two sectors (agriculture and non-agriculture), two factors, multi-households approach - Studied the effect of transferring hydropower export royalties to the urban and rural households	- Real exchange (ratio of traded to non-traded goods prices) rate decline (appreciation) - Export contracts in both agriculture and non-agriculture sectors - Poverty level decreases as government transfer to rural households increases. - No dynamic nature and no energy factor used, Only two sectors considered

Reference	Country	Approach/ Model Name	Analysis details	Main Findings/Limitations
Barry (2009)	Central Asia (Turkmenistan, Uzbekistan and Kazakhstan)	Static CGE global model/ Global Trade Analysis Project (GTAP) model	- Effect of foreign direct investment (FDI) on the energy sector - 10 sectors, 8 regions and 5 factors used. - FDI in natural as sector increased by increasing productivity of the sector	- Natural gas sector get better off - Negative effects on the production on net exports of non-petroleum related industries - Decrease in the trade balance - Non- dynamic nature
Dhungel (1996)	Paraguay	Econometric methods	- Macroeconomic effects induced by large inflows of foreign capital associated with hydropower (Itaipu and Yacyreta) infrastructure development and electricity exports	- Higher inflation rate, appreciation of real exchange rate, decline in exports, and increase of wage during construction period (Dutch Disease) - A sustained depreciation of the official nominal exchange rate and controlled money supply would reduce impact - Indicate that electricity export will create Dutch Disease-type effects - Partial equilibrium nature
Holmoy and Heide (2005)	Norway	Dynamic CGE/ MSG6	- 2 factors, 60 commodities, 39 sectors, aggregate consumption is constrained by intertemporal budget constraint formulated as a non-Ponzi game condition on the accumulation of net foreign debt - Estimate sustainable path for wage growth and activity in the traded good sector under wind fall from petroleum rent	- Increase in petroleum rent based revenue results increase in the nominal wage rate and decrease in the growth rate of traded good sector in the long run - Maximum sustainable annual nominal growth rate of wage is 4.2% - No energy factor used

Table 2.5: National level studies related to macroeconomic effects of carbon tax policy

Reference	Country	Approach/ Model Name	Analysis details	Main Findings/Limitations
Devarajan et al. (2009)	South Africa	Static CGE	- 9 aggregated sectors, each sector has three types of energy inputs, coal, petroleum, and electricity & gas nested through Armington (or CES) aggregation function, the composite energy is imperfectly substitutable with capital - C-tax effects on CO_2 emission and welfare	- Welfare costs of achieving significant reductions in CO_2 emissions are fairly small - The welfare losses from a tax on carbon are small regardless of the elasticity of substitution in production - If the revenue generated can be used to reduce pre-existing tax distortions, the net welfare cost becomes negligible -
Timilsina and Shrestha (2002), Timilsina and Shrestha (2007)	Thailand	Static CGE	- 6 energy sectors and 15 non-energy sectors, production behavior nested through CES function, electricity sector is sub-divided into 7 technology level sub-sectors. - Effects of C-tax as well as sulphur tax, energy tax and output tax on national economy and environmental emission - Effects of revenue recycling through lump-sum transfer, increase in public consumption, reduction of direct income tax, indirect tax	- Welfare impacts from the two cases of revenue recycling are similar mainly because a direct income tax in a static model with no factor accumulation is similar to a lump-sum transfer - If the tax revenue is recycled to households through a lump-sum transfer, sulphur and carbon taxes would be more efficient than energy and output taxes

Reference	Country	Approach/ Model Name	Analysis details	Main Findings/Limitations
Yusuf and Resosudarmo (2007)	Indonesia	Static CGE model based on ORANI-G model,	- 38 production sectors and 43 commodities, energy commodity include coals, natural gas, gasoline, automotive diesel oil, industrial diesel oil, kerosene, LPG, and other fuels - Effect on sectoral GDP distribution under C-tax - C-tax revenue-recycling through uniform lump sum transfers and reduction in commodity tax among different income group	- C-tax results contraction of energy intensive industry and expansion of agriculture and service sectors - C-tax favors the lower income households - Revenue-recycling through uniform lump sum transfers may enhance the progressivity
Zhong (1998)	China	Recursive dynamic CGE model	- Includes 10 producing sectors, energy use is disaggregated into coal, oil, natural gas, and electricity nested through Cobb Douglas production function - Macro-economic and sectoral effects of C-taxes to cut China's carbon emissions in 2010 by 20 per cent and 30 per cent	- China's GNP drops by 1.5 per cent and 2.8 per cent, and its welfare reduces by 1.1 per cent and 1.8 per cent under 20% and 30% carbon emissions reduction scenarios, compared with the baseline case - Aggregate gross output tends to decrease at an increasing rate of C-tax
Van Heerden et al. (2006)	South Africa	Static CGE model similar to the ORANI-G CGE model	- 39 sectors - The environmental tax instruments considered are carbon tax, fuel tax, electricity tax and energy tax	- Real GDP and real consumption, decrease under environmental tax. - All environmental taxes reduce CO2 emissions, and if revenue is recycled through a food tax handback, they all increase GDP and reduce poverty: yielding triple dividends.

Reference	Country	Approach/ Model Name	Analysis details	Main Findings/Limitations
Siriwardana et al.(2011)	Australia	Static CGE model based on ORANI-G	- 35 sectors which produce 35 goods and services; energy sectors are disaggregated into black coal, brown coal, gas, auto petrol, kerosene, LPG, other petrol - Electricity supply sector is split to black coal electricity, brown coal electricity, oil electricity, gas electricity and renewable electricity - Economic and welfare effects of introducing C-tax of $23	- Introduction of C-tax results 0.68 % decline in GDP, 0.75% rise in consumer prices and 26% increase in the price of electricity as compare to base case - Results substantial cut in CO2 emissions by 12% - The tax burden is unequally distributed among different household groups with low-income households carrying a relatively higher burden
Xu (2010)	China	Recursive dynamic CGE model	- 38 production sectors including 8 energy sectors - Macroeconomic impacts of C-tax and cap-and-trade policies	- There is slight increase in GDP under cap-and-trade scenario, but over 3% decrease in GDP under C-tax scenario compared to base case in 2020 - C-tax cases bring about smaller reduction in carbon emissions in 2020, but greater accumulated reduction for the total simulation years (2008-2020) - C-tax increase the share of service sector in national production (due to less energy intensive compared to other sectors)

Reference	Country	Approach/ Model Name	Analysis details	Main Findings/Limitations
Zhou et al. (2011)	China	Dynamic energy-environment-economy CGE model	- 39 production sectors including 9 energy sectors - Energy sectors includes coal, oil, natural gas, oil refined products, coke, fuel gas, thermal power electricity, other electricity and heat - Economic effects of different levels of C-tax (carbon tax rate of 30, 60, and 90 RMB per ton CO_2)	- Reduce CO2 emission in the ragnge of 4.5% to 12.3% compared to base case. - Reduces CO2 emission intensity of GDP (in the range of 34.8% to 39.9%) - GDP decrease in the range of 0.11% to 0.39% in 2020 - Imposing carbon tax will have adverse impacts on energy production, energy intensive sectors, and on household income
Quasem et al. (2008)	Malaysia	Static environmental CGE model	- Consists of ten production sectors - Macroeconomic effects of limiting carbon emissions by introducing different level of C-taxes to reduce 1.21%, 2.08% and 3.17% of carbon emission	- Imposition of C-tax reduces the nominal GDP (in the range of 0.82% to 3.17%) and exports (in the ragne of 2.08% to 5.71%) compared to base line - Fixed capital investment increase in 1.21% reduction case but decrease in other reduction cases as compared to base line

Chapter 3

Methodology of Research

This chapter presents an insight on how the research was carried out to answer the research questions: What will be the effects on the energy system development, energy security, environmental and economic implications of transport sector electrification policy and carbon tax policy in Nepal. A bottom up, technology extensive, cost minimization, energy system model “Nepal-ESM" was developed to analyze the effects of those policies on the energy system development, energy security, energy system costs and both global and local environmental pollutants emissions. For studying the economy-wide effects in terms of GDP distribution, commodity trade, exchange rate, national welfare, energy intensity and GHG emission intensity a multi-sector, single region, recursive dynamic, computable general equilibrium model “Nepal-CGE” was developed. A soft link is established between those two models by using outputs related to the technology-wise distribution of transportation sectors under different scenarios of Nepal-ESM model as inputs in the Nepal-CGE model for analysing transport electrification policy. In case of C-tax policy analysis, the emission factor for CH_4 and N_2O emissions from different aggregated sectors (excluding technology level disaggregated transport and electricity sectors) and household consumption in Nepal-CGE model are derived from the emission per unit fuel used by corresponding sectors and household in Nepal-ESM model analysis as these emission are very much technology specific as contrary to the CO_2 emission.

3.1 Research Framework

The study was carried out by following the frame work as shown in figure 3.1. The study methodology consists of issues identification and research question, analytical model development, scenarios analysis and conclusion and policy reccommendations.

3.1.1 Issue Identification and Research Question

An extensive literature review was carried out on the issues related to the Low Carbon Development (LCD) based policies, especially focusing in the context of developing country framework. Two LCD related policies, namely, transport electrification policy and carbon tax policy were selected for further study. These policies were selected, as they were relevant in the context of increasing concerns for the meaningful participation of the developing world if we were to control the long term GHG emission so as to attain 2 degree temperature rise by the end of this century (Blanford et al. 2009; IPCC 2007b; UNEP, 2010). In addition, as Nepal is preparing to adopt the LCD path and also envisages to develop LCD plan by 2013 as mentioned in the recent Climate Change Policy 2010 of the country, detailed study on the long term implications of such policies will help the policy makers of the country and different stakeholders of the national and international communities to understand, develop and implement such policies in a most effective manner.

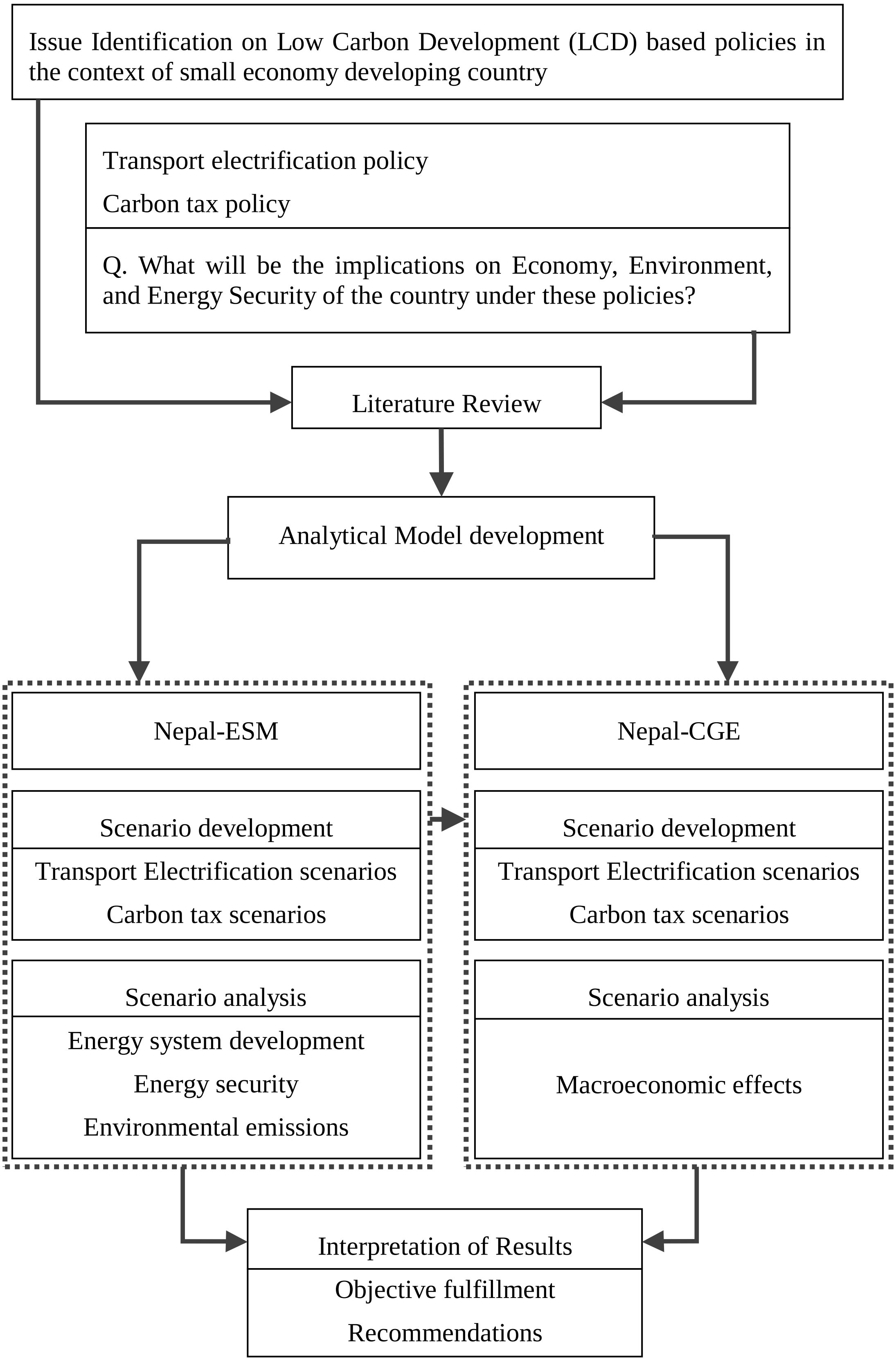

Figure 3.1 Research Frame work of the Study

Based on this, the following research questions were formulated to determine the overall implications of such policies:

a. What would be the effects of selected LCD policies on the energy system development and use of indigenous energy resource?

b. How would selected LCD policies affect national energy security?

c. What would be the implications of selected LCD policies on the emissions of GHG and local pollutants?

d. What would be the implications of selected LCD policies on GDP distributions, national household welfare, energy intensity and GHG intensity?

3.1.2 Analytical Model Development

Literature review on previous and ongoing studies on long-term energy, environmental and economic implications of transport electrification and C-tax policies were carried out. Analytical models were developed for analyzing the energy, environmental and economy-wide effects of selected LCD policies. A group of models is generally required to answer different questions related to the LCD policies as a single model cannot cover every thing (ESMAP, 2012). MARKet ALlocation (MARKAL) modeling framework was used for developing bottom-up energy system model of the country to analyse the implications of selected LCD policies in terms of the energy system development, energy system costs and environmental emission. Detail on the development of the energy system model of Nepal (hereafter, Nepal-ESM) is given in the Chapter 4. As bottom up type of model cannot address economy-wide implications (ESMAP, 2012; Nakata et al., 2011; van Vuuren et.al, 2009) due to the intervention of the policy under consideration, an original recursive dynamic Computable General Equilibrium (CGE) model of Nepal (hereafter, Nepal-CGE) was developed using GAMS PATHNLP program. A soft link was established between Nepal-ESM and Nepal-CGE by introducing technology mix of land freight and land passenger transport demand generated by Nepal-ESM under different scenarios during the analysis of transport electrification policy. Similarly, the sector specific emission factor of fuel for non-CO_2 GHG emission used in Nepal-CGE model was derived from the Nepal-ESM output. In order to calibrate energy consumption and resulting GHG emission under base case scenario between two models, minimum level was set for total investment through iteration process in each year. The labor growth rate in dynamic module of Nepal-CGE was set as same as the the population growth rate considered for end use demand projection under Nepal-ESM. The real GDP was used as exogenous independent variable for demand projections in Nepal-ESM where as it was considered as endogenous variable in Nepal-CGE. The discussion on the formulation and development of Nepal-CGE model is given in the Chapter 7.

3.1.3 Development of scenarios

Base case scenario and other policy related scenarios are developed to represent the objective questions under study. For analyzing transport electrification policy, one base case scenario and other five policy related scenarios representing penetration of different level of electric mass transport system and electric vehicles in the country. The details of the transport electrification scenarios used in the study are discussed in the Chapter 5.

In case of carbon tax policy analysis, one base case and there C-tax policy with different level of carbon tax were developed. The details of the C-tax scenarios used are explained in the Chapter 6. The scenarios representing macroeconomic effects of transport electrification policy and C-tax policy are discussed in the Chapter 8 and Chapter 9 respectively.

3.1.4 Scenario Analysis

The results of the base case scenario and different policy based scenarios are collected, tabulated and compared to analyze the implications of the policy under study. The detail discussions of the analysis of the results are given in Chapter 5, Chapter 6, Chapter 8 and Chapter 9.

3.1.5 Interpretation of Results

Interpretation of the results are done based on the fulfilling the objectives of this study. Conclusions and recommendations are given after analysis and interpretation of the results in Chapter 10.

Chapter 4

Formulation of a Nepal-ESM model

This chapter presents the development of a bottom up cost minimization energy system model of Nepal using MARKAL framework. It discusses the overview of MARKAL framework followed by development of physiographic, economic and sectoral disaggregations used in the energy system model of Nepal. It also presents the procedures followed for the projections of the energy service demands for the study period used in the model.

4.1 Overview of MARKAL based model

MARKAL is a bottom up cost minimization energy system model which was initially developed by the Energy Technology Systems Analysis Programme (ETSAP). MARKAL stands for MARKet ALlocation and the model is designed to produce optimized solution for fulfilling the end-use energy demand in the market using available energy resources under specified constraints based on minimization of the cumulative discounted annual total energy system cost during the study period. The total energy system cost comprises of energy supply and demand technology investment costs, net fuel import cost, domestic fuel cost, and supply and demand related operation and maintenance costs. The imposition of emission and other forms of tax is handled in the model by assigning resulting tax as an additional energy system cost. The model includes constraints on fulfillment of each type of service demand, availability of energy resources, and limits on power supply capacity (Loulou et al. 2004).

Standard MARKAL uses linear programming based solver for optimization. However, other versions of MARKAL using non-linear programming based solvers are also available (ETSAP, 2010). MARKAL model is designed to provide understanding to the planners, policy makers and academia about the interactions among energy use, environmental effects and economy of the energy system in the local, national, regional or global level. It has been used to analyze various energy and environmental issues by more than 80 institutions in more than 40 countries (Levin et al., 2011). Chapter 2 presents reviews relevant to this research using MARKAL framework in India (IIM, 2009; Mathur et al., 2003; Shukla et al., 2008), Korea (Jegarl et al., 2009) and Japan (Ichinohe and Endo, 2006).

4.2 Introduction of Nepal-ESM Model

The integrated national energy system model of Nepal consists of four modules namely: primary energy supply, conversion and process technology, end-use service demand and environmental emissions. Primary energy supply module represents extraction of primary energy from indigenous energy resources (mainly hydropower and biomass) and import of fossil fuels. Conversion and process technology module consists of secondary energy generation, transmission and distribution to the end-use services.

End-use service demand module contains five economic sectors namely agriculture, commercial, industrial, residential, and transport. These sectors are further subdivided into 114 end-use services. Environmental emissions consisting of GHG emissions (CO_2, CH_4 and N_2O) and local pollutants (CO, SO_2, NO_X, (Non-methane Volatile Organic Compound) NMVOC, and PM_{10}) are dealt with in the environmental emissions module.

The model is disaggregated into three physiographic regions (i.e., southern plain (popularly known as "Terai"), mid-hills, and northern mountains) to capture the differences in residential energy consumption patterns due to the physiographic variations. The physiographic regions have been further disaggregated into urban and rural sub regions to capture effects due to the level of development. The Kathmandu valley has been considered as a separate region of the mid-hills due to the large concentration of the economic activities and urban population in the valley. Detail physiographic and economic disaggregation in the model is shown in Figure.4.1.

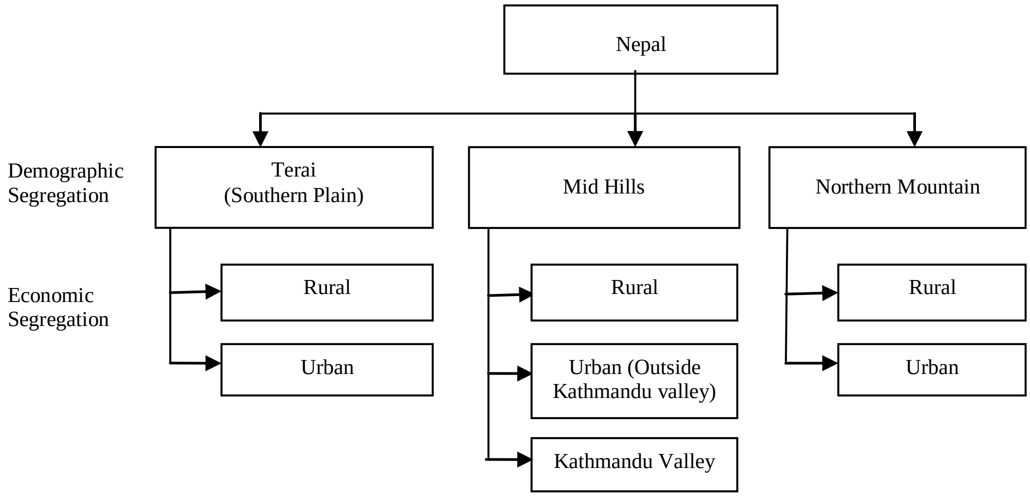

Figure 4.1: Detail physiographic and economic disaggregation use in the model

Residential sector is disaggregated into seven subsectors as mentioned above. Transport sector is disaggregated into freight and passenger transport subsectors in the Kathmandu valley and the rest of Nepal (RoN) in the absence of disaggregated data on transport demand by physiographic region as well as by urban and rural areas. For a similar reason, service demands in other economic sectors are considered only at the national level.

Demands for energy-using services for the base year 2005 are estimated by using data obtained from various published and unpublished sources. The major sources used for primary energy resource potential in Nepal are WECS (2006a), ADB/ICIMOD (2006) and PREGA (2006b). The demand and technology stock for the base year are estimated by using information from WECS (1999, 2000, 2001, 2005b, 2006b), CBS (2008) and NRB (2006). Energy technologies data are mostly used from NIES (2007), IEA (2005, 2008), USEPA (2006), TERI (2006), Gyawali et al. (2004) and Dhakal (2006).

4.3 Disaggregation of End-use Service Demands

Detailed disaggregation of end-use service demands are given in Appendix A. In the residential sector, energy consuming end-use service demands consist of lighting, cooking, water heating, space heating, space cooling, agro-processing and animal feed preparation and other electrical appliances. The subsectors considered in the commercial sector are, education, health, hotel and restaurant and other sectors. The end-use service demands consist of lighting, space heating, space cooling (air conditioner), water heating and other electrical appliances. In the residential and commercial sectors, technologies based on different types of fuels with different levels of energy efficiency are considered to meet above service demands. In addition, emerging technologies like light emitting diode (LED) lamps, LED and plasma technology based television sets (TVs), are also considered.

In the industry sector, the major manufacturing processes in Nepal are those related to the production of cement, brick, iron and steel products, sugar, pulp and paper. The rest are grouped as "other industries". Alternative standard production processes with different energy intensities are considered in the case of cement, brick, iron and steel products, sugar, as well as pulp and paper industries. In case of the other industries, the production process is differentiated into motive power and boiler applications. In motive power, conventional and efficient electrical options are considered where as in case of boiler application, different fuel based options (coal, wood, and diesel) together with conventional and efficient options are provided in the model. The cogeneration option has been considered for the sugar industry (CBS, 2008).

Demands for water pumping for irrigation and land tilling have been considered in the agriculture sector. Technology options based on different fuels and efficiency levels are considered for water pumping and land tilling services. A diesel and electricity based pumping options are provided for irrigation services. Conventional and efficient technology options are provided for both irrigation and tilling services. The level of irrigation related water pumping service demand has been set to reflect the target set by the GoN in its National Water Plan 2005 (WECS, 2005a).

In the transport sector, the end use service demand for land passenger transport is divided into six road based passenger transport modes, namely, bus, microbus, car, 2-wheelers, 3-wheelers, taxi. The land based freight transport has been disaggregated into three modal types, i.e., truck, tractor and pick-up. The transport service demands are considered for freight ropeway and passenger ropeway (cable car). Conventional transport technologies based on fossil fuels as well as new technologies based on electricity and fuel cell are also considered in the model. The options of electric mass transport system include electric surface rail mass rapid transit (MRT) system for the Kathmandu valley and electric train for the rest of the country. However as mentioned in MOPPW (2007), since electric train is less feasible in some mountainous terrain, the rope ways has been considered for those regions (considering its share with respect to the population distribution in that region). The electric mass transport systems are considered to be available only from 2020 onwards (given the long lead time required for infrastructure development). Techno-economic characteristics and emission factors of technology options considered and source of data used in the model are given in appendices B and C respectively.

4.4 Energy Service Demand Projection

The demand projection for different sectoral end-use services are done using econometric methods as mentioned in Shrestha and Rajbhandari (2009).

The end-use service demand in residential sector and land passenger transport was estimated by

$$ESD(i,t) = \left(\frac{POP(t)}{POP(0)}\right)^{\alpha_{1i}} * \left(\frac{GDP(t)}{GDP(0)}\right)^{\alpha_{2i}} * ESD(i,0) \qquad \text{…....(1)}$$

The freight transport demand was obtained from

$$ESD(i,t) = \left(\frac{GDP(t)}{GDP(0)}\right)^{\alpha_{2i}} * ESD(i,0) \qquad \text{……..(2)}$$

The end-use demand in other sectors were estimated using

$$ESD(i,t) = \left(\frac{VA(t)}{VA(0)}\right)^{\alpha_{3i}} ESD(i,0) \qquad \text{……..(3)}$$

Where,

ESD (i,t) = level of service demand type i in year t for every sectors or sub-regions;

POP (t) = population in year t

GDP (t)= aggregate GDP in year t.

VA (t)= value added in the relevant sector in year t for every sectors.

α_{1i} = population elasticity of service demand type i

α_{2i} = GDP elasticity of demand for service type i

α_{3i} = sectoral value added elasticity of demand for service type i

Here, an elasticity of service demand relates the percentage change in energy service demand (ESD (i, t)) to a percentage change in the respective independent variable (e.g., GDP (t), POP (t), VA (t)). In case of air passenger transport demand, GDP per capita is used instead of GDP in equation (2). It should be noted that other studies using the partial equilibrium modals have adopted similar approaches for the service demand projections (FOSTCA, 2001; Kypreos et al., 2006; Nguyen, 2005; NIES, 2007; Shrestha and Rajbhandari, 2010; Shukla et al., 2008). The values of elasticity are gradually decreased from the initial historical data based estimation for Nepal to lower level comparable to the data used for high income countries (FOSTCA, 2001; Kypreos et al.,

2006) along the study period (see Nguyen (2005) and Shrestha and Rajbhandari (2010)). The values of elasticity used in the study are given in Appendix D

The estimated demand projection for electrical appliances of the Kathmandu valley following the above approach results in values of appliance ownership per thousand households of the valley in 2050 are comparable with that of the value for Shanghai in 2002 (Bardley et al., 2006). This indicates the projected levels of appliance ownership are realistic. The estimated appliance ownership values are 1,022 number of refrigerators per thousand households, 1,676 number of color televisions per thousand households and 604 computers per thousand households.

Different energy efficient technology options and new emerging technologies are provided in the model as candidate options to capture the effect of energy efficiency improvement in the energy supply and demand sides of the national energy system at later period. Gradual penetration is allowed for new technology options and at the same time gradual replacement is allowed for old technology options to represent real world technology intervention.[1] Future expected energy efficiency improvement and change in cost of most of the technology options are used from IEA (2005, 2008).

4.5 Determinants of Service Demands

4.5.1 Population Projection

The projected district wise population from 2001 to 2021 for mountain, hills and terai physiographic regions as well as Kathmandu valley by Central Bureau of Statistics (CBS, 2003a; CBS, 2003b) was used to project physiographic population for analysis years 2005 to 2020 in this study. It is observed that exponential growth rate of projected population till 2021 is in decreasing order as per the decreasing total fertility rate under medium variant growth scenario. In this study, it is assumed that the total population would follow the medium variant growth rate as mentioned in UNPD (2009) during 2020 to 2050. Disaggregation of physiographic distribution of population for 2020 to 2050 is done by projecting the population growth trend observed in the physiographic regions during 2005-2020 (2003b) and calibrating it according to the national population projected by UNPD (2009). The disaggregation of the urban and rural population was carried out following UN (1974) (as mentioned in CBS 2003b). Accordingly, the share of urban population is estimated to increase from 16% in 2005 to 55.6% by 2050. Detailed physiographic population projection is shown in Table 4.1.

[1] This is necessary as some new technology options are cost effective compared to the existing technology options in terms of cost per useful energy (Dutt, 1994) but still they are not use in the real world.

Table 4.1: Physiographic population projection during 2005-2050

Physiographic region	2005	2015	2030	2050
Northern Mountain-Rural	1,755	2,045	2,464	2,712
Mountain Urban	49	96	250	779
Kathmandu Valley	1,828	2,363	3,142	3,854
Hill Rural	8,615	9,817	11,045	10,118
Hill Urban	597	1,139	2,791	7,305
Terai Rural	10,487	11,805	12,073	8,684
Terai Urban	1,703	3,214	7,191	14,966
Total Rural	20,857,672	23,666,463	25,581,731	21,513,797
Total Urban	4,175,999	6,811,580	13,373,132	26,904,504
Total Nepal	25,034	30,478	38,955	48,418

4.5.2 GDP Projection

Sectoral GDP values are used as a determinant for the estimation of future service demands in the agriculture, commercial, and industrial, while total GDP is used as a determinant for service demand in the residential and transport sectors. GDP per capita is used as a determinant for the projection of air passenger transport service demand. The real GDP (at constant 2000/2001 prices) is assumed to grow at an ACGR of 5.5% during 2010-2015, 5.8% during 2015-2020 and 6% during 2020-2050.[2]

Table 4.2: Projected Gross Value Added during 2005-2050 (million NRs at Constant Prices of 2000/01)

Economic Sector	2005	2015	2030	2050
Agriculture	179,811	235,123	417,413	870,640
Industry	79,925	129,776	324,076	1,200,216
Transport	39,272	72,810	203,516	745,931
Commercial	179,625	321,502	857,380	2,963,706
Total value addition	478,633	759,211	1,802,385	5,780,493
GDP at producers price	496,027	784,005	1,861,247	5,969,272

The projection of the GDP of the Kathmandu valley is assumed to follow the historical growth rate based on the GDP data available for the years 1991 (JICA, 1992) and 2001 (UNDP, 2004). Sectoral disaggregation (value additions) of GDP have been calculated for the study period by using the ACGR observed during the fiscal year

[2] A GDP growth rate of 6% is considered in the low growth scenario in the Ten-Year Hydropower Development Plan (2010-2020) (MOWR, 2009). In the recent Twenty-Year Hydropower Development Plan the average growth rate of GDP during 2005 to 2030 has been considered as 5.6% (MOE, 2010).

1987/88 to 2007/08 and calibrating it with the aggregated GDP projection. The projected GDP during 2005 to 2050 is given in Table 4.2.

4.6 Transport Demand Projection

The transport sector of the country is disaggregated into two parts, i.e., transport systems in the Kathmandu valley (the capital city) and the rest of Nepal (hereafter "RoN") in order to capture the dominant role of the capital city in the national transport sector. The Kathmandu valley contributes around 62% of the total registered passenger service vehicles and 16% of total freight service vehicles of the country in 2005 (CBS, 2007; Dhakal, 2006). The estimated values of land based transport demands in the Kathmandu valley and the RoN under the base case are given in Table 4.3.

The value of elasticity in the transport demand projection equation was gradually decreased during the study period in order to address issues of changing elasticity with respect to level of economic development as mentioned in section 4.4. In 2050, the values of freight and passenger transport service demands in the Kathmandu valley in per capita terms, are estimated to be 520 ton-km and 9,018 passenger-km respectively.[3] Similarly for the RoN the per capita value of freight transport service demand and passenger transport service demand would increase to 384 ton km per capita and 4,418 passenger-km per capita respectively in 2050.

Table 4.3: Land transport demand under base case during 2005-2050

Sub-region	Transport Type	2005	2010	2015	2020	2030	2050	Ratio 2050/2005
Kathmandu valley	Land Freight (billion ton-km)	0.3	0.5	0.6	0.8	1.2	2.0	6.0
	Land Passenger (billion passenger-km)	4.1	5.8	8.1	10.9	17.8	34.8	8.4
Rest of Nepal (RoN)	Land Freight (billion ton-km)	1.9	2.5	3.5	4.9	8.4	17.1	9.1
	Land Passenger (billion passenger-km)	16.7	24.3	36.3	52.1	94.2	196.9	11.8

The model split for annual road passenger transport demand according to the category of vehicles in the model is done in two steps. Firstly, vehicle wise road passenger transport demand is projected by assuming that the vehicle ownership level per thousand people in 2050 for different category of vehicles in Kathmandu valley would gradually increase to reach the level as that of Bangkok in 1991 (Kenworthy and

[3] The per capita value of the land freight demand for India in 2001 was 873 ton-km per capita (TERI, 2006) and the estimated value of the same for China in 2005 was 2000 ton-km per capita (Brinckerhoff, 2007). Ruehle (2005) has estimated the value of passenger demand for South Asia to be 9,018 passenger-km per capita in 2050. Considering these, the estimated values for of the road freight transport and passenger transport demands for Kathmandu in 2050 is reasonable.

Laube, 1999) considering similar economic condition of the valley by 2050.[4] In second step, the road passenger transport demand of the individual category of vehicle is adjusted by calibration factor given by the ratio of annual total road passenger transport demand projected by Equation 1 with the cumulative annual passenger transport demand of all the category of vehicle as mentioned in the first step. Similar method is used for the model split of the freight transport demand. It is assumed that in 2050, the ratio of vehicle ownership per thousand people by vehicle type in the RoN to that in the Kathmandu valley will be in the same proportion as is the GDP per capita of the RoN to the GDP per capita of the Kathmandu valley.

4.7 Conclusion

In this chapter, detailed description of the energy system model developed for analyzing energy supply mix, energy system cost, energy security and environmental emissions were discussed. The overview of MARKAL framework used for developing the energy system model of Nepal were also presented. The representations of the physiographic, economic and sectoral desegregations in the model were highlighted. The procedures followed for the projections of the energy service demands for the study period used in the model was detailed.

[4] These assumptions for vehicle ownership have been done to maintain realistic per capita vehicle ownership for Kathmandu in 2050 whose economic condition is expected to be similar as that of Bangkok in 1990. The GDP/capita at constant price of 2005 for Bangkok in 1990 was US$ 6,039/capita (based on the share of Bangkok (40.5%) in the national GDP of Thailand in 1990 as mentioned by Yusuf and Nabeshima (2006)), and the estimated GDP/capita at constant price of 2005 for Kathmandu in 2050 is US$ 5,745/capita.

Chapter 5

Implications of Transport Sector Electrification on Hydropower Development, Energy Security, Environment and Economy

This chapter discusses the implications of transport sector electrification in terms of hydropower development, reductions of greenhouse gas and local pollutants emissions, improvement in energy security and employment generation during 2015-2050 in the case of Nepal. It assesses the effects of meeting a part of the land transport service demand through electrified mass transport system and electric vehicles. The Chapter is divided into four sections. The first section presents descriptions of the scenarios. This is followed by a discussion of the energy system development and its environmental implications in the base case. The third section discusses the effects of different transport electrification scenarios. Finally, key findings of the study are summarized in the last section.

5.1 Description of Scenarios

This study analyses six scenarios: base case and five alternative scenarios. The base case is considered as "Business as usual" scenario and it considers the energy system development to meet future service demands at minimum cost without any cleaner transport or energy policy restrictions.

In this case, the real GDP (at constant 2000/2001 prices) and population are assumed to grow as mentioned in section 3.5. The household electrification rate (defined as the electrified households as a percentage of total households) would increase from 40% in 2005 to 100% by 2030 according to the National Water Plan 2005 (WECS, 2005a). The electrification rate is considered in estimating the demands for end use services that can be met using electrical appliances.

The available primary energy resource stocks for biomass, lignite, hydropower, solar are taken from WECS (2006a, 1995). The availability of fuelwood in different regions is assumed to follow the trend as mentioned in ADB/ICIMOD (2006) and the maximum annual domestic availability of fuel wood is estimated to be 7.15 Mtoe from 2020 onwards. Similarly, the maximum annual domestic supply of agriculture residue and animal waste is estimated to be 6.95 Mtoe and 2.28 Mtoe respectively WECS (2006a). The maximum domestic availability of the biodiesel is estimated to be 0.137 Mtoe following Rai and Koirala (2006), and that of the ethanol to be 0.025 Mtoe considering 10% of molasses produced during sugar production used for ethanol production. It is assumed that the biomass is produced in a sustainable basis so there is no net emission of CO_2 involved in their use. The maximum availability of lignite is estimated to be 0.548 Mtoe (25% of the possible reserve from Kathmandu and Dang regions as mentioned in WECS (1995)). The prices of biomass are adopted from WECS (2006a and 2006b) and the price escalation rates for the biomass price during 2005-2050 are based on EREC/GREENPEACE (2008).[5]

[5] EREC/GREENPEACE (2008) has assumed price of solid biomass to increase from 2.5 US$/GJ in 2005 to 4.9 US$/GJ in 2050 for 'other regions'.

Supply of petroleum products and coal are entirely from imports. Prices of the imported petroleum products, lignite and coal for 2005 are based on MOF (2009) and TERI (2006). Future prices of the petroleum products are projected using the ACGR mentioned in EIA (2009a).[6] In the case of lignite and coal, the ACGR value of 0.9% is used after 2010 (EIA, 2009b).

The import of electricity into Nepal is limited to 150 MW[7] (657 GWh) from 2020 onwards, while the export of electricity is set to increase up to 2,091 MW (12,378 GWh) after the completion of export oriented projects, i.e., West Seti, Arun III and Upper Karnali in 2017 as mentioned the Twenty-Year Hydropower Development Plan 2010-2030 document (MOE, 2010). Altogether 70 individual candidate hydropower plants (15,105 MW) are considered in the study as given in Appendix E. The sources of cost and energy generation data for the candidate hydropower plants are taken from various documents (major sources: NEA, 2008a, 2008b, 2005; MOE, 2010; MOWR, 2009; Shiwakoti, 2006; Nexant SARI/Energy, 2002). Other candidate electricity generation technologies include diesel-fired power plants (300 MW), wood based gasification combined cycle power plants (500 MW), and municipal solid waste (MSW) land fill gas based power plant (5 MW).[8] Besides, micro-hydro plants, solar home systems (average installed capacity of 34 Wp) and small solar home systems (capacity of 10 Wp) are considered for the remote areas of the country.

Emission factors for the major GHG emissions i.e., CO_2, CH_4 and NO_2, are based on IPCC (2006), while that for local pollutants i.e., SO_2, NO_X, CO, PM_{10} and NMVOC are based on various sources (Dhakal, 2006; EEA, 2009; EMEP/CORINAIR, 2007; Reddy and Venkataraman, 2002a, 2002b; Smith et al., 2000; Zhang et al., 2000). The global warming potential for CH_4 and N_2O has been considered as 25 and 298 respectively (IPCC, 2007a). A 10% real discount rate was used in the present study (ADB, 2002; World Bank, 2003). All the costs used in the model are expressed at the constant prices of year 2005.

The transport sector end use service demand for land passenger transport is divided into six modes, namely, bus, microbus, car, 2-wheelers, 3-wheelers, taxi. Land freight transport has been disaggregated into truck, tractor and pick-up. In the base case, these service demands are mostly met by using fossil fuel based technologies with a nominal contribution of electric 3-wheelers in the Kathmandu valley and electric ropeways in the case of RoN in the absence of effective government policies. However, for alternative transport electrification scenarios, electrical and hydrogen fuel cell based

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[6] EIA (2009a) has assumed future average world oil price to rise from $61 per barrel in 2009 to $110 per barrel in 2015 and $130 per barrel in 2030 at real price in 2007 US$ term in the reference case.

[7] Power exchange capacity between Nepal and India is expected to increase from 50 MW in 2004/05 to 300 MW in 2019/20 under cooperative scenario of the Sector Study of Power Sector in the Kingdom of Nepal (JBIC, 2004).

[8] Kathmandu valley is estimated to generate 150 thousand tons of organic urban solid waste in 2005 considering average per capita urban solid waste generation of 0.124 tons per capita (ADB/ICIMOD, 2006). Considering specific methane generation from urban solid waste as 0.079 Gg CH4/Gg waste (PREGA, 2006b), operation of 5 MW capacities of urban solid waste land fill gas based power plants has been considered.

options are considered to be available in the future. Types of transport technology considered and source of data used for cost, efficiency, occupancy rate, annual distance travel, future efficiency improvement are given in the Appendix B. The model split for category of vehicles in the transport demand has been done by assuming that the vehicle ownership level per thousand people in 2050 for different category of vehicles in Kathmandu valley would gradually increase to reach the level as that of Bangkok in 1991 (Kenworthy and Laube, 1999) considering similar economic condition of the valley by 2050[9]. It is assumed that in 2050, the ratio of vehicle ownership per thousand people by vehicle type in the RoN to that in the Kathmandu valley will be in the same proportion as is the GDP per capita of the RoN to the GDP per capita of the Kathmandu valley. Other sectors and end use demands considered in the model is given in Appendix A.

To analyze the effects of transport sector electrification, the counterfactual scenarios were developed with the different level of exogenous penetration of the electric mass transport and electric mode of vehicles in the road transport demand. The level of penetration of the electric mass transport and electric vehicles were considered based on the relevant studies carried out for the country and other developing countries (RITES/SILT, 2010; Shrestha et al., 2008; TERI, 2006).

Besides the base case, the following five transport electrification scenarios are considered in the study:

(i) a shift of 10% of the road transport demand to the electric mass transport system from 2020 onwards and all other things remaining the same as in the base case (hereafter "EMT10"),
(ii) a shift of 10% of the road transport demand to the electric mass transport system in 2020 and gradually increase the shift to 20% by 2050 (hereafter "EMT20"),
(iii) a shift of 10% of the road transport demand to the electric mass transport system in 2020 and gradually increase the shift to 30% by 2050 (hereafter "EMT30")[10],
(iv) a shift of 20% of the road transport demand to the electric mass transport system as in the EMT20 and shift of another 5% of the demand to electric vehicles in 2015 with gradually increase in the shift of electric vehicles to 10% by 2050 (hereafter "EMT20+EV10"), and
(v) a shift of 20% of the road transport demand to the electric mass transport system as in the EMT20 and shift of another 5% of the demand to electric vehicles in 2015 with gradually increase in the shift of electric vehicles to 15% by 2050 (hereafter "EMT20+EV15").

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[9] These assumptions for vehicle ownership have been done to maintain realistic per capita vehicle ownership for Kathmandu in 2050 whose economic condition is expected to be similar as that of Bangkok in 1990. The GDP/capita at constant price of 2005 for Bangkok in 1990 was US$ 6,039/capita (based on the share of Bangkok (40.5%) in the national GDP of Thailand in 1990 as mentioned by Yusuf and Nabeshima (2006)), and the estimated GDP/capita at constant price of 2005 for Kathmandu in 2050 is US$ 5,745/capita.

[10] The share of rail mode in passenger transport is 23% and freight transport is 37% in 2001 in India (TERI, 2006). The recent feasibility study of Mechi-Mahakali and Pokhara-Kathmandu Electric Railway carried out by RITES/SILT (2010) has considered up to 55% modal shift from bus to rail mode and 40% model shift from car and freight transport to rail mode by 2035. Our assumption of up to 30% model shift to electric mass transport can be considered as realistic option under these facts.

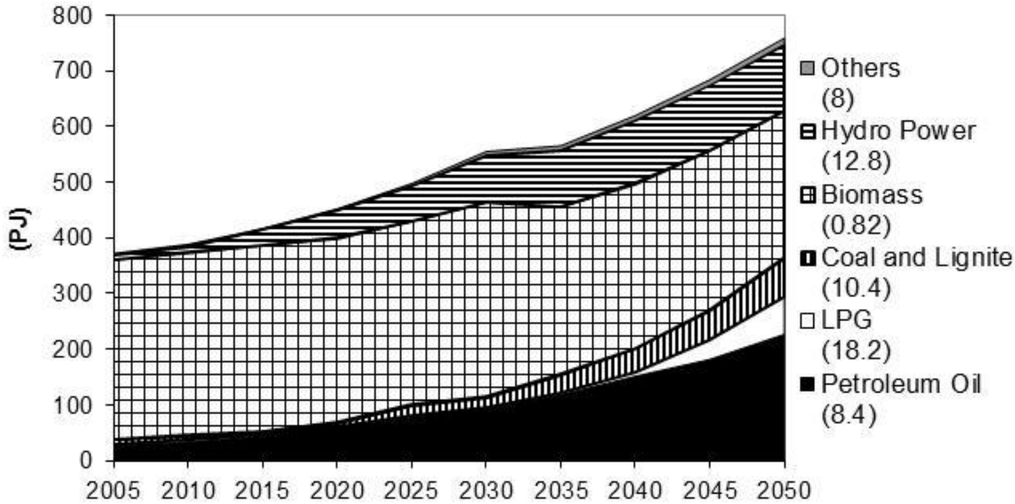
The options of the electric mass transport system include electric MRT for the Kathmandu valley and electric train for RoN. However as mentioned in MOPPW (2007), since electric train is less feasible in some mountainous terrain rope way/ cable car has been considered for those regions (considering its share with respect to the population distribution in that region). The electric mass transport systems are considered to be available only from 2020 onwards (considering long lead time necessary for infrastructure development).

5.2 Analysis of the Base Case Results

This section discusses the evolutions of energy system supply and demand, power generation, energy security and environmental implications in the base case.

5.2.1 Primary Energy Supply Mix

The total primary energy supply (TPES) is estimated to grow at ACGR of 1.61%, i.e., from 372 Peta Joule (PJ) in 2005 to 759 PJ in 2050 as shown in the Figure 5.1. There would be an 8.3 folds increase in the imported energy during the study period.



Note: Figure inside parenthesis indicate ratio of TPES values for 2050 and 2005

Figure 5.1: Primary energy supply in Nepal during 2005-2050 (PJ)

There would be a 9.7 fold increase in the imported energy during the study period. The use of hydropower would increase by nearly 13 times, while biomass use would decrease by 18% mostly due to fuel switching with urbanization.[11] At the same

[11] Shrestha and Rajbhandari (2010) estimated that there would be reduction in the annual biomass consumption by more than 50% during 2005 – 2050 in Kathmandu valley. The consumption of fuel wood

time, other energy sources consisting of bio-diesel, ethanol, municipal solid waste, solar, micro-hydro would increase by 8 times. The share of biomass energy resources would decrease (from 87.1% in 2005 to 35% in 2050), while there would be an increase in the shares of petroleum products (by 22.6%), hydropower (by 13%), LPG (by 7.9%), coal (by 7.5%), and others (by 1.1%) in the base case during the study period.

5.2.2 Power Generation Mix

Power generation capacity in Nepal is estimated to increase 12.9 fold during the study period and would be dominated by hydropower as shown in Table 5.1[12]. By 2050, hydropower plants would account for 89.5% of the total installed power generation capacity, while other renewables (micro-hydro, solar home systems, cogeneration, wood based power plants, and MSW based power plant) would have the combined share of 7%. The thermal power plants would account for 3.5% of the total capacity in 2050.

Table 5.1: Electricity Generation in Nepal during 2005-2050

	2005		2030		2050	
Power Plant	GW	TWh	GW	TWh	GW	TWh
Hydropower*	0.55	2.55	4.50	23.17	7.75	32.67
Thermal Plants	0.11	0.05	0.00	0.00	0.30	0.63
Other Renewables	0.01	0.07	0.30	1.00	0.61	2.74
Total	0.67	2.67	4.81	24.17	8.66	36.03

* This excludes micro-hydro plants

The annual electricity generation in Nepal is estimated to increase 13.5 fold during the study period. The share of other renewables in annual electricity generation is expected to increase during 2005-2050, while that of hydropower and thermal plants would decrease.

5.2.3 Final Energy Consumption

The total final energy consumption (TFEC) in the country is estimated to increase from 366 PJ in 2005 to 684 PJ in 2050 (i.e., at the ACGR of 1.4%). As can be seen in Table 5.2 the sectoral final energy consumption would grow at the ACGR of 5.7%, 6.7%, 5.1% and 3.5% in the transport, commercial, industrial and agriculture sectors respectively.

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alone has been estimated to decrease by 35% during the period, while the consumption of agriculture residues and animal dung would be reduced to zero by 2050.

[12] MOE (2010) has projected national power generation capacity demand to reach 4.6 GW under the low growth scenario and 11.4 GW under the high growth scenario by 2030. NEA (2008a) has forecasted the electricity demand to reach 13.9 TWh and power generation capacity demand to reach 2.9 GW by 2024/2025. Similarly, Nepal Water Plan 2005 has estimated the power generation capacity to reach 4 GW by 2027 under base case scenario (WECS, 2005a). The electricity demand estimated in the study tallies with the above projections by the national agencies.

The residential sector energy consumption including traditional biomass (agriculture residue, animal dung and fuelwood) would decrease minimally at the ACGR of 0.06% (Table 5.2); however, if the traditional biomass is excluded, the residential energy consumption would increase at the ACGR of 4.9% during the study period (Table 5.3). This would happen mostly due to fuel switching, i.e., from biomass to higher grade fuels (e.g., kerosene, LPG and electricity) with growing urbanization and partly due to penetration of more efficient biomass based devices (improved cook stoves and biogas).[13] The annual TFEC excluding traditional biomass is estimated to increase from 44 PJ in 2005 to 471 PJ in 2050 (i.e., at the ACGR of 5.4%).

Table 5.2: Final energy consumption in Nepal during 2005-2050 (PJ)

Sector	2005	2030	2050	Ratio 2050/2005
Transport	13.10	77.95	159.76	12.2
Industrial	11.63	41.53	110.28	9.5
Residential	333.97	367.94	324.68	1.0
Commercial	4.10	16.01	74.37	18.1
Agriculture	3.10	9.61	14.47	4.7
Total	365.89	513.03	683.57	1.9

Table 5.3: Final energy consumption excluding traditional biomass use in Nepal during 2005-2050 (PJ)

Sector	2005	2030	2050	Ratio 2050/2005
Transport	13.10	77.95	159.76	12.2
Industrial	9.40	34.95	97.84	10.4
Residential	14.25	48.39	124.54	8.7
Commercial	3.77	15.78	74.26	19.7
Agriculture	3.10	9.61	14.47	4.7
Total	43.61	186.68	470.86	10.8

Table 5.4: Share of fuel consumption of the transport sector in Nepal (%)

Sector	2005	2030	2050
Diesel	62.5	60.0	64.9
LPG	0.36	0.04	0.00
Gasoline	19.0	30.5	24.9
Electricity	0.2	0.1	0.1
Aviation Turbine Fuel	18.1	9.3	7.9
Bio-fuels	0.00	0.05	2.21
Total	100	100	100

[13] The renewable energy promotion programme implemented by the GoN under its Alternative Energy Promotion Centre (AEPC) has set a target to install additional 500,000 units of ICS and Biogas plants during 2007-2012 (AEPC, 2009). Also given the decreasing trend in the use of agriculture residues and animal waste in the urban areas (Shrestha and Rajbhandari, 2010), in this study it is assumed that the use of agriculture residues and animal waste will be decreased to zero by 2050 and 2035 respectively. As incomes rise, households prefer to switch from lower grade fuels to high grade fuels following energy ladder (Dutt and Ravindranath, 1993).

The final energy consumption of the transport sector is estimated to grow 12.2 fold as shown in Table 5.3. Its share in the TFEC would increase by more than six times (from 3.6% in 2005 to 23.4% in 2050). It would represent 68.9% of total petroleum product imports and 42.8% of total imported energy consumption in the country in 2050. The transport sector continues to depend on imported fossil fuels except for small share of bio-fuels (2.21%) and a negligible share of electricity (0.07%) in 2050 as shown in Table 5.4.

5.2.4 Greenhouse Gas and Local Environmental Emission

In the base case, GHG emissions would increase more than fivefold (i.e., from 5.67 million tons CO_2e in 2005 to 29.7 million tons CO_2e in 2050)[14] as shown in Table 5.5.

Table 5.5: Emissions level in base case scenario (10^3 tons)

Emission	2005	2030	2050	Ratio 2050/2005
CO_2	2,844	8,655	27,426	9.6
CH_4	96	99	67	0.7
N_2O	1.40	1.90	2.04	1.5
CO	1357	1852	1839	1.4
NO_X	37	76	134	3.6
SO_2	32	56	107	3.4
NMVOC	189	238	242	1.3
PM_{10}	32	83	86	2.7
Total GHG emission[a], 10^3 ton CO_2e	5674	11689	29700	5.2

[a] GHG here includes CO_2, CH_4 and N_2O.

It is interesting to note that the share of non-CO_2 GHG emissions were almost half of the total GHG emissions in 2005 mainly due to predominant share of traditional biomass in the energy system.[15] However, the share of non-CO_2 emissions tends to decrease in the subsequent years. The emissions of CH_4 are estimated to decrease mostly due to lower value of emissions per unit of useful energy delivered for petroleum products compared to the biomass fuels in the domestic and commercial applications.

In terms of sectoral contributions to total GHG, the residential sector alone accounted for 60.6% of GHG emissions in 2005, while the shares of transport and

[14] According to MOPE (2004), the share of non-CO_2 GHG emission accounted 58.6% of the total GHG emission from the energy consumption in Nepal for 1994/95. The share of traditional biomass energy (fuelwood, agriculture residues, animal wastes) in TPES was around 92% in 1994/95.

[15] In this study the values of global warming potential for CH_4 and N_2O have been considered to be 25 for CH_4 and 298 for N_2O following IPCC (2006).

industrial sectors were 17.1% and 13.7% respectively. There would be a substantial change in the sectoral contributions in the GHG emissions by 2050 in that the transport sector would account for 39% of the total GHG emissions in that year, while the residential, industrial and commercial sectors would have a share of 16.7%, 23.3% 15.8% respectively (Figure 5.2). The per capita energy related GHG emissions in Nepal are estimated to rise from 0.23 ton CO_2e/capita in 2005 to 0.61 ton CO_2e/capita by 2050. In addition, there would be an increase in the emissions of local pollutants during 2005-2050, ranging from 28% in the case of NMVOC to 262% in the case of NO_X (see Table 5.5).

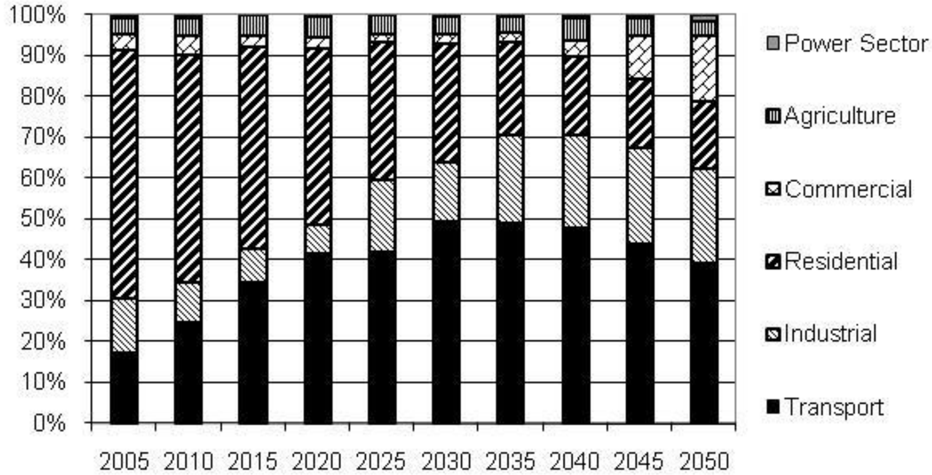


Figure 5.2: Sectoral share of GHG Emissions during 2005 – 2050

5.2.5 Energy Security

How would the energy security of the country be affected over time in the base case? To answer this question, three indicators of energy security i.e., Shannon-Weiner Index (SWI)[16], net energy import ratio (NEIR), and oil consumption per capita (OCPC) are presented for selected years in Table 5.6 (see APERC, 2007; Grubb et al., 2006 for more details on the indicators).

SWI measures the level of diversification of energy resources with its higher value indicating a more diversified energy resource mix. Here, six type of energy resource is assumed for calculation purpose (petroleum products, LPG, coal, biomass, hydropower and others). The maximum possible value of SWI is 1.7918 (if equal amount of energy is supplied by each energy resource) and minimum possible value is zero (if supplied by only one type of energy resource). Similarly, NEIR and OCPC measure the

[16] Shannon-Wiener Index $$\boldsymbol{SWI = -\sum_i s_i \ln s_i}$$

where, s_i = the share of fuel 'i'.

economic dependence on imported fuels with their higher value signifying a higher level of import dependency.

Table 5.6: Energy security indicators in the base case during 2005-2050

Indicator	2005	2030	2050
Net energy import ratio (%)	10.29	19.34	45.36
Shannon-Weiner Index	0.54	1.05	1.48
Oil consumption per capita (kgoe/capita)	25.37	56.54	109.75

The increasing trend of SWI shows the growing diversification in the supply of primary energy resources during the study period, which is mostly due to a decrease in the share of traditional biomass and an increase in the shares of hydropower, fossil fuels, and other renewables (see Figure 5.2). At the same time, the increasing trend of other two energy security indicators shows the growing dependency on imported fuels (especially, petroleum products).

5.3 Implications of Transport Sector Electrification

How important would be the co-benefits of the transport sector electrification? In particular, how would it affect the hydropower development, energy security, environmental emissions, energy system costs, and employment in the country? These issues are discussed in this section for five different scenarios of transport sector electrification considered in the present study.

5.3.1 Effects on Energy System Development

There would be a decrease in cumulative TPES in all the alternative scenarios except EMT20 (see Table 5.7). The range of reduction in cumulative TPES would be 0.85% (201 PJ) in EMT10 to 2.74% (650 PJ) in EMT20+EV15 as compared to the base case value.

Table 5.7: Cumulative primary energy supply during 2005-2050 by energy type in different scenarios (PJ)

Scenario	Petroleum Products	Coal	LPG	Hydro	Biomass	Others	Total
Base Case	4,433	1,094	517	3,143	14,301	236	23,724
EMT10	4,178	890	586	3,211	14,419	239	23,523
EMT20	4,032	865	505	3,256	14,839	233	23,730
EMT30	3,883	832	547	3,306	14,709	225	23,502
EMT20+EV10	3,894	911	606	3,301	14,460	226	23,399
EMT20+EV15	3,781	815	557	3,517	14,177	226	23,073

In the case of EMT20, the increase in cumulative TPES is due to the increased consumption of biomass compared to the base case under least cost optimization of the model. The cumulative petroleum product requirement is estimated to decrease by 5.8%

(255 PJ) in EMT10 and by 14.7% (652 PJ) in EMT20+EV15. However, the cumulative supply of primary energy from hydropower during the study period would increase in the range of 2.2% (69 PJ) in EMT10 to 11.9% (374 PJ) in EMT20+EV15 as compared to the base case.

As shown in Table 5.8, the cumulative final energy consumption during the study period is estimated to decrease in all the scenarios as compared to the base case. Due to the introduction of electric transport there would be a reduction in the annual consumption of energy in the transport sector (Figure 5.3) mostly due to the higher efficiency of the electricity based transport system (IEA, 2008). It is estimated that the cumulative final energy consumption in the transport sector would decrease in the range of 5% (167 PJ) under EMT10 to 12% (406 PJ) under EMT30 during the study period (Table 5.8). This indicates that policy on electrification of transport system not only help to improve energy efficiency of transport sector but also have positive effects on the energy efficiency of overall national energy consumption.

Table 5.8: Cumulative final energy consumption during 2005-2050 in different scenarios (PJ)

Scenario	Transp.	Indust.	Resid.	Comm.	Agric.	Total
Base Case	3,371	1,984	15,194	955	393	21,897
EMT10	3,204	2,030	15,080	957	395	21,665
EMT20	3,077	2,035	15,388	959	393	21,853
EMT30	2,965	2,044	15,250	970	396	21,626
EMT20+EV10	3,005	2,024	15,105	966	398	21,497
EMT20+EV15	2,975	2,048	14,782	961	393	21,159

Note:Transp.≡transport sector, Indust.≡industrial sector, Resid.≡residential sector, Comm.≡ commercial sector, Agric.≡ agriculture sector.

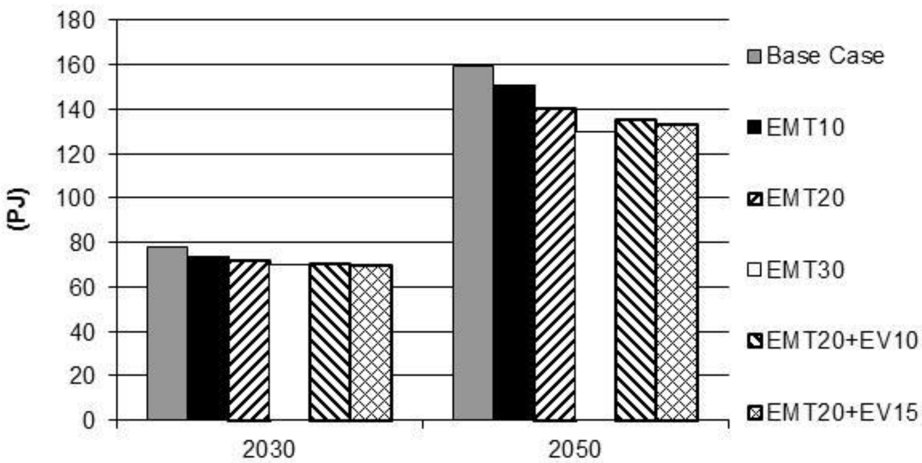


Figure 5.3: Final energy consumption in the transport sector in selected years (PJ)

5.3.2 Environmental Implications

Table 5.9 shows that the cumulative emissions during the study period of selected GHG and local air pollutants would decrease significantly due to the electrification of the transport sector. It is estimated that the cumulative GHG emissions during 2005-2050 would be reduced by 33.52 million tCO_2e (5.8% reduction) in EMT10, while the corresponding figure would be 74.73 million tCO_2e (12.9% reduction) in EMT20+EV15.

There would be a significant reduction in GHG emissions from the transport sector due to fuel switching in the sector (i.e., from petroleum products to hydroelectricity). The cumulative GHG emissions from the transport sector during 2005-2050 are estimated to decrease by 6.2% under EMT10 to 17.6% under EMT20+EV15 (Table 5.10). GHG emissions from the transport sector in 2050 decrease from 7.2% under EMT10 to 25.2% under EMT20+EV15 as compared to the emissions in the base case.

Table 5.9: Cumulative emissions during 2005-2050 in different scenarios (10^6 tons)

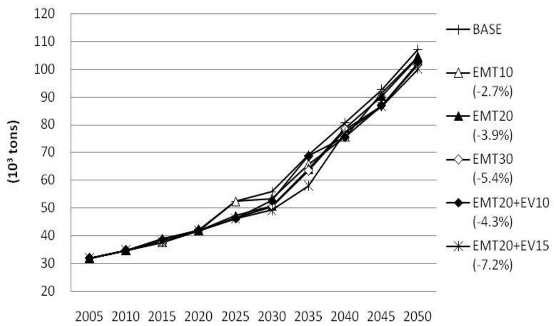
Scenario	CO_2	CH_4	N_2O	CO	NO_X	SO_2	NMVOC	PM_{10}
Base case	459	3.96	0.078	74.68	3.41	2.68	9.59	2.89
EMT10	427	3.90	0.078	70.61	3.22	2.61	9.32	2.86
EMT20	408	4.02	0.079	72.00	3.18	2.57	9.54	2.98
EMT30	397	3.97	0.078	70.39	3.12	2.53	9.36	2.92
EMT20+EV10	409	3.91	0.077	69.13	3.13	2.56	9.21	2.84
EMT20+EV15	389	3.79	0.076	67.29	3.04	2.49	8.91	2.69

Table 5.10: GHG emissions from transport sector under different scenarios (10^6 tons)

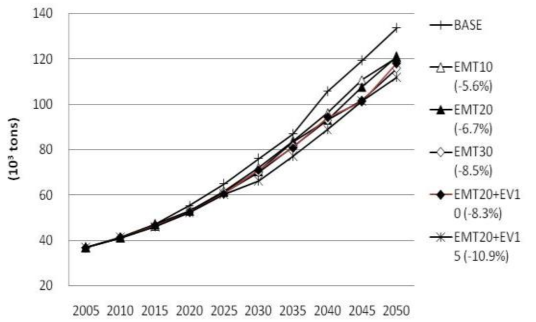
Scenario	2030	2050	Cumulative transport emission (2005 - 2050)	Share of transport sector in cumulative national emission (2005-2050), %
Base case	5.76	11.60	247.29	42.6%
EMT10	5.35	10.76	231.90	42.4%
EMT20	5.16	9.75	219.09	41.2%
EMT30	5.00	8.79	208.33	40.1%
EMT20+EV10	4.93	9.00	208.07	39.3%
EMT20+EV15	4.86	8.67	203.75	40.3%

The annual emissions of short lived local pollutants would decrease in all transport electrification scenarios as compared to the base case in 2050 (see Figure 5.5). There would be a decrease in the emission of SO_2 by 2.4% under EMT10 to by 6.6% under EMT20+EV15 as compared to the base in 2050. The emission of NO_X would reduce by 9.4% in EMT20 to by 16.3% in EMT20+EV15 in 2050. Similarly, the annual emission of NMVOC would decrease by 7% under EMT10 to by 12.3% under EMT20+EV15 in the same year. In case of CO, there would be reduction in the annual emission by 11.3% under EMT20 and by 24.9% under EMT20+EV15. Following, there would be decrease in the emission of PM_{10} by 1.7% under EMT20 and by 8.1% under EMT20+EV15. The change in cumulative term of local pollutants emissions during

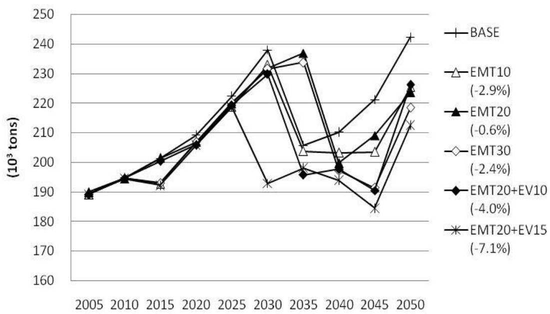
2005-2050 under transport electrification scenarios as compared to the base case are shown in Figure 4.5. Except for cumulative emission of PM_{10}, the change in cumulative emissions of local pollutants during 2005-2050 as compared to the base case follows the similar pattern of change as observed for their annual emission in 2050. There would be slight increase in the cumulative emission of PM_{10} under EMT20 and EMT30 but decreases in all other transport electrification scenarios. This highlights the role of the transport sector electrification in the mitigation of GHG and local pollutant emissions.



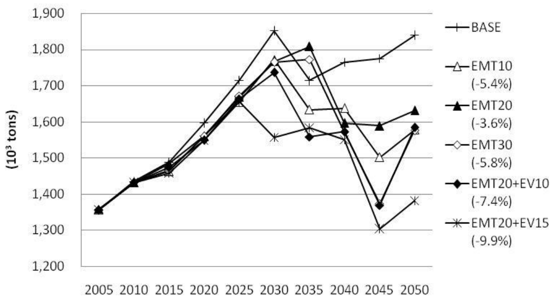
(a) SO_2



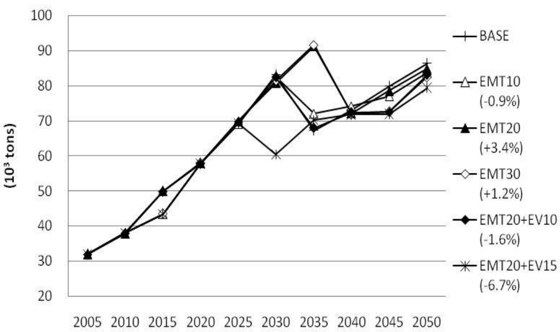
(b) NO_X



(c) NMVOC



(d) CO



(e) PM_{10}

Note: Figure in parenthesis indicates cumulative change during 2005-2050.

Figure 5.4: Annual emission of selected local pollutants during 2005-2050

5.3.3 Energy Security Implications

The change in energy security indicators for primary energy supply in 2050 are shown in Table 5.11. The total net energy imports as a percentage of the cumulative TPES would decline under all the alternative scenarios except for EMT10 and EMT20+EV10 as compared to the base case. However, the absolute amount of the cumulative imported energy during 2005-2050 is expected to decrease in all the scenarios as compared to the base case. The cumulative total imported energy during 2005-2050 is estimated to decrease in all the electrification scenarios; the reduction would be in the range of 6.3% in EMT10 to 14.6% in EMT20+EV15 (Figure 5.5).

Table 5.11: Energy security indicators for primary energy supply in 2050

Scenario	Net energy import ratio (%)	Shannon-Wiener Index	Oil consumption per capita (kgoe/capita)
Base case	45.36	1.48	109.75
EMT10	47.69	1.54	100.80
EMT20	43.97	1.51	97.72
EMT30	43.37	1.52	91.61
EMT20+EV10	45.40	1.54	93.01
EMT20+EV15	44.44	1.54	89.12

These reductions of imported energy imply corresponding savings of foreign exchange and an improvement in the country's trade balance. Similarly, oil consumption per capita would be reduced from 109.7 kgoe/capita in the base case to 100.8 kgoe/capita in EMT10 and to 89.1 kgoe/capita in EMT20+EV15 in 2050. The use of petroleum products in the transport electrification scenarios as a percentage of the total oil consumption in the base case is shown in Table 5.12. Oil consumption in 2050 would be reduced in the range of 8.2% in EMT10 to 18.8% in EMT20+EV15 as compared to the base case consumption.

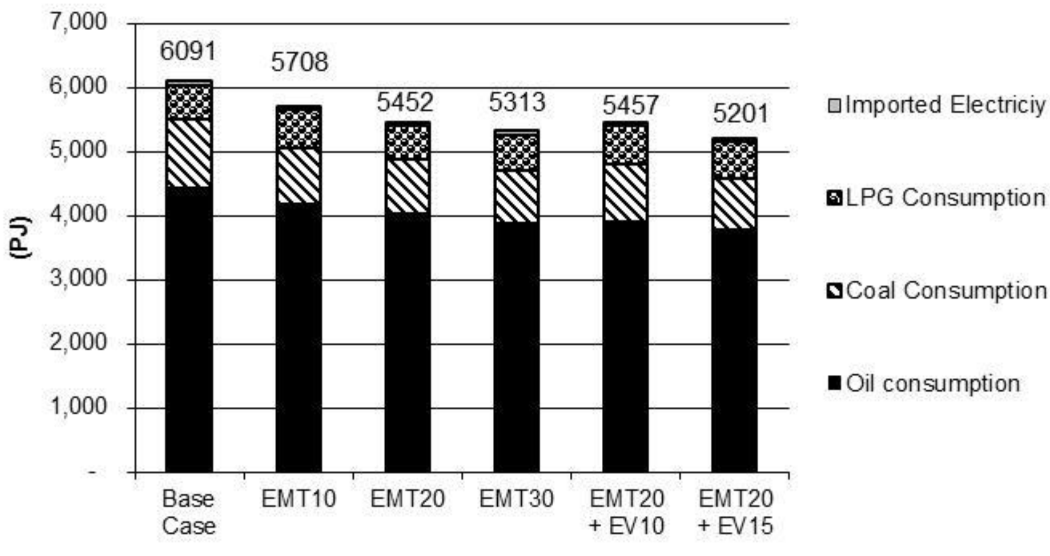


Figure 5.5: Cumulative total imported energy during 2005-2050 (PJ)

Table 5.12: Total oil import in the transport electrification scenarios as a percentage of the total oil import in the base case (%)

Scenario	2030	2050
EMT10	96.2	91.8
EMT20	94.4	89.0
EMT30	89.3	83.5
EMT20+EV10	91.9	84.7
EMT20+EV15	84.4	81.2

Electrification of the transport sector is found to improve the diversification of primary energy supply in 2050 as compared to the base case for all the transport electrification scenarios. The value of Shannon-Wiener Index for TPES is shown in Table 5.12. The foregoing discussion clearly indicates the levels of improvement that the transport sector electrification could bring to the energy security of the country.

5.3.4 System Costs and the Carbon Revenue Benefit

The estimated total discounted energy system cost (TESC) in the base case is 62.85 billion US$ at 2005 prices. The net energy import cost constitutes 18.8% of the discounted TESC. The discounted TESC would decrease in the range of 1.0% in EMT20+EV15 to 2.0% in EMT30. At the same time, the discounted net fuel import cost would decrease in the range of 5.1% under EMT10 to 12.6% under EMT20+EV15. (Table 5.13). This shows that environmentally beneficial policy interventions are also economically beneficial in the long run (decrease in environmental emissions and TESC for all the alternative scenarios as compared to the base case scenario).

Table 5.13: Discounted energy system costs at 2005 constant prices (10^9 US$)

Scenario	Supply side investment	Demand side investment	Net fuel import cost	Domestic fuel cost	O&M and other expenditures	Total system cost
Base case	10.01	27.79	11.79	9.66	3.60	62.85
EMT10	10.14	27.51	11.19	9.71	3.52	62.07
EMT20	10.11	27.49	10.80	9.79	3.53	61.72
EMT30	10.22	27.42	10.63	9.78	3.56	61.61
EMT20+EV10	10.31	27.69	10.62	9.75	3.74	62.11
EMT20+EV15	10.66	27.70	10.30	9.74	3.82	62.23

As shown in Table 5.15, the discounted total transport investment cost during the study period is estimated to decrease for mass transport electrification scenarios EMT10, EMT20 and EMT30 as compared to the base case.[17] This is mostly due to lower investment cost per unit service demand required by electric railway service compared to the conventional fossil fuel based vehicles (due to large difference in occupancy rate per trip). As public funding capacity is currently limited, a long-term strategy would be required to attract public private partnership (PPP) for investment in the development of

[17] Sadeghi and Hosseini (2008) also reported a similar result, i.e., a decrease in discounted total transport sector cost due to modal shift from conventional vehicles to mass transport system for Iran.

the capital-intensive infrastructure of electric mass transport system in the country. In the case of mixed transport electrification scenarios (i.e., EMT20+EV10 and EMT20+EV15), the discounted total transport investment cost is estimated to be higher than that in the base case (mainly due to higher cost of electric vehicles than the fossil fuel vehicle costs).

As electrification of the transport system in Nepal would be based mostly on hydroelectricity, there could be a substantial reduction in GHG emissions through the substitution of the fossil fuels. If the electrified transport system in Nepal is registered as a Clean Development Mechanism (CDM) project, there would be a potential for earning carbon credits through the sale of certified emissions reduction (CER). As can be seen from Table 5.14, the scale of the CER revenue that can be generated through the transport sector electrification at the CER price of US$ 20/tCO_2e would cover about 4.9% to 6.8% of the total electric transport investment cost under the alternative scenarios considered.[18] This shows CER revenues could cover only a small part of electric transport investment cost.

Table 5.14: Discounted transport cost and CER revenue at CER price of US$ 20/tCO_2e

Scenario	Discounted total transport investment (million US$)	Discounted electric transport investment (million US$)	Discounted CER revenue from transport sector (million US$)	Discounted CER revenue as % of total electric transport investment, %
Base case	5,338.49	14.12		
EMT10	5,241.42	405.71	24.71	6.09
EMT20	5,246.05	539.89	36.58	6.78
EMT30	5,257.44	674.11	45.81	6.80
EMT20+EV10	5,442.54	1,021.41	50.36	4.93
EMT20+EV15	5,482.10	1,127.58	54.85	4.86

5.3.5 Effect on Power Generation Capacity Requirements

Table 5.15 presents the hydropower generation capacity and electricity generation needed under different scenarios. The additional hydropower generation capacity required by 2050 under EMT10 would be 7 MW, while the corresponding figure would be 538 MW under EMT30.

Similarly, the additional electricity generation requirement from hydropower in the country would increase by 19.05 TWh under EMT10 to 103.91 TWh under EMT20+EV15 during 2005-2050. Following, the additional electricity generation requirement from other sources would increase by 1.81 TWh under EMT20 to 6.49 TWh under EMT20+EV10 during the study period. The annual electricity consumption in the transport sector would increase as shown in Figure 5.6. The cumulative electricity

[18] Bakker et al. (2007) have used low, moderate and high CER price to be US$ 20/tCO_2e, US$ 45/tCO_2e and US$80/t$CO_2$e in their analysis. If we consider higher level of CER price the revenue related to CER is expected to increase to some extent.

consumption in the transport sector during the study period is estimated to increase in the range of 18.69 TWh in EMT10 to 59.87 TWh in EMT20+EV15 as compared to the base case.

Table 5.15: Annual hydropower generation requirement during 2005-2050

Scenario	2030 GW	2030 TWh	2050 GW	2050 TWh	Cumulative generation (2005-2050) Hydropower TWh	Cumulative generation (2005-2050) Others TWh
Base case	4.50	23.17	7.751	32.67	873.03	73.73
EMT10	4.58	22.96	7.758	35.41	892.07	76.11
EMT20	4.50	23.40	8.189	38.87	904.41	75.54
EMT30	4.76	24.42	8.289	39.34	918.24	76.07
EMT20+EV10	4.35	22.11	8.274	36.83	916.86	80.22
EMT20+EV15	5.64	27.25	8.246	40.01	976.94	76.46

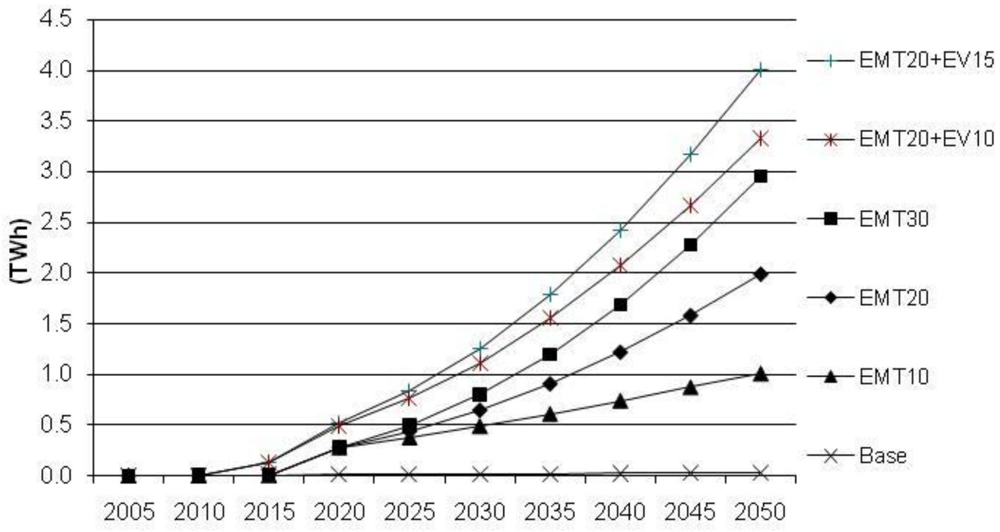


Figure 5.6: Annual electricity consumption by the transport sector during 2005-2050 (TWh)

5.3.6 Employment Generation Benefits

The actual employment generation associated with the construction and operation of a hydropower plant is both site and project specific. Therefore, only the order of magnitude of the employment generation has been attempted in this study rather than the estimation of their precise values. It has been assumed that each MW of hydropower development would generate, on an average, 30.3 man-years of employment each year during the construction phase (MOWR, 2009) and 3.0 man-years of employment each year during the operation phase (Jha et al., 2007).[19]

Thus the increase in the cumulative level of the employment generation during 2015-2050 due to the additional hydropower development under the transport electrification scenarios would be in the range of 5,718 man-years under EMT10 to 125,254 man-years under EMT20+EV15 (see Table 5.16).

Similarly, there would be an additional employment generation in the mixed scenarios (combined mass transport and EV scenarios) especially due to the establishment of recharging stations for electric vehicles. Assuming one recharging station serves 80 electric vehicles per day and employs one person (Morrow et al., 2008), there would be new employment generation in the transport sector of the order of 384,475 man-year under EMT20+EV10 and 532,546 man-year under EMT20+EV15 during the study period.[20]

Table 5.16: Estimated employment generated from additional hydropower development due to transport sector electrification during 2015-2050 (man-year)

Scenario	Construction phase	Operation phase	Total
EMT10	589	5,129	5,718
EMT20	53,719	7,846	61,565
EMT30	62,786	18,272	81,059
EMT20+EV10	57,468	22,443	79,911
EMT20+EV15	58,919	66,335	125,254

5.4 Conclusion and Policy Implications

This chapter has examined various effects of the transport sector electrification in Nepal under five different scenarios having different level of transport electrification during 2015-2050 using a long term energy system optimization model. In particular, the study has analyzed the implications of the transport sector electrification in terms of effect on hydropower development and energy security improvement as well as environmental emissions reduction and employment generation.

The study shows that transport electrification policy would promote the development of indigenous hydropower resource in the country. The hydropower capacity addition would increase by up to 538 MW under high transport electrification scenario EMT20+EV15 (20% modal shifts to electric mass transport (EMT) and 15% penetration of the electric vehicles (EV) by 2050). This clearly highlights the importance

[19] Bhattarai (2005) has mentioned annual employment generation as high as 7.6 man-years during operation phase of hydropower plants of capacity up to 10 MW in Nepal. Jha et al., (2007) have mentioned the average annual employment per hydropower plant during operation phase of 15 existing hydropower plants (with cumulative installed capacity of 398 MW) of Nepal to be 81 man-years per hydropower plant in 2004/05.

[20] However, it is to be noted that there is also possibility of reduction in employment opportunities associated with the operation of conventional transport vehicles which are replaced by the electric vehicles.

of and need for an integrated development strategy for transport sector electrification and hydropower development in the country.

With the electrification of the transport system, there would be a noticeable improvement in the energy security of the country with decline in the cumulative imported energy during 2005-2050. The primary energy supply system of the country would be more diversified as revealed by the increase in the value of Shannon-Wiener Index in the case of all the transport electrification scenarios in 2050.

The present analysis reveals that the implementation of transport electrification would result in a net decrease in the fossil fuel import cost mostly due to the fuel switch from fossil fuels to electricity as well as higher efficiency of electric transport system compared to the conventional one. There would be a decrease in the discounted total energy system cost under transport electrification scenarios as compared to the base case. It is due to the lower cost of per unit transport service delivered by electric mass transport (EMT) system as compared to the fossil fuel based transport vehicles. However, discounted total transport investment cost increases when electric vehicles (EV) are introduction as their cost are relatively higher than conventional non-electric vehicles.

As a climate related co-benefit, there would be a reduction of as high as 13% of GHG emissions in cumulative terms under EMT20+EV15. This study also shows that if the transport system electrification in Nepal could be registered as a CDM project, up to 5% of the discounted investment required for transport system electrification could be offset through the CER revenue at the CER price of US$20/ton CO_2e under the same scenario. In addition, there would be reduction in the emissions of local pollutants consisting of CO, NO_X, SO_2, NMVOC and PM_{10} due to the transport sector electrification. There is a need for adopting appropriate policies to promote sustainable transport system such as subsidizing environment-friendly vehicles and imposing environmental taxes on fossil fuel vehicles.

The study also shows that there would be additional employment generation during 2015-2050 associated purely with the additional hydropower development required under the transport electrification scenarios. In addition, recharging stations serving electric vehicles under the mixed transport electrification scenarios (consisting of both EMT and EV) scenario is estimated to generate additional cumulative employment generation during the study period.

Chapter 6

Implications of Carbon Tax on Hydropower Development, Energy Security, Environment and Economy

This chapter analyzes the effects introducing a time variant carbon tax schemes in Nepal. It discusses the effects of carbon tax on hydropower development, energy mix, environmental emissions, energy supply security, energy efficiency, energy system cost and employment benefit. The chapter is divided into four sections. The first section consists of descriptions of the base case and alternative scenarios of introducing different level of carbon tax. This is followed by a discussion of the energy system development and its environmental implications in the base case. The third section discusses the implications of carbon tax introduction on hydropower development, environmental emission, energy security and employment benefit. Finally, the key findings of the study are summarized along with concluding remarks.

6.1 Description of Scenarios

This study analyses four scenarios: the base case with electric mass transport (EMT) and three alternative carbon tax scenarios.

The base case with EMT is here after referred as “BASE2” and it considers the energy system development to meet the future service demands at the minimum cost without any environment or energy policy restrictions on GHGs emission. In addition to the assumptions considered in the “base case” of Chapter 5 (for analyzing the effects of transport sector electrification), BASE2 also consider the availability of electric MRT for Kathmandu valley and electric train for RoN region from 2020. The railway based EMT is assumed to serve 10% of land transport demand in 2020 and gradually increases to 20% by 2050 to reflect the recent government plan of introducing electric railway system in the country (RITES/SILT, 2010).[21]

Further, the non-fossil fuel based transport options including full-electric, hybrid with battery storage and fuel cell technology based vehicles are also made available in BASE2. Among the electric vehicle (EV), the hybrid and full-electric options are made available from 2015 and the fuel cell vehicle options are made available from 2020 only. The penetration of EV has been constrained with upper limit set at 10% share of the land transport service demand in 2015 and gradually increasing the share to reach 30% by 2050 for Kathmandu valley. In case of rest of Nepal (RoN), the upper limit for the share of EV has been set at 10% in 2015 which would gradually increase to reach 20% by 2050.

[21] The share of rail mode in passenger transport is 23% and freight transport is 37% in 2001 in India (TERI, 2006). The recent feasibility study of Mechi-Mahakali and Pokhara-Kathmandu Electric Railway carried out by RITES/SILT (2010) has considered up to 55% modal shift from bus to rail mode and 40% model shift from car and freight transport to rail mode by 2035. Our assumption of up to 20% model shift to electric mass transport can be considered as realistic option under these facts.

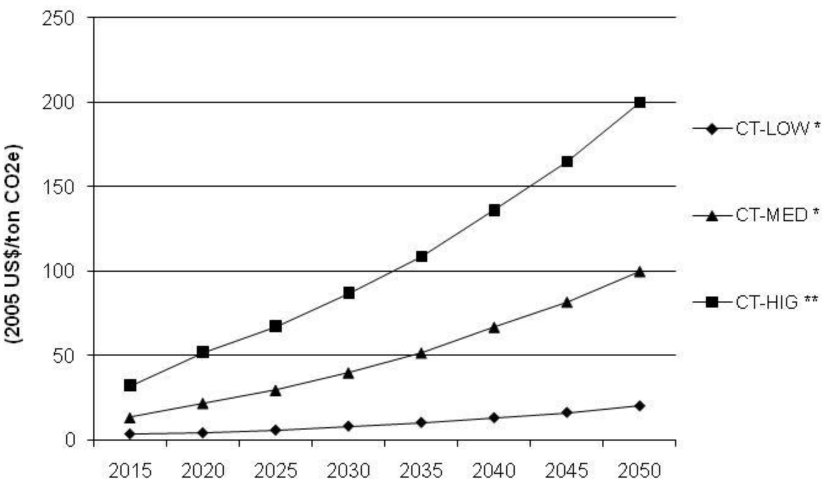
All other assumptions including GDP projection, population projection, energy resource availability, fuel prices, emission factors, candidate power plants, technology options, interest rate are same as the base case of Chapter 5.

Besides the BASE2, following three scenarios related to adopting different levels of carbon tax are also considered in the study:

(i) CT-LOW: introduction of carbon tax starts at US$ 3/tCO_2e in 2015 which would gradually increase to US$ 20/tCO_2e by 2050. This is similar to the global carbon price trajectory under 650 ppmv stabilization target by end of this century (Shukla et al., 2008) and all other things remaining the same as in the BASE2,

(ii) CT-MED: introduction of carbon tax starts at US$ 13/tCO_2e in 2015 which would gradually increase to US$ 100/tCO_2e by 2050. This is similar to the global carbon price trajectory under 550 ppmv stabilization target by end of this century (Shukla et al., 2008) , and

(iii) CT-HIG: introduction of carbon tax starts at US$ 32/tCO_2e in 2015 which would gradually increase to US$ 200/tCO_2e by 2050. This is similar to the global carbon price trajectory under 450 ppmv stabilization target by end of this century (IIM, 2009).



Source: * Shukla (2008), ** IIM (2009)

Figure 6.1: Carbon tax trajectory used in the model

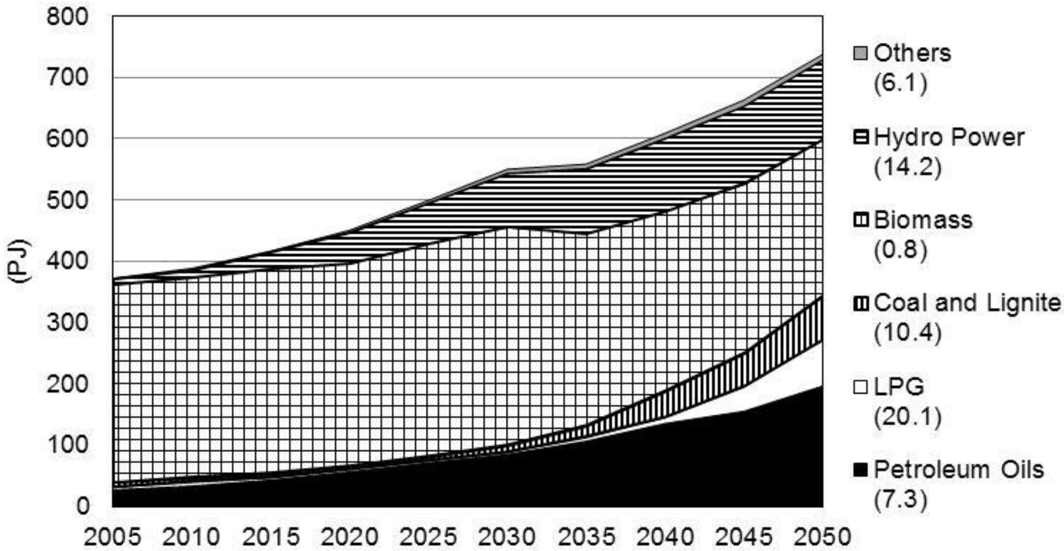
Shukla et al.(2008) and IIM (2009) adopted the carbon price trajectories generated from Global Second Generation Model (SGM) for above mentioned greenhouse gas stabilization targets. The carbon tax trajectory for the three carbon tax scenarios are as shown in Figure 6.1. The 17th Conference of the Parties (COP16) emphasizes on limiting global average temperature rise to 2° by the end of this century which corresponds to the 450 ppmv CO_2e by 2100. Carbon tax used in other studies are given in Appendix F and the carbon tax considered here are within the range used in those studies.

6.2 Analyses of the base case results

In this section, the evolution of overall energy system development as well as their associated energy security and environmental implications are discussed:

6.2.1 Primary energy supply mix

The total primary energy supply (TPES) is estimated to grow at 1.5% (i.e., from 372 PJ in 2005 to 737 PJ in 2050) as shown in Figure 6.2. There would be 9-fold increase in the imported energy consisting of petroleum products, LPG and coal during the study period. The use of hydropower would increase by 13.2 times and that of biomass would decrease by 20.7% mostly due to fuel switch from urbanization.[22] The share of biomass energy resources would decrease (from 87% in 2005 to 35% in 2050), while there would be an increase in the share of petroleum products (from 7.3% to 26.7%), hydropower (from 2.5% to 17.6%), LPG (from 1% to 10.1%), coal (from 1.8% to 9.6%), and others (from 0.4% to 1.2%) as compared to that in the base case during 2005 to 2050.



Note: Figure inside parenthesis indicate ratio of TPES values for 2050 and 2005

Figure 6.2: Base case primary energy supply in Nepal during 2005-2050 (PJ)

[22] Shrestha and Rajbhandari (2010) estimated that there would be reduction in the annual biomass consumption by more than 50% during 2005 – 2050 in Kathmandu valley. The consumption of fuel wood alone has been estimated to reduce by 35% compared to base year value as well as agriculture residue and animal dung eventually reduced to zero by 2030 and 2040 respectively.

6.2.2 Power generation mix

The power generation capacity in Nepal is estimated to increase by nearly 12 times during the study period and is dominated by hydropower as shown in Table 6.1.[23] By 2050 hydropower plants would account for 89.4% of the total installed power generation capacity. The share of the other renewables constitutes 0.75% of micro-hydro plants, 0.34% of solar home systems, 0.13% of cogeneration plants, 5.82% of wood based combined cycle plant, and 0.06% of MSW based power plant. The thermal power plants would account for 3.49% of the total capacity in 2050. The annual electricity generation in Nepal is estimated to increase nearly 15-fold during the study period as shown in Table 6.1. The share of other renewables in annual electricity generation would increase gradually during 2005 to 2050, while the share of hydropower (excluding micr-hydro) and thermal generation decreases during the study period.

Table 6.1: Electricity generation in Nepal during 2005-2050

	2005		2030		2050	
Power Plant	GW	TWh	GW	TWh	GW	TWh
Hydropower	0.552	2.544	4.881	24.430	7.677	36.051
Thermal	0.106	0.054	0.000	0.000	0.300	0.420
Micro-hydro	0.007	0.054	0.064	0.486	0.065	0.486
Solar home systems	0.003	0.008	0.021	0.053	0.030	0.073
Biomass combined cycle plant	0.000	0.000	0.100	0.350	0.500	2.672
Cogeneration plant	0.004	0.009	0.009	0.024	0.011	0.039
MSW plant	0.000	0.000	0.005	0.035	0.005	0.021
Total	0.672	2.669	5.080	25.377	8.587	39.761

6.2.3 Final energy consumption

The annual total final energy consumption (TFEC) in the country is estimated to grow at 1.3% (i.e., from 366 PJ in 2005 to 655 PJ in 2050) as shown in Table 6.2. The sectoral final energy consumption would grow at 6.6%, 5.4%, 5.1% and 3.5% in the commercial, transport, industrial and agriculture sectors respectively. The high growth rate of energy consumption in the commercial sector compared to the other sectors is mostly due to higher growth rate of the commercial sector value added of the country's economy in the study. The commercial sector value added would grow at 6.5% as compared to the GDP growth rate of 4.9% during 1988 to 2007 (MOF, 2009).

[23] MOE (2010) has projected national power generation capacity demand to reach -4.6 GW under the low growth scenario and11.4 GW under the high growth scenario by 2030. NEA (2008a) has forecasted the electricity demand to reach 13.9 TWh and power generation capacity demand to reach 2.9 GW by 2024/2025. Similarly, Nepal Water Plan 2005 has estimated the power generation capacity to reach 4 GW by 2027 under base case scenario (WECS, 2005a). The electricity demand estimated in the study tallies with the above projections by the national agencies.

Interestingly, the total residential sector energy consumption including traditional biomass (fuelwood, agriculture residue and animal dung) would decrease by 4.8% (Table 6.2), while the residential sector consumption of non-biomass energy would increase by about 8 times (Table 6.3). This decrease in the residential sector energy consumption is partly due to a switch from biomass to higher grade fuels (kerosene, LPG and electricity) with urbanization and partly due to the penetration of more efficient biomass energy devices (improved cook stoves and biogas)[24]. The annual TFEC excluding traditional biomass is estimated to grow at 5.3% (i.e., from 44 PJ in 2005 to 455 PJ in 2050).

The consumption of imported fuels is dominated by the transport sector with the sector's estimated share reaching 38.2% by 2050, followed by the commercial, industrial and residential with their shares in 2050 being 19.7%, 19.3% and 16.2% respectively. The transport sector's share in the total consumption of petroleum products would be much higher, i.e., 66.2% by 2050.

Table 6.2: Final energy consumption including traditional biomass use in Nepal during 2005-2050 (PJ)

Sector	2005	2030	2050	Ratio 2050/2005
Transport	13.1	72.0	140.0	10.7
Industrial	11.6	43.3	109.2	9.4
Residential	334.0	365.6	317.8	1.0
Commercial	4.1	16.0	73.4	17.9
Agriculture	3.1	9.6	14.5	4.7
Total	365.9	506.5	654.9	1.8

Table 6.3: Final energy consumption excluding traditional biomass use in Nepal during 2005-2050 (PJ)

Sector	2005	2030	2050	Ratio 2050/2005
Transport	13.1	72.0	140.0	10.7
Industrial	9.4	36.8	96.8	10.3
Residential	14.3	48.5	130.3	9.1
Commercial	3.8	15.8	73.3	19.5
Agriculture	3.1	9.6	14.5	4.7
Total	43.6	182.6	454.8	10.4

[24] The energy efficiency of traditional biomass stoves used in rural areas of Nepal are as low as 10% where as efficiency of improved cook stove is 20% and biogas stove is 55%. The renewable energy promotion programme implemented by the GoN under its Alternative Energy Promotion Centre has set target to install additional 500,000 units of ICS and Biogas plants between 2007-2012 (AEPC, 2009). Also given the decreasing trend in the use of agriculture residue and animal dung in the urban areas (Shrestha and Rajbhandari, 2010), in this study it is assumed that use of agriculture residue and animal dung in the urban areas will be decreased to zero by 2050 and 2035 respectively. Considering these huge differences in the efficiency of devices, efficient device promotion target set by the GoN, reduction in the consumption of agriculture residue and animal dung in the urban areas, the decrease in the residential sector energy consumption is anticipated.

6.2.4 Environmental implications

In the base case, the annual GHG emissions would increase by almost 4 times (i.e., from 5.7 million tons CO_2e in 2005 to 27.8 million tons CO_2e in 2050) as shown in Table 6.4. The emission of CH_4 is estimated to decrease mostly due to the large difference in the CH_4 emission factors of biomass fuels compared to the petroleum products used in the residential and commercial sectors.

In terms of sectoral contributions to GHG emissions, the residential sector alone accounted for 60.6% of total GHG emissions in 2005, while the shares of the transport and industry sectors were 17.1% % and 13.7% respectively with the commercial and agriculture sectors accompanying the rest. There would be a substantial change in the sectoral contributions in the GHG emissions by 2050: the transport sector would account for 34.6% of the emission in that year while the industrial, residential and commercial sectors would have a shares of 24.8%, 19.2%, and 16.2% respectively (Figure 6.3). The energy system of the country would be more GHG emission intensive over time during the planning horizon in the base case as shown by the 2.5-fold increase in the value of GHG emission intensity of TPES.

Table 6.4: Emission levels in base case scenario (10^3 tons)

Emission	2005	2030	2050	Ratio 2050/2005
CO_2	2,844	14,375	25,653	9.0
CH_4	96	77	63	0.6
N_2O	1.40	1.86	1.89	1.3
CO	1,357	1,701	1,665	1.2
NO_X	37	99	123	3.3
SO_2	32	77	100	3.2
NMVOC	189	204	225	1.2
PM_{10}	32	70	80	2.5
Total GHG emission[a], 10^3 ton CO_2e	5,674	16,843	27,784	4.9
GHG emission intensity of TPES, kg CO_2e/toe	650	1,305	1,606	2.5

[a]*GHG here includes CO_2, CH_4 and N_2O*

The per capita energy related GHG emissions in Nepal is estimated to rise from 0.23 ton CO_2e in 2005 to 0.57 ton CO_2e by 2050. In addition, there would be an increase in the emission of local pollutants between 2005 and 2050. The emission of NO_X increases by 231.9%, SO_2 increases by 215.2% and PM_{10} increases by 149.5% in 2050 as compared to the level of emission in 2005. Similarly, NMVOC increases by 19.2% and CO increases by 22.7% (see Table 6.4).

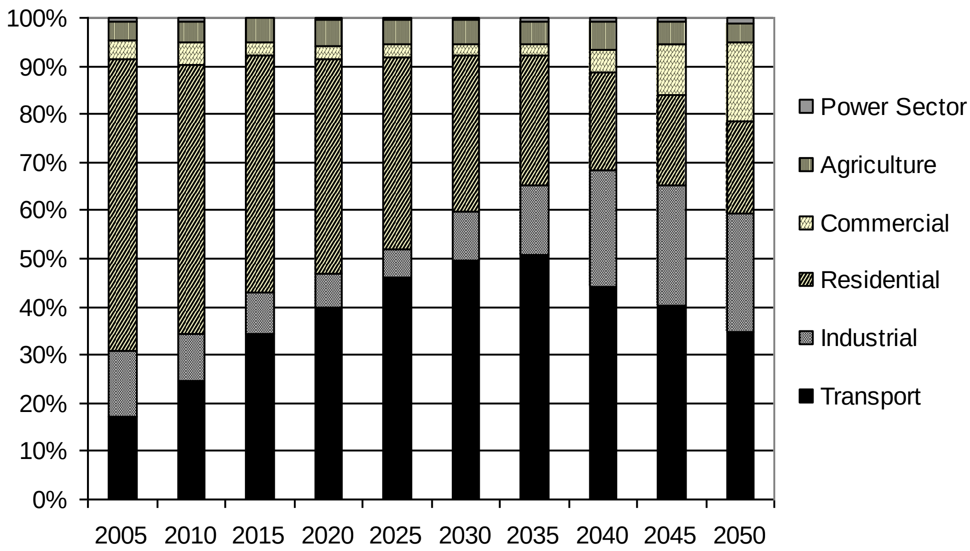


Figure 6.3: Sectoral share of annual GHG Emission during 2005 – 2050

6.2.5 Energy security

The values of energy security indicators, i.e., Shannon-Wiener Index (SWI), net energy import ratio (NEIR), and share of oil in TPES (SOTP) (APERC, 2007; Kruyt et al., 2009) for selected years are shown in Table 6.5. The SWI measures the level of diversification of energy resources with its higher value indicating a more diversified energy resource mix. NEIR and SOTP measure the economic dependence on imported fuels with their higher value signifying increased level of import dependency. The increasing trend of SWI shows a growing diversification in the deployment of primary energy resources during the study period, which is mostly due to a decrease in the share of traditional biomass (initially dominating) and increase in the shares of hydropower, fossil fuels, and other energy resources (see Figure 6.2). At the same time, the other two energy security indicators show the increasing dependency on imported fuels (especially petroleum products).

Table 6.5: Energy security indicators in the base case during 2005-2050

Indicator	2005	2030	2050
Net energy import ratio (%)	10.30	18.11	46.24
Share of oil in TPES (%)	7.27	15.43	26.66
Shannon-Wiener Index	0.55	1.03	1.55

6.3 Effects of carbon tax

This section highlights the implications of carbon tax on the hydropower development, energy security, environmental emissions, energy system costs, and employment in the country. Three different counterfactual scenarios representing different levels of carbon tax were considered in the present study as mentioned in the section 6.1.

6.3.1 Effects on GHG emissions

The estimated annual GHG emissions during the study period for the base case and carbon tax scenarios are shown in Figure 6.4. There would be a reduction in the cumulative emission of GHGs by 5.5% (29.1 million tons CO_2e) under CT-LOW, by 8.3% (44.2 million tons CO_2e) under CT-MED and by 12.0% (63.8 million tons CO_2e) under CT-HIG (see Table 6.6). The sectoral structures of GHG emissions reduction under different scenarios are shown in Table 6.7. The industrial sector dominates the cumulative GHG emissions reduction under the carbon tax scenarios with its share being above two-thirds mostly due to the substitution of coal by fuelwood and efficiency improvement in production processes (discussed in section 6.2.6). Clearly, this is in line with the objective of the Industrial Policy 2010, which emphasized the adaption of cleaner production processes (MOI, 2010). In the case of other sectors, GHG emission is reduced mostly due to the fuel switching from fossil fuels to electricity and also due to efficiency improvement in the energy utilization devices (sees section 6.2.6). In the transport sector, the use of biodiesel to partly substitute diesel would also reduce the GHG emission to some extent under the carbon tax scenarios.

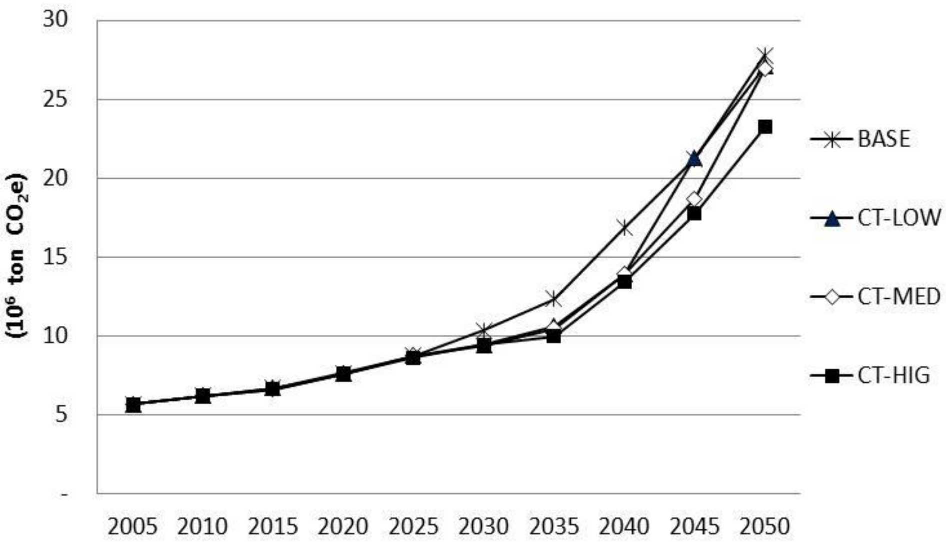


Figure 6.4: Annual GHG emissions under different scenarios

Table 6.6: Cumulative GHG emissions during 2005-2050 in different scenarios (10^6 tons)

Scenario	CO_2	CH_4	N_2O	Total GHG	% Reduction
BASE2	411.72	3.94	0.077	533.21	
CT-LOW	383.32	3.91	0.077	504.09	-5.5%
CT-MED	368.97	3.88	0.077	489.00	-8.3%
CT-HIG	347.51	3.94	0.078	469.36	-12.0%

There would be a cumulative reduction in CO_2 emission by 6.9% (28.4 million tons CO_2) under CT-LOW as compared to the base case, with the industrial sector contributing the most (81.7%), followed by the residential (10.6%) and commercial

(4.4%) sectors. Under CT-MED, there would be a reduction in cumulative emission of CO_2 by 10.4% (42.7 million tons CO_2).25 The industrial sector would dominate the reduction of cumulative CO_2 emission under CT-MED with its share of 83.2%; this is followed by the residential sector (11.3%) and the agriculture sector (2.4%).26 In the case of CT-HIG, the reduction of cumulative CO_2 emission during 2005 to 2050 would be 15.6% (64.2 million tons CO_2) as compared to the emission in the base case.[27] The sectoral shares in the cumulative CO_2 emission would be 68.2% from the industrial sector, 15.5% from the residential sector and 7.4% from the commercial sector. This is followed by agriculture sector, power sector and transport sector with share of 4.5%, 2.3% and 2.1% respectively[28].

Table 6.7: Sectoral GHG emissions reduction during 2005-2050 (10^3 tons) compared to the base case

	GHG Emission, 10^3 ton			% Share in total emission		
Sector	CT-LOW	CT-MED	CT-HIG	CT-LOW	CT-MED	CT-HIG
Transport	12	359	1,346	0.04	0.78	2.11
Industrial	22,789	36,180	42,987	78.26	79.07	67.33
Residential	4,058	7,130	10,479	13.94	15.58	16.41
Commercial	1,248	(1,546)	4,806	4.29	0.00	7.53
Agriculture	901	1,081	2,924	3.09	2.36	4.58
Power Sector	112	1,007	1,306	0.38	2.20	2.05
Total	29,120	44,211	63,848	100	100	100

Note: Figures in the parenthesis indicate an increase in the GHG emission.

6.3.2 Effects on local pollutants emissions

The annual emission of local pollutants consisting of SO_2, NO_X and NMVOC would decrease in all carbon tax cases as compared to the base case in 2050 (see Figure 6.5a, 6.5b and 6.5c). However, the annual emission of CO and PM_{10} would decrease only under CT-LOW and CT-MED (see Figure 6.5d and 6.5e). There would be a decrease in the emission of SO_2 by 0.4% under CT-LOW to by 11.9% under CT-HIG as compared to the base in 2050. The emission of NO_X would reduce by 0.1% in CT-LOW to by 7.3% in CT-HIG in 2050. Similarly, the annual emission of NMVOC would decrease by 0.7% under CT-HIG to by 7% under CT-MED in the same year. In case of CO, there would be reduction in the annual emission by 4.1% under CT-LOW and by 7.9% under CT-MED, but increase by 3.5% under CT-HIG compared to the base case in 2050. Following, there

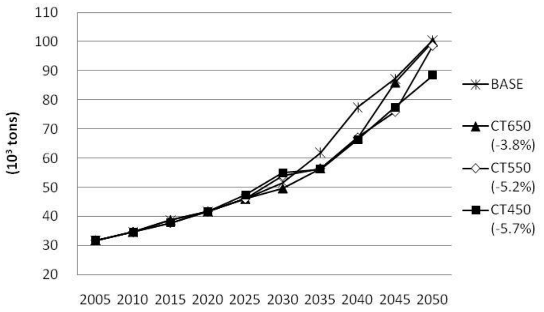
[25] This is higher than the value reported for Thailand (i.e., 6%) (Shrestha et al. 2008) and lower than the value reported for India (i.e., 38.6%) (Shukla et al. 2008) under similar the carbon tax trajectory (CT-MED).

[26] Power sector plays the dominant role in CO_2 emission reduction for India (64%) and Thailand (70%) under carbon tax similar to CT-MED, where as it contributes nominal value (2.2%) in case of Nepal due to dominance of hydropower in power sector.

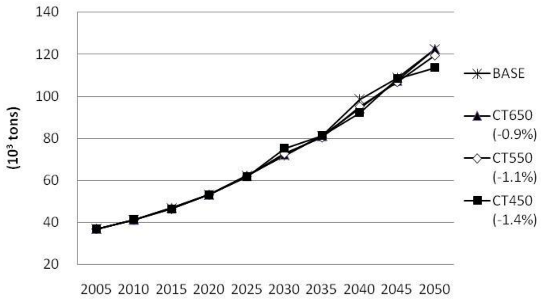
[27] The extent of estimated percentage reduction for Nepal is lower than the percentage reduction reported for India (48.1%) (IIM 2009) under similar carbon price trajectory (CT-HIG).

[28] Under a similar carbon tax path (CT-HIG), the power sector is reported to hold the major share of 67.5% in the cumulative CO_2 emission reduction in the case of India during 2000 to 2050 (IIM 2009).

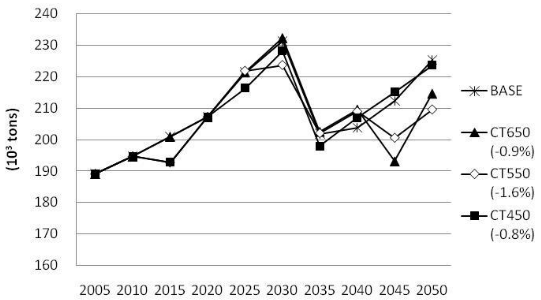
would be decrease in the emission of PM_{10} by 1.7% under CT-LOW and by 3.6% under CT-MED, but increase by 3.2% under CT-HIG. The small increase in the annual emission of CO and PM_{10} under CT-HIG is mostly due to the replacement of coal by biomass in the industrial sector. The change in cumulative term of local pollutants emissions during 2005-2050 under carbon tax cases compared to the base case are shown in Figure 6.5.[29]



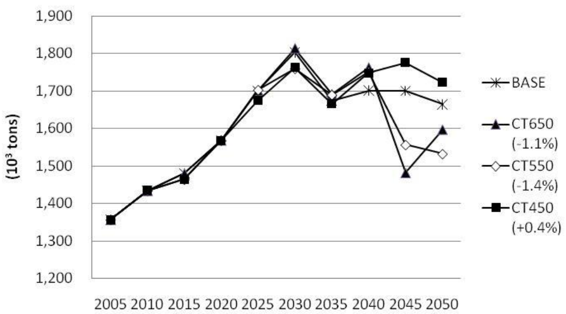
(a) SO_2



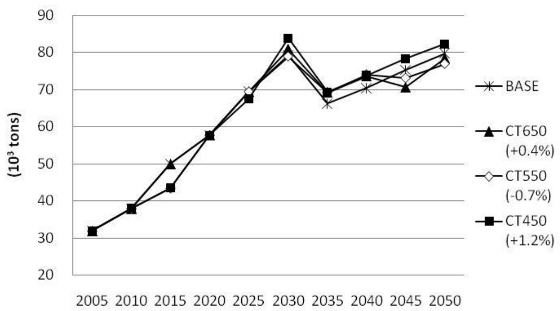
(b) NO_X



(c) NMVOC



(d) CO



(e) PM_{10}

Note: Figure in parenthesis indicates cumulative reduction during 2005-2050.

Figure 6.5: Annual emission of selected local pollutants during 2005-2050

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[29] Shrestha et al. (2008) mentioned 7.6% reduction in the cumulative emission of SO_2 and 2.8% reduction in the cumulative emission of NO_X under carbon price trajectory similar to CT-MED as compared to base case during 2000-2050 for Thailand. In case of Nepal there would be cumulative reduction of SO_2 by 5.2% and NO_X by 1.1% under CT-MED as compared to the base case during 2005-2050.

6.3.3 Effects on the use of renewable energy resources

The carbon tax would promote the use of renewable energy resources, in that its share in the cumulative total primary energy supply would increase from 76.7% in the base case to 78.1%, 78.6% and 79.9% under CT-LOW, CT-MED and CT-HIG respectively during 2005-2050 (Table 6.8).

Table 6.8: Fuel wise distribution of cumulative primary energy supply during 2005-2050 (PJ)

Scenarios	Petroleum Products	LPG	Coal	Biomass	Hydro-power	Electricity Import	Other Renewables	Total
BASE2	3991	558	912	14433	3312	59	182	23448
CT-LOW	3947	528	667	14584	3465	64	180	23436
CT-MED	3900	577	523	14673	3445	64	176	23358
CT-HIG	3819	443	450	15039	3510	65	173	23498

The use of fossil fuels is estimated to decrease, while the use of the major indigenous renewable energy resources like hydropower and biomass (fuelwood, agriculture waste and animal waste) would increase in all carbon tax scenarios. The cumulative TPES during 2005-2050 is estimated to decrease under CT-MED and CT-LOW, and increases under CT-HIG as compared to the base case.

6.3.4 Effect on electricity generation requirement

Under the carbon tax, the cumulative electricity generation requirement would increase by 3.8% (37.9 TWh) in CT-LOW, by 3.5% (34.4 TWh) in CT-MED and by 6.3% (62.2 TWh) in CT-HIG during 2005 to 2050 (Figure 6.6). As a result, the additional hydropower capacity needed under the carbon tax scenarios would be 706 MW in CT-LOW, 614 MW in CT-MED and 945 MW in CT-HIG by 2050. Similarly, there would be a 2.8 MW of additional cogeneration capacity under CT-MED and CT-HIG by 2050 (Figure 6.7). This shows the need for an integration of climate and energy policies in the country.[30]

[30] The effect of the carbon tax on electricity generation requirement, however, depends a lot on the availability of renewable energy based power generation sources in a country. For example, in the case of Thailand, where electricity generation is based heavily on fossil fuels, Shrestha et al. (2008) have reported no significant change in the level of electricity generation under a carbon tax scenario similar to CT-MED.

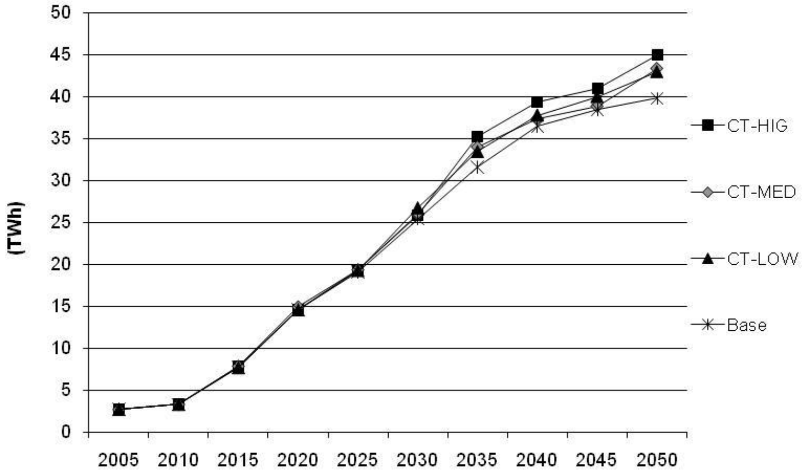


Figure 6.6: Annual electricity generation during 2005-2050

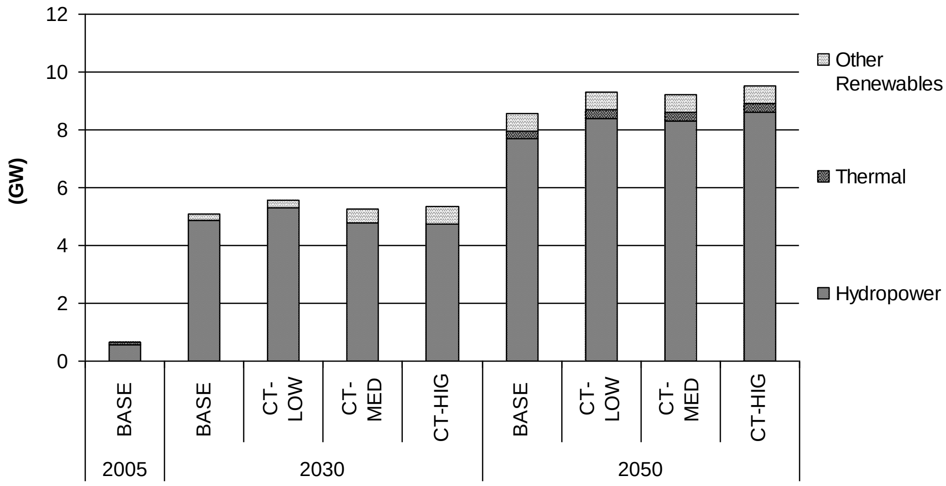


Figure 6.7: Annual power generation capacity requirement in 2050

6.3.5 Effects on the end use energy efficiency improvement

The cumulative total final energy consumption (TFEC) would decrease in all the carbon tax scenarios indicating improvement in the efficiency of overall energy consumption in the country. Reduction in TFEC would range from 0.03% under CT-HIG to 0.5% under CT-MED as shown in Table 6.9.

In terms of sectoral final energy consumption (FEC), the introduction of carbon tax would result in a decrease in the cumulative FEC in the commercial, agriculture and residential sectors but, it would result in an increase of the same in the industrial sector under CT-LOW. Under CT-MED, there would be a decrease in the cumulative FEC under all sectors except in the industrial and commercial sectors. In case of CT-HIG, there would be a decrease in cumulative FEC under all sectors except the industrial. The increase in the cumulative FEC in the industrial sector under the carbon tax is mostly due to fuel-switching, i.e., from coal to fuelwood (having lower thermal efficiency) in the industrial boilers. Similarly, a decrease in the cumulative FEC under the carbon tax in other sectors is mostly due to an additional penetration of high grade fuel and more efficient end use devices (see section 6.2.6).

Table 6.9: Sectoral cumulative final energy consumption

Sector	Cumulative final energy consumption, 2005-2050 (PJ)				Difference from BASE (%)		
	BASE2	CT-LOW	CT-MED	CT-HIG	CT-LOW	CT-MED	CT-HIG
Transport	3081	3081	3080	3074	0.0	-0.1	-0.3
Industrial	2022	2090	2123	2134	3.4	5.0	5.5
Residential	15160	15072	14954	15072	-0.6	-1.4	-0.6
Commercial	951	947	960	933	-0.4	0.9	-1.9
Agriculture	393	393	390	388	-0.2	-0.8	-1.3
Total	21607	21584	21507	21601	-0.1	-0.5	< -0.1

6.3.6 Selection of cleaner and efficient technologies

Carbon tax is expected to increase penetration of cleaner and efficient technology options in all the sectoral end-use service demands.

In the residential sector, an increase in the use of electricity would take place in cooking replacing kerosene, LPG, fuelwood from 2035 under CT-LOW and from 2020 under CT-MED and CT-HIG. An increased use of electricity in space heating becomes cost effective from 2030 under CT-LOW and CT-MED and from 2025 under CT-HIG. Similarly, an increase in the use of electric water heater becomes cost effective from 2035 under CT-LOW and CT-MED and from 2025 onwards under CT-HIG. In addition, there would be an increased penetration of CFL lamps under CT-HIG compared to the base case.

Similarly, in the commercial sector, there would be more use of electricity (than that in the base case) in space heating replacing kerosene heater from 2025 onwards. The additional use of electricity in cooking is expected to become cost effective only under CT-HIG from 2040. However electric cooking is replaced by LPG cooking under CT-LOW and CT-MED during least cost minimization of total energy system in the model.

In the transport sector, there would be an additional substitution of diesel by biodiesel under the carbon tax scenarios. Under CT-MED additional transport electrification takes place with introduction of diesel-hybrid pickup truck from 2025. However, significant transport electrification takes place in CT-HIG with introduction diesel-hybrid pickup truck from 2025, electric micro bus from 2030 as well as diesel-hybrid bus and electric taxi from 2050.

A cleaner biomass fuel replaces coal from 2030 in thermal (boiler) applications in the industrial sector. Under CT-HIG, additional use of efficient brick kilns (e.g., Vertical Shaft Brick Kiln) takes place. Similarly, the use of efficient burners would increase in cement production under CT-HIG. In the agriculture sector, electric pump becomes cost effective over diesel pumps from 2040 under the carbon tax scenarios.

6.3.7 Energy security implications

This analysis shows that there would be a reduction in energy import dependency of the country under all the carbon tax scenarios considered (see the net energy import ratio (NEIR) for primary energy in Table 6.10). The cumulative total imported energy during 2005-2050 is estimated to decrease by 5.8% (319 PJ) in CT-LOW, 8.4% (460 PJ) in CT-MED and 13.5% (742 PJ) in CT-HIG as compared to the base case (Figure 6.8). This reduction in the imported energy can be interpreted into the saving of valuable foreign currency necessary for procuring those imported fuels.[31]

The value of Shannon-Wiener Index, which is an indicator used to measure the extent of diversity in energy resource mix, is found to vary from 1.49 under CT-HIG to 1.57 under CT-MED in 2050 (Table 6.10). As compared to the base case, there would be a slight improvement in the diversity of energy supply under CT-LOW and CT-MED in 2050. On the contrary, there would be a slightly lower level of diversification under CT-HIG as compared to the base case (mostly due to increase in previously dominating biomass). The level of diversification in the primary energy supply in 2050 would be significantly higher in all the scenarios compared to that in 2005 of the base case (Table 6.10).

Table 6.10: Energy security indicators for primary energy supply in 2050

Scenario	BASE2	CT-LOW	CT-MED	CT-HIG
Net energy import ratio (%)	46.24 (10.30)	45.43	45.77	38.58
Shannon-Wiener Index	1.55 (0.55)	1.56	1.57	1.49

Note: Figure in parenthesis indicates energy security values in 2005.

[31] In case of India, IIM (2008) and Shukla et al. (2008) expected adverse impact on the energy security due to increased dependence on the imported uranium under carbon tax scenario compared to base case. In case of Thailand the imposition of carbon tax does not seem to have any appreciable effect in reducing import dependency owing to its relatively small renewable energy resource potential (Shrestha et al. 2008).

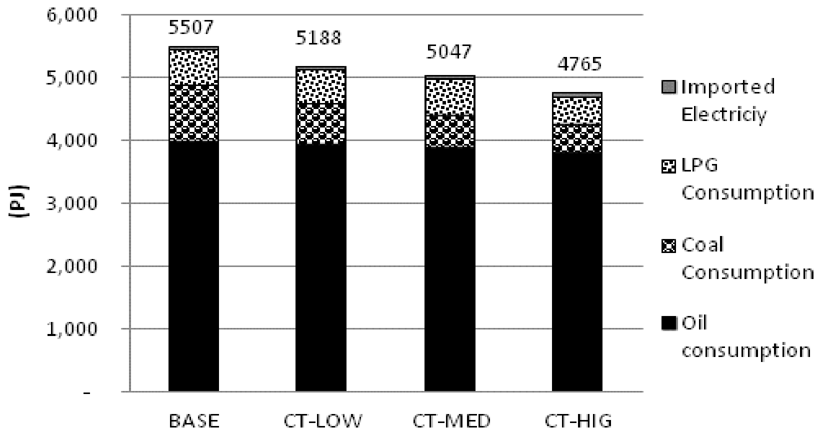


Figure 6.8: Cumulative total imported energy during 2005-2050

6.3.8 Energy system costs and Carbon tax revenue

The estimated discounted total energy system cost (TESC) in the base case is 62.2 billion US$. The discounted net fuel import cost accounts for 17.5% of the discounted TESC (Table 6.11). This study shows that the discounted net fuel import cost would decrease in all the carbon tax scenarios in the range of 2.2% under CT-LOW to 5.0% under CT-HIG, thus reducing economic vulnerability on balance of payment from import of fossil fuels. At the same time, the discounted TESC would increase in all the alternative scenarios by 0.6% under CT-LOW and by 4.7% under CT-HIG.

Table 6.11: Discounted energy system costs (10^9 US$ @ 2005 price)

Scenario	technology investment	Net fuel import cost	Domestic fuel cost	O&M and others	Carbon Tax	Total energy system cost including emission tax
BASE2	37.89	10.86	9.80	3.66	-	62.22
CT-LOW	38.12	10.62	9.85	3.69	0.29	62.56
CT-MED	38.04	10.61	9.89	3.69	1.40	63.62
CT-HIG	38.24	10.31	9.93	3.72	2.97	65.16

In the MARKAL framework, carbon tax is also included in the annual cost during minimization of the net present value of total annual energy system cost throughout the study period (Loulou et al., 2004). If the emission tax is considered to be recycled to the economy then the total energy system cost net of the carbon tax revenue would increase under CT-LOW and CT-MED while it would decrease under CT-HIG as compared to the TESC in the base case. The discounted carbon tax revenue would range from 0.3 billion US$ under CT-LOW to 3 billion US$ under CT-HIG.

6.3.9 Employment generation effects

The carbon tax can affect employment generation associated with construction and operation of additional hydropower plants implied by the increased use of electricity under the tax. It can also increase the employment level through electrification of the transport sector (e.g., recharging of batteries of electric vehicles) as there would be an increased use of electric vehicles under CT-MED and CT-HIG.

Though the actual employment generation associated with the construction and operation of a hydropower plant is both site and project specific, we have attempted here to determine the order of magnitude of the employment generation rather than an estimation of precise level of employment generation. It has been assumed that each Mega-Watt of hydropower development would generate, on an average, 30.3 man-years of employment each year during construction phase (MOWR, 2009) and 3.0 man-years of employment each year during the operation phase (Jha et al., 2007).[32] Thus the increase in the cumulative level of the employment generation during 2015-2050 due to the additional hydropower development under carbon tax scenarios would be 119 thousands man-years under CT-LOW, 90 thousands man-years under CT-MED, and 151 thousands man-years under CT_HIG as shown in Table 6.12.

Table 6.12: Estimated employment generated from hydropower development during 2015-2050 (man-year)

Scenario	Construction phase	Operation phase	Total
BASE2	1,102,679	741,227	1,843,906
CT-LOW	1,187,794	775,127	1,962,921
CT-MED	1,175,853	758,594	1,934,446
CT-HIG	1,211,277	783,697	1,994,974

Similarly, under CT-MED and CT-HIG there would be additional employment generation related to the establishment and operation of recharging stations for electric vehicles. Assuming one recharging station serves 80 electric vehicles per day and employs one person (Morrow et al., 2008), there would be new employment generation in the transport sector in the order of 7,146 man-year under CT_MED and 36,957 man-year under CT_HIG during 2015-2050[33]. This indicates the potential economic co-benefits under carbon tax scenarios.

[32] Jha et al. (2007) have mentioned the average annual employment per hydropower plant during operation phase of 15 existing hydropower plants (with cumulative installed capacity of 398 MW) of Nepal to be 81 man-years per hydropower plant in 2004/05.

[33] In addition, there could also be new employment generated (during production, installation, operation and maintenance) associated with energy efficiency improvement and clean energy technologies, which have not been addressed in the present study due to requirement of macroeconomic model that considers the effects on different factors of production including labor.

6.4 Conclusion and Policy Implications

In this chapter, the implications of introducing different carbon tax profiles in Nepal using a long term energy system model were examined. Altogether, three alternative carbon tax scenarios are considered in the study: low, medium and high with their value similar to the carbon price trajectories required to attain the global greenhouse gas (GHG) stabilization targets of 450 ppmv, 550 ppmv and 650 ppmv by Second Generation Model (SGM) (Shukla et al. 2008; IIM 2009). The study analyses the effects of the selected carbon tax profiles on hydropower development, energy supply mix, environmental emissions, energy supply security, energy efficiency, employment and energy system cost under these scenarios.

In the base case, the total primary energy supply is estimated to grow two fold and the total primary energy supply would increasingly depend on imported fossil fuels (petroleum products, LPG and coal) with their share increasing from 10% in 2005 to 46% by 2050. The carbon tax would increase the use of indigenous renewable energy resources in the country. There would be a reduction in the cumulative total imported energy consumption during the study period ranging from 5.8% (319 PJ) in CT-LOW to 13.5% (742 PJ) in CT-HIG as compared to the base case. The study shows that the implementation of carbon tax would nominally increase the diversification of primary energy supply under CT-LOW and CT-MED, while it would slightly decrease the diversification under CT-HIG (due to high consumption of biomass replacing use of coal) in 2050.

The GHG emissions from the energy system would grow from 5.7 million tons CO_2e in 2005 to 27.8 million tons CO_2e in 2050 in the base case. Clearly, the GHG emission is growing much faster than the TPES. The study shows that the introduction of the carbon tax would result in the reduction of cumulative GHG emissions during 2005-2050 in the range of 5.5% under CT-LOW to 12% under CT-HIG as compared to the base case. These give an indication of the GHG emission mitigation potential under a Clean Development Mechanism (CDM) at CER prices that are close to the carbon tax considered in the present study.

This study also shows the levels of reduction in the emission of short-lived local pollutants. In particular, there would be a reduction of SO_2 by up to 11.9% under CT-HIG, NO_X by up to 7.3% under CT-HIG and NMVOC by up to 7.0% under CT-MED scenario in 2050. The emission of CO and PM_{10} would decrease under CT-LOW and CT-MED cases. However, their emissions would slightly increase under CT-HIG in 2050.

Under the carbon tax scenarios considered in the present study, the domestic requirement for electricity generation would increase by 3.5% (34.4 TWh) in CT-MED to by 6.3% (62.2 TWh) in CT-HIG as compared to the base case during 2005-2050. In order to supply the increased electricity demand, there would be a need to install additional hydropower capacity of 614 MW in CT-MED to 945 MW in CT-HIG by 2050. This shows that the climate policy like carbon tax would have to be considered together with policies for energy resources development, in particular the policies for hydropower development in Nepal.

The present study indicates an improvement in the efficiency of the cumulative total final energy consumption in all the carbon tax scenarios compared to the base case. The improvement in the efficiency would result mostly from the increased use of electric end-use devices in the residential, commercial and agriculture sectors. In the transport sector, there would be a significant efficiency improvement in CT-HIG with the penetration of electric light duty passenger vehicles, diesel-hybrid bus and diesel-hybrid pickup truck. The study also estimated the co-benefits in terms of employment generation associated with additional hydropower development under the carbon tax scenarios and that through the establishment of more electric recharging stations under CT-MED and CT-HIG.

The analysis also reveals that the adoption of carbon tax would decrease the discounted net fuel import cost and thus reduce the economic vulnerability (in terms of balance of payment) to import of fossil fuels. The discounted total energy system cost including carbon tax shows an increase under all carbon tax scenarios. However, if recycling of 100% of the carbon tax back to the economy is considered, the discounted total energy system cost excluding carbon tax is expected to decrease under CT-HIG.

The present study indicates that the introduction of a carbon tax can be an effective tool to implement recently introduced Climate Change Policy 2010 by the Government of Nepal (MOEV, 2010) which states the main objectives as (i) promotion of the use of clean and renewable energy resources in the country and (ii) adoption of climate friendly socio-economic development by following a low carbon development path. As the policy also envisages the formulating of the national low carbon development plan by 2013 the significance of the present study becomes more justified to access the effects of such policies on the overall energy system, environment and the national economy.

Chapter 7

Formulation of a Nepal Computable General Equilibrium Model

This chapter presents a formulation of a multi-sector, single region recursive dynamic computable general equilibrium framework of Nepal focused on analyzing macroeconomic implications under transport electrification policy and carbon tax policy. The model has been specially developed with technology level disaggregation of the transport sector and electricity generation sector in order to represent transport electrification policy in more detail. The foreign investment is set exogenous and exchange rate is set endogenous during macroeconomic closure for analyzing the presence of Dutch diseases effect under transport electrification policy. Similarly, detail representation of fossil fuels in production activities of different sectors and household consumption demand have been done in the Social Accounting Matrix (SAM) in order to study the macroeconomic effects of imposing carbon emission tax on the consumption of those fuels. The formulation of the model named "Nepal-CGE" consists of a design of basic structure of the model, preparation of a SAM, determination of parameter values for the base year (2005) and model calibration process.

7.1 Overview of Nepal-CGE Model

This section presents the background and formulation of a CGE model of Nepal developed for this study. The CGE modeling approach is mainly used to determine overall impacts in an economy under different intervention policies (i.e., transport electrification, trade liberalization, C-tax etc.) and changes in exogenous shocks (i.e., change in international prices of fuels, setting or removal of quotas for import and export of commodities etc.). The model consists of the top-down modeling approach with the equilibrium reached by a number of agents simultaneously operating in the respective markets. In this study, the CGE analysis is used to evaluate economic impacts on the sectoral levels of the national economy and the household welfare under following two policies (i) transport electrification policy with different share of foreign direct investment used to cover the additional investment needed under the policy in the transport and hydropower sectors and (ii) C-tax policy with introduction of different levels of C-tax on the consumption of fuel commodities.

The first application of the CGE model called Applied General Equilibrium (AGE) model in relevant energy issues is primarily developed by Hudson and Jorgenson (1974) known as econometric AGE model. The model has replaced the fixed input-output coefficients for inter-industry transactions by econometric model of producer behavior to generate the demand functions for inputs. The second model tradition involved a group of consumers having each an initial endowment and a set of preferences (Bhattacharyya, 1996) that is closely followed by the Walrasian theory of general equilibrium.

CGE model is based on a fundamental concept of the economic circular flow and theory of Walrasian general equilibrium. Households, firms and government are the main institutions (agents or actors) in the simple circular flow of closed economy. Each household own an initial endowment of factors which are sold to the firms at factor market. Households also are the final consumers and they have a set of preferences in their demand functions for each commodity purchased from product markets. Household earns revenue mostly consists of factor income and transfers from other institutions and expends part of it to fulfill its commodity demand. The firm rent the factors of production from the households to produce goods and services. The government plays passive role by collecting taxes and disbursing revenues to households and firms as subsidies and lump-sum transfers to rules of budgetary balance. In case of the open economy, rest of the world (RoW) act as the fourth institution involving in the trade of commodities, factors, foreign transfer between the country and outside the country (See Burfisher (2011) and Hosoe et al. (2010) for further details). Figure 7.1 presents the basic circular flow of open economy in the model.

Equilibrium in the economic flow results based on the “Walrasian general equilibrium”: i.e., market clearance, zero profit and income balance conditions (Sue Wing, 2003). For market clearance condition, firms’ outputs are fully consumed in the commodity market (by households, other firms and export) and that household’s endowments of primary factors are fully employed in the factor market (by firms). The zero profit in equilibrium is that the sum total of revenue from the production of goods must be allocated to households (as receipts for primary factors rentals), to other industries (as expenditure for intermediate inputs), to the government (as taxes) or to import of intermediate inputs. The income balance’ defined as the returns to households’ endowments of primary factors accruing to households as income that the households exhaust on goods purchases and even for saving.

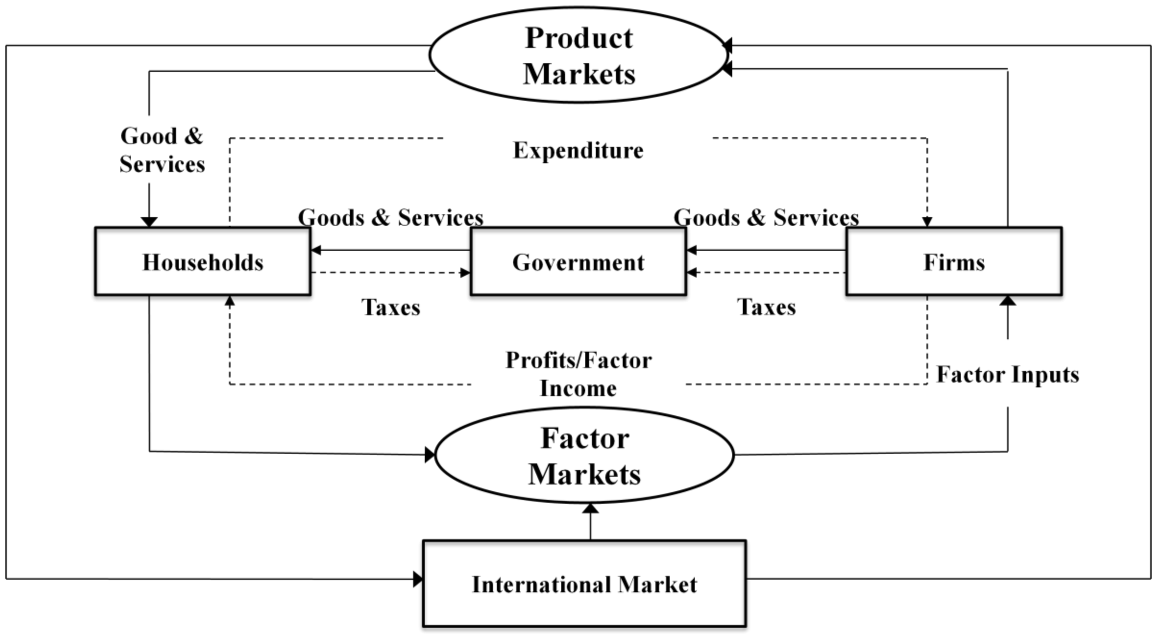


Figure 7.1: Circular flow of open economy in the model

For analyzing energy, environment and transport related policy both static and dynamic versions of CGE model are found to be used in the literature. Static versions of CGE model are used by Benjamin et al. (1989), Barry (2009), Estache et al. (2008), Gilbert and Banik (2010), Levy (2007) and Warr (2006). Similarly, dynamic versions of CGE model are used by Chuanyi (2009), Holmoy and Heide (2005), Siddiqui (2007) and Watcharejyothin (2010). In static CGE model, demands and prices are assumed to be adjusted instantaneously in response to the external shocks (policy shifts), which is less realistic. The dynamic CGE model, however allows time for adjustments and capture lagged effects of intervention policies (Timilsina, 2001). The dynamic models are further divided into recursive dynamic and forward-looking dynamic model. In the recursive dynamic model, decisions about production, consumption, saving and investment are made based on current period variables (prices). This is also referred to as myopic expectation (Paltsev et al., 2005). Decisions about production, consumption, saving and investment are made based on expectations (future returns on investment and change in future price of consumption) for all periods over study time horizon which are assumed to be known with certainty in case of the forward-looking dynamic model (Babiker et al., 2008). However, dynamic CGE models assume stable relative prices to obtain steady-state (balanced) growth equilibrium with future foresight requiring all capital stocks to grow at same rate, which is also unrealistic (Timilsina, 2001).

A recursive dynamic version of the CGE model is in fact an intermediate approach between static model and forward-looking dynamic model. It captures the lagged effects of policy under study with an occurrence of economic equilibrium in each period on the basis of past performance and quantifies the economic equilibrium in the next period from exogenous assumptions consisting of growth of labor force, accumulation of physical capital stocks, change of factor (labor and capital) productivity, technological improvement over time horizon during the study period (Devarajan and Go, 1998; Kim, 2004; Watcharejyothin, 2010).

Constructing a CGE model requires combination of at least three related but distinct areas: formulation (economic theory), parameter estimation (econometrics) and numerical solution (applied mathematics) (Scaramucci et al., 2005; Watcharejyothin, 2010). Boringer et al. (2003) presented major steps for the formulation of basic CGE model as follows:

1. Define clear policy issue which would determine the basic design of model and requirement of data.
2. Develop complex numerical model representing applied economic theory to analyze the issues.
3. Prepare the relevant dataset related to Social Accounting Matrix (SAM), elasticities of substitution and other exogenous variables to complete the framework for numerical policy analysis. This also includes setting-up of alternative policy instruments and strategies against the reference situation.
4. Computer simulations: calibration and simulations.
    a. Calibration involves with selecting parameter values from a consistent one year's data together with exogenous elasticities that are often taken from literature surveys. Then, the calibrated model must be able to generate the base year benchmark equilibrium as a model solution.
    b. Policy simulation and sensitivity analysis: single parameters or exogenous variables are changed and a new (counterfactual) equilibrium is computed. Then, comparison of the counterfactual and the benchmark equilibrium provides results on the policy induced changes of economic variables. Sensitivity analysis on key elasticities also is performed before concrete policy recommendations are derived.
5. Conclusion and policy recommendation based on changes in economic variables.

7.2 Structure of a Nepal-CGE Model

7.2.1 Basic Structure of the Model

A number of studies are available on the development and analysis of CGE model in Nepal (Acharya, 2010; Acharya and Cohen; 2008; Bhattarai, 1996; Buehrer and di Mauro, 1993; Sapkota and Cockburn, 2008; Sapkota and Sharma, 1998). However, these studies were mostly based on analyzing implications from trade liberalization and other macroeconomic policies but not based on the implications from energy, environment as well as transport policies. Sapkota and Sharma (1998) have used a static neoclassical CGE model to study the effect of reducing the import duty, currency depreciation and increasing labor wages on the national economy. Bhattarai (1996) analyzed the impacts of financial sector liberalization in Nepal using forward-looking multi-sectoral dynamic CGE model of decentralized markets. Buehrer and di Mauro (1993) have studied the effect of reduction in tariff by using the recursive dynamic CGE model. Sapkota and Cockburn (2008) studied the effects of trade liberalization on the household welfare and poverty level of the country by using static model. Acharya (2010) analyzed the macroeconomic implications of devaluation of Nepalese currency using static CGE model. Similarly, Acharya and Cohen (2008) studied the effect on household welfare due to trade liberalization in the country. In the context of Nepal, there is a research gap in the macroeconomic implications from the implementation of transport electrification and C-tax policies using elaborate CGE framework for the country.

The CGE model of Nepal developed for this study (here after referred as Nepal-CGE model) consists of several distinctive features which are not yet available in other earlier CGE model developed for the country. They are as follows:

- It considers disaggregated electricity sector including hydropower and other power generation technologies (diesel-fired power plant, wood gasification combined cycle power plant and MSW-based power plant).
- The model considers disaggregated land transport sectors comprising of freight and passenger transport service sectors. Household transport demand consists of the consumption of public passenger transport service and private mode of transportations.
- It also considers energy as a factor of production.
- Fossil fuels are disaggregated into gasoline, diesel, kerosene, LPG, aviation turbine fuel (ATF) and coal in the social accounting matrix (SAM).

The Nepal-CGE is a multi-sector recursive-dynamic CGE model designed for an assessment of effect on sectoral distribution of the GDP and household welfare due to the transport electrification policy and C-tax policy in the country during 2005-2050. It includes four institutions, which are household, production firms, government and RoW. Economic behavior of households deal with maximization of their utilities under their budget constraints. The production firms maximize their profits (minimizes their costs) during equilibrium process. The model adopts a neo-classic approach with full employment of capital and labor supplied by household in the factor market. The government institution acts as the central agency which collects taxes and receives foreign transfer and it spends the collected revenue through public consumption, public investment and institutional transfer to the household. An assumption of a small open-economy is considered in the model with Nepalese economy regarded as price taker from the world market. The RoW acts as a foreign agent involving in the trade of commodities and institutional transfer. It is assumed that the country's economy is initially in equilibrium condition. . The model is developed based on a Social Accounting Matrix (SAM) of Nepal for the year 2005 and using General Algebraic Modeling System (GAMS) programming language. It is based on relaxed mixed integer nonlinear programming and uses GAMS/PATHNLP solver (See Brooke et al., 1998; Rosenthal, 2011).

The macroeconomic implications of transport electrification policy is analyzed by exogenously introducing the individual electric mass transport system and electric vehicles technology based demands in the transport sectors and household consumption with their share in the total land transport demand estimated based on the share generated by the Nepal-ESM model under different transport electrification scenarios (see section 5.6). The effect of foreign direct investment (FDI) is studied by introducing foreign owned capital to cover exogenously specified shares of the additional investment required in the transport and electricity sectors under different transport electrification scenarios as compared to the base case.

Similarly, the macroeconomic implications of C-tax on the consumption of fuel commodities is done by introducing different level of C-tax on the consumption of each fuel based on the carbon content. Then, the effect of government transfer of C-tax revenue to household (25%, 50%, and 100% of the C-tax revenue) is studied.

7.2.2 Classification of Production Sector and Commodities

Recently developed Global Trade Assistance and Production (GTAP) compatible input-output table for 2000/01 by IRPAD (2007) consist of 57x57 commodities as well as activities. The Nepal-CGE model considers aggregated 12x12 activities based production sectors in order to highlight main features involved in the policy issues, availability of data and need for easing the computing time and cost (Table 7.1). The aggregation of the production sectors is based on the major economic sectors considered in the economic survey report by MOF (2009). The desegregations in the transport and energy sectors are done to capture the issues relating to implications of transport electrification policy. There are 5 non-energy commodity production sectors, 3 energy commodity production sectors and 4 transport service sectors. The non-energy sectors consist of agriculture and forestry, manufacturing, motor vehicles, commercial and other public services. Three energy good sectors consist of electricity, lignite and fuelwood. The electricity sector includes four power generation technologies; hydropower, diesel-fired power plant, wood gasification combined cycle power plant and MSW-based power plant as subsectors to generate electricity commodity. Transport sectors consist of land freight, land passenger, air transport sectors and other transport. The land freight and land passenger transport sectors are disaggregated into road transport, rail transport and ropeway transport subsectors. The road transport sector is further disaggregated to the individual technology level as discussed in subsequent Section 5.6.

Altogether 12 commodities are produced from domestic production sectors and 6 fossil fuels are treated as separate imported commodities. The imported fossil fuels consisting of diesel, gasoline, kerosene, LPG, ATF and industrial grade coal are the major energy based imported intermediate input to the production sectors and main consumption commodities of the household. As Nepal is totally dependent on import for fossil fuels, incorporation of these in the SAM is very important for actual representation of input/output dynamics in the economy as well as introduction of carbon tax on the cost of concerning fuels.

Table 7.1: Production sectors and produced/imported commodities in the Nepal-CGE model

	Production Sectors		Produced/Imported Commodities
1	Non-Energy	Agriculture and Forestry	Agriculture and Forestry products
2		Manufacturing	Manufacturing products
3		Motor Vehicles	Motor Vehicles
4		Commercial	Commercial service
5		Public service	Public service
6	Energy	Electricity generation: hydropower, diesel generator, thermal-fuel wood based, and MSW-based technologies	Electricity
7		Lignite	Lignite
8		Fuel wood	Fuel wood
9	Transport	Land freight transport: road (further sub divided into different modes and technologies), rail and ropeway transport services	Land freight transport service
10		Land passenger transport: road (further sub divided into different modes and technologies), rail and ropeway transport services	Land passenger transport service
11		Air transport	Air transport service
12		Other transport	Other transport service includes heavy duty vehicles and others.
		Imported fossil fuels	Diesel
			Gasoline
			Kerosene
			Liquefied Petroleum Gas (LPG)
			Aviation Turbine Fuel (ATF)
			Industrial grade coal

7.3 Description of a Nepal-CGE Model

The basic structure of the model is differentiated into major six modules consisting of production; income and expenditure; investment; price; macroeconomic closure and market clearing; and recursive dynamic characteristics. The following conventions are adopted for the description of the model. The capital letters are used to represent the endogenous variables and the small letters designate the exogenous variables. Greek symbols represent the exogenous parameters calibrated from the SAM in the base year and elasticity parameters. The subscript '*i*' stands for production activities and the subscript '*cm*' stands for commodities.

7.3.1 Production Module

Nepal-CGE model consists of 12 aggregated production sectors producing one commodity per sector. The production behavior of each production sector is represented by nested production function structure composed of six-step hierarchical profit optimization process (Figure 7.2). Similar nested structure is used by Paltsev et al. (2004, 2005), Schafer and Jacoby (2005), Jacoby et al. (2006), Watcharejyothin (2010) and Dai et al. (2011). The producing firms minimize their costs of production for each level of the output. The country is assumed to be small economy country so that the domestic firm production will have no effect on the international market or, in order words, import and export price are fixed exogenously. In addition, the firms have to compete among themselves for using the common production factors consisting of capital and labor. The firms try to minimize their production costs at the given production technologies under the constant returns to scale.

At the upper nest of a six-layer production structure, the gross domestic output excluding production tax (Z_i) from the production sector (i) (except for electricity sector and freight and passenger land transport sectors) is from the aggregate energy-capital-labor primary factor (EKL_i) and aggregate non-energy intermediate inputs bundle (XM_i) with the assumption of a constant elasticity of substitution (CES). At the second level, the producer optimizes its level of aggregate energy-capital input (EK_i) and labor input (L_i) under the nested CES production function. Similarly aggregate non-energy intermediate inputs bundle (XM_i) consists of nested CES production function of domestic non-energy intermediate inputs (DM_i) and imported (non-competitive) non-energy intermediate inputs (MM) under the same level. Inclusion of imported intermediate input material in the production process is very important as government provide special tariff facilities for imported intermediate input commodities to be used in domestic production (it is also adopted by Acharya (2010) and Burfisher (2011)). At the third level, energy composite and capital is nested according to the CES production function. Also, the producer allocates individual domestic non-energy intermediate inputs (M_i) according to the CES production function under the same level. At the fourth level, the producer selects the optimal level of electricity (EL_i) and non-electric fuels (FS_i) according to the CES production function. The producer allocates the non-electric energy bundle (i.e., fuel wood, coal, LPG, gasoline, diesel, kerosene) by the CES production function at the fifth level.

Further, at the lowest level, demand of the domestic good and service (X_{cm}) is supplied by the domestic produced (XDD_{cm}) and import (XDM_{cm}) nested under the CES Armington's specification (i.e., assumption of imperfect substitutability between domestic and imported goods Armington(1969)). In case of non-competitive imported fuel and intermediate input commodities they are supplied from import only. All variables, parameters and equations in the production block starting from the top to bottom levels are presented in the following sections.

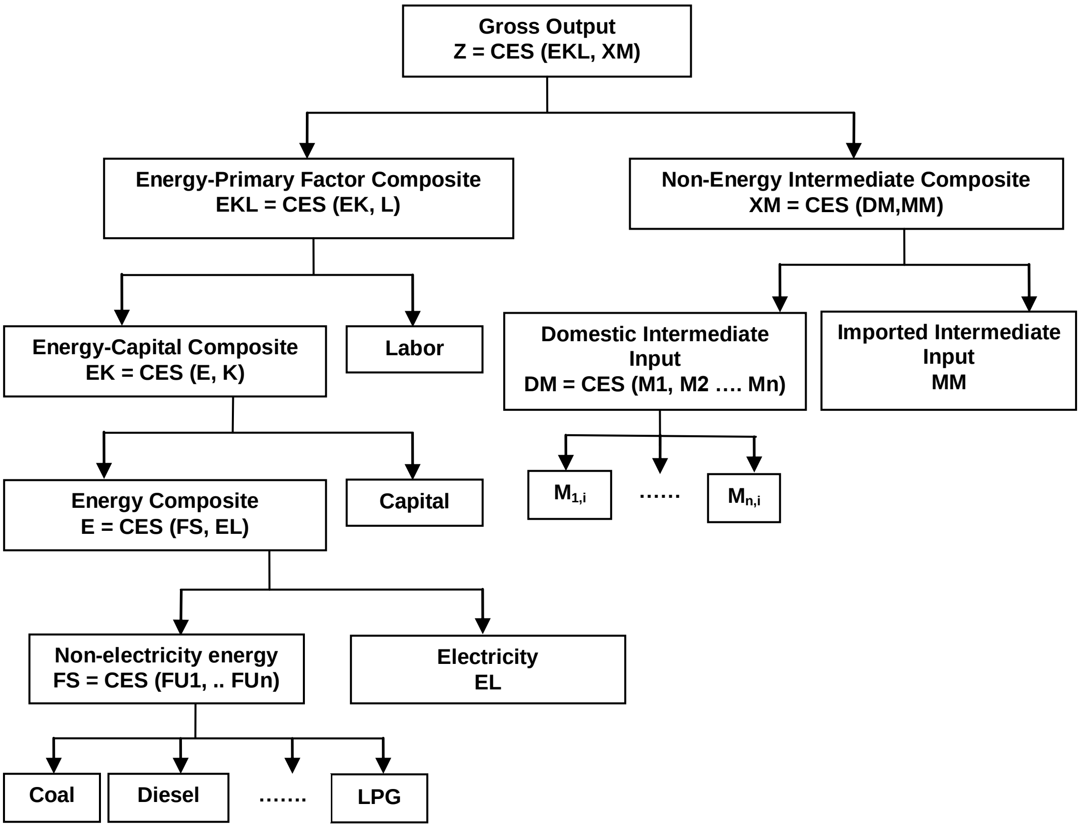


Figure 7.2: Nested production structure

a) Demand for Energy-Primary Factor Composite and Aggregate Non-energy Intermediate Input

At the highest level, the firm produces the gross output (Z_i) from combination of the aggregate energy-capital-labor primary factor (EKL_i) and aggregate non-energy intermediate input (XM_i) under the nested standard CES production function (Shoven and Whalley, 1992; Kim, 2004) as follows:

$$Z_i = \left[\delta_{Zi}^{\frac{1}{\sigma_{Zi}}} . EKL_i^{\frac{\sigma_{Zi}-1}{\sigma_{Zi}}} + (1-\delta_{Zi})^{\frac{1}{\sigma_{Zi}}} . XM_i^{\frac{\sigma_{Zi}-1}{\sigma_{Zi}}} \right]^{\frac{\sigma_{Zi}}{\sigma_{Zi}-1}} \qquad (7.1)$$

Where:

Z_i = gross domestic output excluding production tax of sector i

EKL_i = energy-capital-labor composite used by sector i

XEM_i = aggregate intermediate inputs of energy and non-energy commodities used by sector i

δ_{Zi} = CES function share parameter associated with energy-capital-labor composite and aggregate non-energy intermediate inputs of sector i

PXD_i = producer price of commodity produced by sector i

σ_{Zi} = elasticity of substitution between energy-capital-labor composite and aggregate non-energy intermediate inputs.

The producer maximizes profit (π_i) by choosing levels of composite inputs EKL_i and XM_i subject to the production function as mentioned in Equation 7.1.

$$\max_{EKL_i, XM_i} (\pi_i) = (Z_i . PZ_i) - (EKL_i . PEKL_i + XM_i . PXM_i) \tag{7.2}$$

Where:
$PEKL_i$ = price of energy-capital-labor composite
PXM_i = price of aggregate non-energy intermediate inputs

Here instead of solving Equations 7.1 and 7.2 for profit maximization, a dual cost minimization (Equation 7.3) approach is used to determine the least cost combination of composite inputs EKL_i and XM_i subject to the constraint of its production function (7.1) (Kim, 2004; Sue Wing, 2009; Watcharejyothin, 2010).

$$\min_{EKL_i, XM_i} Cost(EKL_i, XM_i) = EKL_i . PEKL_i + XM_i . PXM_i \tag{7.3}$$

Demands for primary factor composite and aggregate intermediate inputs are obtained by the first order conditions for cost minimization of the Lagrangian function (Kim, 2004; Sue Wing, 2009; Watcharejyothin, 2010) of Equation 7.1 and 7.3 as follows[34]:

$$EKL_i = \delta_{Zi} . \left(\frac{PZ_i}{PEKL_i} \right)^{\sigma_{Zi}} . Z_i \tag{7.4}$$

$$XM_i = (1 - \delta_{Zi}) . \left(\frac{PZ_i}{PXM_i} \right)^{\sigma_{Zi}} . Z_i \tag{7.5}$$

The production function must satisfy the zero profit condition under Walrasian general equilibrium as mentioned in the cost function below:

$$Z_i . PZ_i = EKL_i . PEKL_i + XM_i . PXM_i \tag{7.6}$$

Where, PZ_i is the before tax price of commodity XD_i produced.

Substituting the value of EKL_i and XM_i in Equaltion 7.6, the before tax price of commodity Z_i is given by:

$$PZ_i = \left[\delta_{Zi} . PEKL_i^{1-\sigma_{Zi}} + (1 - \delta_{Zi}) . PXM_i^{1-\sigma_{Zi}} \right]^{\frac{1}{1-\sigma_{Zi}}} \tag{7.7}$$

[34] The Lagrangian function is as following:

$$L = EKL_i . PEKL_i + XM_i . PXM + \lambda \left[Z_i - \left[\delta_{Zi}^{\frac{1}{\sigma_{Zi}}} . EKL_i^{1-\frac{1}{\sigma_{Zi}}} + (1 - \delta_{Zi})^{\frac{1}{\sigma_{Zi}}} . XM_i^{1-\frac{1}{\sigma_{Zi}}} \right]^{\frac{1}{1-\frac{1}{\sigma_{Zi}}}} \right]$$

b) Demand for Energy-Capital-Labor Composite

Demand of energy-capital-labor composite (EKL_i) nested under CES function is expressed as follows:

$$EKL_i = \left[\delta_{EKL\,i}{}^{\frac{1}{\sigma_{EKLi}}} . EK_i{}^{\frac{\sigma_{EKLi}-1}{\sigma_{EKLi}}} + \{\alpha_{L\,i} . (1-\delta_{EKL\,i})\}^{\frac{1}{\sigma_{EKLi}}} . L_i{}^{\frac{\sigma_{EKLi}-1}{\sigma_{EKLi}}} \right]^{\frac{\sigma_{EKLi}}{\sigma_{EKLi}-1}} \tag{7.8}$$

Where:
EK_i = Energy-capital composite used by sector i
L_i = Labor factor used by sector i
α_{Li} = Productivity of labor input of sector i and its value is 1 in the base year
δ_{EKLi} = CES function share parameter associated with energy-capital composite and labor inputs
σ_{EKLi} = elasticity of substitution between energy-capital composite and labor inputs

The producer optimizes its output production based on minimizing cost function. The zero profit condition is fulfilled by following cost function.

$$EKL_i . PEKL_i = EK_i . PEK + L_i . W \tag{7.9}$$

Where:
PEK = price of energy-capital composite
W = national average wage rate (price of labor)

As in the previous case, demands for energy-capital composite and labor are obtained by the first order conditions for cost minimization as follows:

$$EK_i = \delta_{EKL\,i} . \left(\frac{PEKL_i}{PEK} \right)^{\sigma_{EKLi}} . EKL_i \tag{7.10}$$

$$L_i = \{\alpha_{L\,i} . (1-\delta_{EKL\,i})\} . \left(\frac{PEKL_i}{W} \right)^{\sigma_{EKLi}} . EKL_i \tag{7.11}$$

Similarly $PEKL_i$ is derived from Equations 7.9, 7.10 and 7.11 as follows:

$$PEKL_i = \left[\delta_{EKL\,i} . (PEK)^{1-\sigma_{EKLi}} + \{\alpha_{L\,i} . (1-\delta_{EKL\,i})\} . (W)^{1-\sigma_{EKLi}} \right]^{\frac{1}{1-\sigma_{EKLi}}} \tag{7.12}$$

c) Demand for Aggregate Non-Energy Intermediate Input

The non-energy intermediate input composite demand is represented by a CES function of domestic non-energy intermediate input composite (DM_i) and imported non-energy intermediate input composite (MM_i) used by sector i as follows:

$$XM_i = \left[\delta_{XM\,i}^{\frac{1}{\sigma_{XMi}}} . DM_i^{\frac{\sigma_{XMi}-1}{\sigma_{XMi}}} + \left(1-\delta_{XM\,i}\right)^{\frac{1}{\sigma_{XMi}}} . MM_i^{\frac{\sigma_{XMi}-1}{\sigma_{XMi}}} \right]^{\frac{\sigma_{XMi}}{\sigma_{XMi}-1}} \tag{7.13}$$

Where:
DM_i = domestic intermediate input composite used by sector i
MM_i = imported intermediate input composite used by sector i
δ_{XMi} = CES function share parameter associated with domestic intermediate input composite and imported intermediate input composite
σ_{XMi} = elasticity of substitution between associated with domestic intermediate input composite and imported intermediate input composite

Again, zero profit condition is satisfied by following equation:

$$XM_i . PXM_i = DM_i . PDM_i . + MM_i . PMM_i \left(1 + trf_i\right) \tag{7.14}$$

Where:
PDM_i = price of domestic non-energy intermediate input composite
PMM_i = price of imported non-energy intermediate input composite

As in previous case, the demands for domestic intermediate input composite and imported intermediate input composite are obtained by the first order conditions for cost minimization as follows:

$$DM_i = \delta_{XM\,i} . \left(\frac{PXM_i}{PDM_i .} \right)^{\sigma_{XMi}} . XM_i \tag{7.15}$$

$$FS_i = \left(1 - \delta_{XM\,i}\right) . \left(\frac{PXM_i}{PMM_i \left(1 + trf_i\right)} \right)^{\sigma_{XMi}} . XM_i \tag{7.16}$$

Similarly, PXM_i is derived from equations 7.14, 7.15 and 7.16 as below.

$$PXM_i = \left[\delta_{XM\,i} . \left(PDM_i\right)^{1-\sigma_{XMEi}} + \left(1 - \delta_{XM\,i}\right) . \left(PMM_i . \left(1 + trf_i\right)\right)^{1-\sigma_{XMi}} \right]^{\frac{1}{1-\sigma_{XMi}}} \tag{7.17}$$

d) Demand for Energy-Capital Composite

Demand of intermediate input composite (EK_i) nested under CES function is expressed as follows:

$$EK_i = \left[\delta_{EK\,i}^{\frac{1}{\sigma_{EKi}}} . E_i^{\frac{\sigma_{EKi}-1}{\sigma_{EKi}}} + \left(1-\delta_{EK\,i}\right)^{\frac{1}{\sigma_{EKi}}} . K_i^{\frac{\sigma_{EKi}-1}{\sigma_{EKi}}} \right]^{\frac{\sigma_{EKi}}{\sigma_{EKi}-1}} \tag{7.18}$$

Where:
E_i = energy composite used by sector i
K_i = capital factor input used by sector i

δ_{EKi} = CES function share parameter associated with energy composite and capital factor of sector i
σ_{EKi} = elasticity of substitution between energy composite and capital factor of sector i

The zero profit condition must satisfy the following cost function:

$$EK_i.PEK_i = E_i.PE_i + K_i.PK_i \tag{7.19}$$

Where:
PEi = price of energy composite
PKi = price of capital factor input

As in the previous case, demands for energy composite and capital input are obtained by the first order conditions for cost minimization as follows:

$$E_i = \delta_{EK\,i}\left(\frac{PEK_i}{PE_i}\right)^{\sigma_{EKi}} EK_i \tag{7.20}$$

$$K_i = (1-\delta_{EK\,i})\left(\frac{PEK_i}{PK_i}\right)^{\sigma_{XEMi}} EK_i \tag{7.21}$$

Similarly, PEK_i is derived from equations 7.19, 7.20 and 7.21 as follows:

$$PEK_i = \left[\delta_{EK\,i}.PE_i^{1-\sigma_{EKi}} + (1-\delta_{EK\,i}).PK_i^{1-\sigma_{EKi}}\right]^{\frac{1}{1-\sigma_{EKi}}} \tag{7.22}$$

e) Demand for Energy Composite

The energy composite demand is represented by a CES aggregation of electricity (EL_i) and non-electricity energy inputs (F_i) used by sector i as follows:

$$E_i = \alpha_{AEEI\,i}\left[\delta_{E\,i}^{\frac{1}{\sigma_{Ei}}}.EL_i^{\frac{\sigma_{Ei}-1}{\sigma_{Ei}}} + (1-\delta_{E\,i})^{\frac{1}{\sigma_{Ei}}}.FS_i^{\frac{\sigma_{Ei}-1}{\sigma_{Ei}}}\right]^{\frac{\sigma_{Ei}}{\sigma_{Ei}-1}} \tag{7.23}$$

Where:
EL_i = electricity used by sector i
FS_i = non-electricity energy inputs
α_{AEEIi} = annual energy efficiency improvement (AEEI) factor associated with energy input of sector i
δ_{XEMi} = CES function share parameter associated with electricity and non-electricity energy input
σ_{XEMi} = elasticity of substitution between associated with electricity and non-electricity energy input

Again, zero profit condition is satisfied by following equation:

$$E_i.PE_i = EL_i.PEL_i + FS_i.PFS_i \tag{7.24}$$

Where:
PEL$_i$ = price of electricity
PFS$_i$ = price of non-electricity energy inputs

There is no import tariff on electricity imported to Nepal. As in previous case, the demand for electricity and non-electricity energy input is obtained by the first order conditions for cost minimization as follows:

$$EL_i = \alpha_{AEEI\,i}{}^{\sigma_{Ei}-1}\ \delta_{E\,i}.\left(\frac{PE_i}{PEL_i}\right)^{\sigma_{Ei}} E_i \qquad (7.25)$$

$$FS_i = \alpha_{AEEI\,i}{}^{\sigma_{Ei}-1}\ (1-\delta_{E\,i}).\left(\frac{PE_i}{PFS_i}\right)^{\sigma_{Ei}} E_i \qquad (7.26)$$

Similarly, PE$_i$ is derived from equations 7.24, 7.25 and 7.26 as below.

$$PE_i = \frac{1}{\alpha_{AEEI\,i}}\left[\delta_{E\,i}.\ (PEL_i)^{1-\sigma_{Ei}} + (1-\delta_{E\,i}).\ (PFS_i)^{1-\sigma_{Ei}}\right]^{\frac{1}{1-\sigma_{Ei}}} \qquad (7.27)$$

f) Demand for Domestic Intermediate Input Composite

The domestic intermediate input composite demand is represented by a CES aggregation of non-energy domestic intermediate inputs (M$_{k,i}$) used by sector i as follows:

$$DM_i = \left[\sum_k \delta_{DMk,i}{}^{\frac{1}{\sigma_{DMi}}}.M_{k,i}{}^{\frac{\sigma_{DMi}-1}{\sigma_{DMi}}}\right]^{\frac{\sigma_{DMi}}{\sigma_{DMi}-1}} \qquad (7.28)$$

k $\in$ intermediate material

Where:
M$_{k,i}$ = domestic intermediate input used by sector i
δ_{DMi} = CES function share parameter associated with domestic intermediate input
σ_{DMi} = elasticity of substitution for domestic intermediate input

Again, zero profit condition is applied as follows:

$$DM_i.PDM_i = \sum_j M_{k,i}.PM_{k,i}.(1+indt_k) \qquad (7.29)$$

As in the previous case, the demand for intermediate material input is obtained by the first order conditions for cost minimization as follows:

$$M_{ij} = \delta_{DM\,i}\left(\frac{PDM_i}{PM_{k,i}.(1+indt_k)}\right)^{\sigma_{XMi}} DM_i \qquad (7.30)$$

Where:

$PM_{k,i}$ = price of intermediate material input
$Indt_k$ = indirect tax on intermediate material input

Similarly, PDM_i is derived from equations 7.29 and 7.30 as follows:

$$PDM_i = \left[\sum_j \delta_{DMk,i} . \left(PM_{k,i} . (1 + indt_K) \right)^{1-\sigma_{DMi}} \right]^{\frac{1}{1-\sigma_{DMi}}} \tag{7.31}$$

g) Demand for Non-electricity energy input

The demand for non-electricity energy input is represented by a CES aggregation of fuelwood, lignite and imported fossil fuels (diesel, gasoline, LPG, kerosene, ATF and coal) inputs ($X_{f,i}$) used by sector i as follows:

$$FS_i = \left[\sum_f \delta_{FSf,i}^{\frac{1}{\sigma_{FSi}}} . X_{f,i}^{\frac{\sigma_{FSi}-1}{\sigma_{FSi}}} \right]^{\frac{\sigma_{FSi}}{\sigma_{FSi}-1}} \tag{7.32}$$

Where:
f = fuel type
$X_{f,i}$ = non-electricity energy input used by sector i
$\delta_{FSf,i}$ = CES function share parameter associated with non-electricity energy input
σ_{FSi} = elasticity of substitution for non-electricity energy input

Again, firm follows the zero profit condition as below:

$$FS_i . PFS_i = \sum_f X_{f,i} . PX_{f,i} \tag{7.33}$$

Following previous case, the demand for fuel input is obtained by the first order conditions for cost minimization as follows:

$$X_{f,i} = \delta_{FS\,i} \left(\frac{PFS_i}{PX_{f,i}} \right)^{\sigma_{FSi}} FS_i \tag{7.34}$$

Where:
$PX_{f,i}$ = price of non-electricity fuel

Similarly PFS_i is obtained from equations 7.33 and 7.34 as follows:

$$PFS_i = \left[\sum_j \delta_{FSk,i} . \left(PX_{f,i} \right)^{1-\sigma_{FSi}} \right]^{\frac{1}{1-\sigma_{FSi}}} \tag{7.35}$$

7.3.1.1 Production Module for Disaggregated Electricity Generation Sector

The formulation of production module for electricity generation sector is disaggregated to represent individual technology used for electricity generation (Figure 7.3). The gross domestic output before production tax (Z_e) from the electricity generation sector is nested by CES function of hydropower electricity generation and other thermal electricity generation (i.e., diesel generation plants, biomass based electricity generation and MSW based electricity generation). The individual technology based electricity generation further comprised of intermediate inputs and factors composition combined in fixed proportion. In order to facilitate technology choice based on least cost, gross output is represented in PJ and price in million NRs per PJ at technology level production subsector. The gross output of the aggregated electricity sector is represented in monetary unit (million NRs by using fixed conversion factor (million NRs per PJ). Similar approach of dual units was used in the Second Generation Model (Sands and Fawcett, 2005).

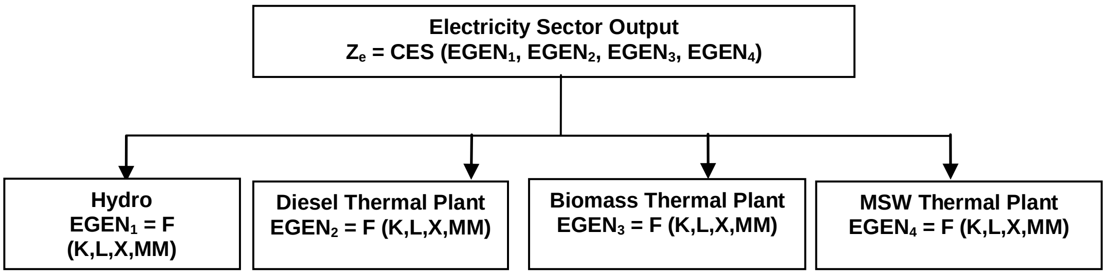


Figure 7.3: Nested production structure for Electricity Sector

The electricity sector output consists of the CES production function defined as below:

$$Z_e = \left[\sum_j \delta_{Z\,j,e}{}^{\frac{1}{\sigma_{Ze}}} . EGEN_j{}^{\frac{\sigma_{Ze}-1}{\sigma_{Ze}}} \right]^{\frac{\sigma_{Ze}}{\sigma_{Ze}-1}} \qquad (7.36)$$

Where:
$EGEN_j$ = electricity produced from 'j' electricity generation technology
$\delta_{Zj,e}$= CES function share parameter associated with individual electricity generation technology
σ_{Ze} = elasticity of substitution for electricity generation technologies

Again, firm follows zero profit condition as follows:

$$Z_e . PZ_e = \sum_j EGEN_j . PEGEN_j \qquad (7.37)$$

Where:
$PEGEN_j$ = price of electricity generation from 'j' electricity generation technology

As in the previous case the demand for electricity generation from 'j' electricity generation technology is obtained by the first order conditions for cost minimization as follows:

$$EGEN_j = \delta_{Z\,j,e}\left(\frac{PZ_e}{PEGEN_j}\right)^{\sigma_{Ze}} Z_e \qquad (7.38a)$$

For backstop or new technology which is not available in the base year, its share would be included only if its price per unit physical unit is below the price of related reference technology. Here price of hydropower is considered as the reference technology. The syntax for the above mentioned endogenous relational operation functions are developed by using Relaxed Mixed Integer Nonlinear Programming (RMINLP) of GAMS/PATHNLP solver. The penetration of the new technology is controlled by assigning initial share of penetration and rate of increment of the share as presented below.

$$EGEN_{new,t} = \delta_{Z\,new,e}\left(\frac{PZ_{e,t}}{PEGEN_{new,t}}\right)^{\sigma_{Ze}} Z_{e,t} \quad \text{for, } PEGEN_{new,t} \le PEGEN_{ref,t}$$

$$= 0 \quad \text{for, } PEGEN_{new,t} > PEGEN_{ref,t} \qquad (7.38b)$$

Where,

$$\delta_{Znew,t+1} = \delta_{Znew,t} \,.\, \left(1 + shgw_{new,t}\right) \quad \text{for, } \delta_{Znew,t} > 0;\ PX_{new,t} \le PX_{ref,t}$$

$$= \delta_{Znew,t} \quad \text{for, } \delta_{Znew,t} = 0;\ PX_{new,t} \le PX_{ref,t}$$

$PEGEN_{new,t}$ = Cost per physical unit of electricity for new technology (10^{12} NRs/PJ) in period n

$PEGEN_{ref,t}$ = Cost per physical unit of electricity for reference technology (10^{12} NRs/PJ) in period n

$\delta_{Znew,t}$ = initial share parameter of new technology for the period t.
$shgw_{new,t}$ = increment rate of the share composition of new technology for the period t.

Similarly PZ_e is derived from equations 7.37, 7.38a and 7.38b as below.

$$PZ_e = \left[\sum_j \delta_{Zj,e} . PEGEN_{j,e}^{\;1-\sigma_{Ze}}\right]^{\frac{1}{1-\sigma_{Ze}}} \qquad (7.39)$$

7.3.1.2 Production Module for Disaggregated Land Freight Transport Sector

In this study, transport sector production function is represented at the level of specific technology based on transport mode (road, rail and ropeway), transport category (truck, pickup, and tractor), fuel type, and motive power generation (internal combustion, electric and hybrid). The formulation of production module for land freight transport sector is disaggregated to represent individual land freight transport technology (Figure 7.4). At the upper nest of a production structure, the gross domestic output before production tax (Z_f) from the land freight transport sector consists of nested CES function of freight rail (TFRL), freight road (TFRD) and freight ropeway (TFRW) transportation modes. At the next level, the producer selects the optimal level of three different types of land freight transport technologies comprising of truck (TFA), pickup (TFB) and tractor (TFC) nested by CES production function. Then, the producer selects the optimal level of different types of individual road freight transport technologies nested by CES production function. The individual technology based transport demand comprised of fixed ratio intermediate inputs and factors composition.

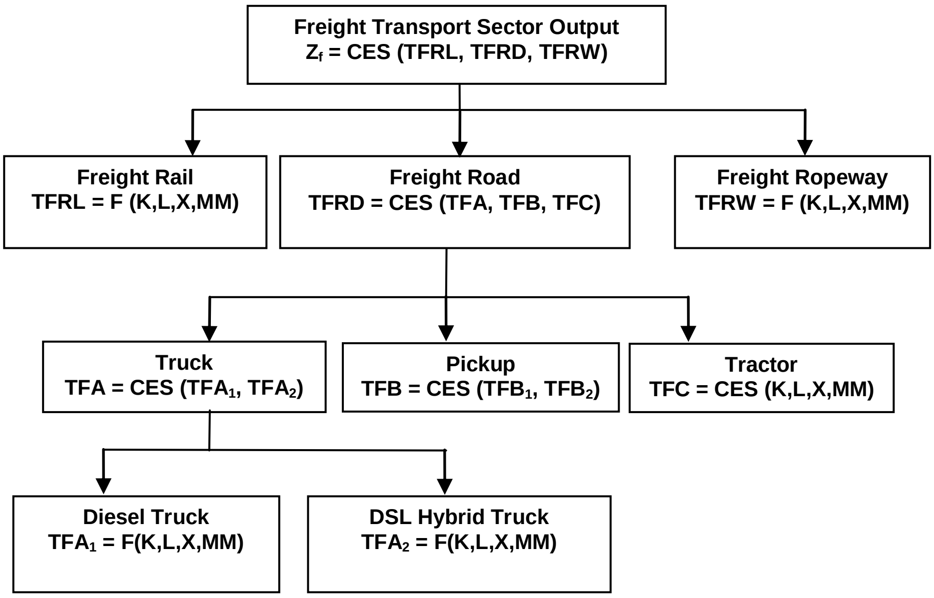


Figure 7.4: Nested production structure for Land Freight Transport Sector

a) Demand for different mode of Land Freight Transport

The land freight transport sector output is nested by the CES aggregation of road freight, ropeway freight and rail freight modes of transportation in the second level. The aggregate land freight transport demand is defined as below:

$$Z_f = \left[\delta_{TFL1}^{\frac{1}{\sigma_{Z_f}}}.TFRD^{\frac{\sigma_{Z_f}-1}{\sigma_{Z_f}}} + \delta_{TFL2}^{\frac{1}{\sigma_{XD_f}}}.TFRW^{\frac{\sigma_{Z_f}-1}{\sigma_{Z_f}}} + \delta_{TFL3}^{\frac{1}{\sigma_{Z_f}}}.TFRL^{\frac{\sigma_{Z_f}-1}{\sigma_{Z_f}}} \right]^{\frac{\sigma_{Z_f}}{\sigma_{Z_f}-1}} \qquad (7.40)$$

Subject to zero profit condition:

$$Z_f.PZ_f = TFRD.\ PTFRD + TFWD.\ PTFWD + TFRL.\ PTFRL \qquad (7.41)$$

Where:
TFRD = transportation from road mode

TFRW = transportation from ropeway mode
TFRL = transportation from rail mode
PTFRD = price of transportation from road mode
PTFRW = price of transportation from ropeway mode
PTFRL = price of transportation from rail mode
$\delta_{TFL1}, \delta_{TFL2}, \delta_{TFL3}$ = CES function share parameter associated with road, ropeway and rail modes of transportation
σ_{Zf} = elasticity of substitution for road, ropeway and rail modes of transportation

As in the previous case, the demand for land freight transportation from road, ropeway and rail modes is obtained by the first order conditions for cost minimization as follows:

$$TFRD = \delta_{TFL1}\left(\frac{PZ_f}{PTFRD}\right)^{\sigma_{Z_f}} Z_f \tag{7.42}$$

$$TFRW = \delta_{TFL2}\left(\frac{PZ_f}{PTFRW}\right)^{\sigma_{Z_f}} Z_f \tag{7.43}$$

$$TFRL = \delta_{TFL3}\left(\frac{PZ_f}{PTFRL}\right)^{\sigma_{Z_f}} Z_f \tag{7.44}$$

Similarly, PTFL is derived from a equations 7.41, 7.42, 7.43 and 7.44 as below.

$$PZ_f = \left[\delta_{TFL1}.PTFRD^{1-\sigma_{Z_f}} + \delta_{TFL2}.PTFRW^{1-\sigma_{Z_f}} + \delta_{TFL3}.PTFRL^{1-\sigma_{Z_f}}\right]^{\frac{1}{1-\sigma_{Z_f}}} \tag{7.45}$$

b) Demand for different category of Road Freight Transport input

The road freight transport output is nested by the CES aggregation of truck, pickup and tractor categories of transportation in the third level. The road freight transport demand is defined as below:

$$TFRD = \begin{bmatrix} \delta_{TFA}^{\frac{1}{\sigma_{TFRD}}}.TFA^{\frac{\sigma_{TFRD}-1}{\sigma_{TFRD}}} + \delta_{TFB}^{\frac{1}{\sigma_{TFRD}}}.TFB^{\frac{\sigma_{TFRD}-1}{\sigma_{TFRD}}} \\ + \delta_{TFC}^{\frac{1}{\sigma_{TFRD}}}.TFC^{\frac{\sigma_{TFRD}-1}{\sigma_{TFRD}}} \end{bmatrix}^{\frac{\sigma_{TFRD}}{\sigma_{TFRD}-1}} \tag{7.46}$$

Subject to zero profit condition:

$$TFRD.PTFRD = TFA.PTFA + TFB.PTFB + TFC.PTFC \tag{7.47}$$

Where:
TFA = freight transportation from truck

TFB = freight transportation from pickup
TFC = freight transportation from tractor
PTFA = price of transportation from truck
PTFB = price of transportation from pickup
PTFC = price of transportation from tractor
δ_{TFA}, δ_{TFB}, δ_{TFC} = CES function share parameter associated with truck, pickup and tractor
σ_{TFRD} = elasticity of substitution for truck, pickup and tractor

As in the previous case, the demand for rod freight transportation from truck, pickup and tractor is obtained by the first order conditions for cost minimization as follows:

$$TFA = \delta_{TFA}\left(\frac{PTFRD}{PTFA}\right)^{\sigma_{TFRD}} TFRD \tag{7.48}$$

$$TFB = \delta_{TFB}\left(\frac{PTFRD}{PTFB}\right)^{\sigma_{TFRD}} TFRD \tag{7.49}$$

$$TFC = \delta_{TFC}\left(\frac{PTFRD}{PTFC}\right)^{\sigma_{TFRD}} TFRD \tag{7.50}$$

Similarly, PTFRD is derived from a equations 7.47, 7.48, 7.49 and 7.50 as below.

$$PTFRD = \left[\delta_{TFA}.PTFA^{1-\sigma_{TFRD}} + \delta_{TFB}.PTFB^{1-\sigma_{TFRD}} + \delta_{TFC}.PTFC^{1-\sigma_{TFRD}}\right]^{\frac{1}{1-\sigma_{TFRD}}} \tag{7.51}$$

c) Demand for Technology Specific Road Freight Transport input

The technology specific road freight transport output in terms of motive power generation is nested by the CES aggregation of internal combustion and hybrid system in the fourth level. The technology and category specific road freight transport demand is defined as below:

$$TFA = \left[\delta_{TFA1}^{\frac{1}{\sigma_{TFA}}}.TFA1^{\frac{\sigma_{TFA}-1}{\sigma_{TFA}}} + (1-\delta_{TFA1})^{\frac{1}{\sigma_{TFA}}}.TFA2^{\frac{\sigma_{TFA}-1}{\sigma_{TFA}}}\right]^{\frac{\sigma_{TFA}}{\sigma_{TFA}-1}} \tag{7.52}$$

Subject to zero profit condition:

$$TFA.PTFA = TFA1.PTFA1 + TFA2.PTFA2 \tag{7.53}$$

Where:
TFA1 = freight transportation from truck with internal combustion technology
TFA2 = freight transportation from truck with hybrid technology
PTFA1 = price of transportation from truck with internal combustion technology
PTFA2 = price of transportation from truck with hybrid technology

δ_{TFA1} = CES function share parameter associated to truck with internal combustion and hybrid technology
σ_{TFA} = elasticity of substitution for truck with internal combustion and hybrid technology

As in the previous case, the demand for road freight transportation from specific technology of truck is obtained by the first order conditions for cost minimization as follows:

$$TFA1 = \delta_{TFA1}\left(\frac{PTFA}{PTFA1}\right)^{\sigma_{TFA}} TFA \tag{7.54}$$

$$TFA2 = \left(1-\delta_{TFA1}\right).\left(\frac{PTFA}{PTFA2}\right)^{\sigma_{TFA}} TFA \tag{7.55}$$

Similarly, PTFA is derived from a equations 7.53, 7.54, and 7.55 as below.

$$PTFA = \left[\delta_{TFA1}.PTFA1^{1-\sigma_{TFA}} + \left(1-\delta_{TFA1}\right).PTFA2^{1-\sigma_{TFA}}\right]^{\frac{1}{1-\sigma_{TFA}}} \tag{7.56}$$

The above Equations 7.52 to 7.56 is applicable for freight transport with different technologies of pickup.

7.3.1.3 Production Module for Disaggregated Land Passenger Transport Sector

Similar to the land freight transport sector, the production function of land passenger transport is represented with disaggregation of specific technology based on transport mode (road, rail and ropeway), transport category (3-wheeler, bus, microbus and taxi), fuel type, and motive power generation (internal combustion, hybrid and full-electric). The formulation of production module for land passenger transport sector is disaggregated to represent individual land passenger transport technology (Figure 7.5). At the upper nest of a five-layer production structure, the gross output (Z_p) from the land passenger transport sector is a nested by CES function of rail passenger (TPRL), road passenger (TPRD) and ropeway passenger (TPRW) transportation modes. The producer selects the optimal level of four different types of road passenger transport technologies comprising of 3-wheeler (TP3W), bus (TPB), microbus (TPMB) and taxi (TPTX) nested by CES production function. At the fourth level, the producer selects the optimal level of different types of individual road passenger transport technologies nested by CES production function. The endogenous operation relation functions are used for the introduction of new (back stop) technology which is not available in the base year as discussed for electricity generation technology in the Section 7.3.1.1. The individual technology based transport demand is further comprised of fixed ratio intermediate inputs and factors composition.

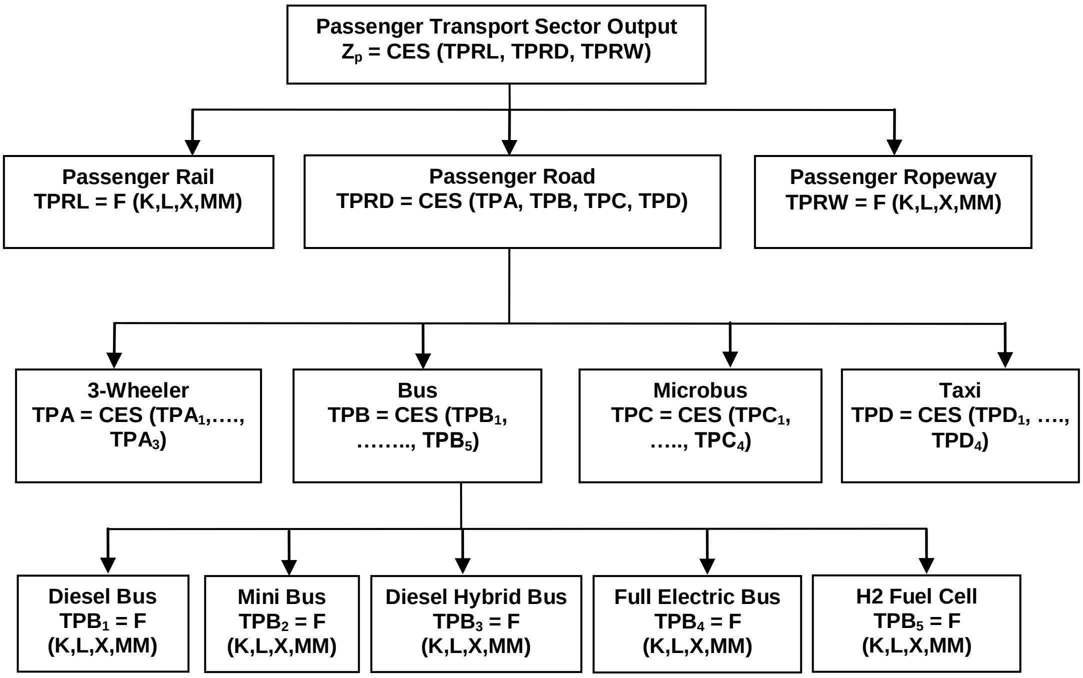


Figure 7.5: Nested production structure for Land Passenger Transport Sector

a) Demand for different mode of Land Passenger Transport

The land passenger transport sector output is nested by the CES aggregation of road passenger, ropeway passenger and rail passenger modes of transportation. The aggregate land passenger transport demand is defined as shown below:

$$Z_p = \left[\delta_{TPL1}^{\frac{1}{\sigma_{Z_p}}}.TPRD^{\frac{\sigma_{Z_p}-1}{\sigma_{Z_p}}} + \delta_{TPL2}^{\frac{1}{\sigma_{Z_p}}}.TPRW^{\frac{\sigma_{Z_p}-1}{\sigma_{Z_p}}} + \delta_{TPL3}^{\frac{1}{\sigma_{Z_p}}}.TPRL^{\frac{\sigma_{Z_p}-1}{\sigma_{Z_p}}} \right]^{\frac{\sigma_{Z_p}}{\sigma_{Z_p}-1}} \tag{7.57}$$

Subject to zero profit condition:

$$Z_p.PZ_p = TPRD.PTPRD + TPWD.PTPWD + TPRL.PTPRL \tag{7.58}$$

Where:
TPRD = passenger transportation from road mode
TPRW = passenger transportation from ropeway mode
TPRL = passenger transportation from rail mode
PTPRD = price of passenger transportation from road mode
PTPRW = price of passenger transportation from ropeway mode
PTPRL = price of passenger transportation from rail mode
$\delta_{TPL1}, \delta_{TPL2}, \delta_{TPL3}$ = CES function share parameter associated with road, ropeway and rail modes of transportation
σ_{Zp} = elasticity of substitution for road, ropeway and rail modes of transportation

As in the previous case, the demand for land passenger transportation from road, ropeway and rail modes is obtained by the first order conditions for cost minimization as follows:

$$TPRD = \delta_{TPL1}\left(\frac{PZ_p}{PTPRD}\right)^{\sigma_{Z_p}} Z_p \tag{7.59}$$

$$TPRW = \delta_{TPL2}\left(\frac{PZ_p}{PTPRW}\right)^{\sigma_{Z_p}} Z_p \tag{7.60}$$

$$TPRL = \delta_{TPL3}\left(\frac{PZ_p}{PTPRL}\right)^{\sigma_{Z_p}} Z_p \tag{7.61}$$

Similarly, $PTPL_i$ is derived from a equations 7.58, 7.59, 7.60 and 7.61 as below.

$$PTPL = \left[\delta_{TPL1}.PTPRD^{1-\sigma_{Z_p}} + \delta_{TPL2}.PTPRW^{1-\sigma_{Z_p}} + \delta_{TPL3}.PTPRL^{1-\sigma_{Z_p}}\right]^{\frac{1}{1-\sigma_{Z_p}}} \tag{7.62}$$

b) Demand for different category of Road Passenger Transport input

The road passenger transport output is nested by the CES aggregation of 3-wneeler, bus, microbus and taxi categories of transportation in the third level. The road passenger transport demand is defined as below:

$$TPRD = \begin{bmatrix} \delta_{TPA}^{\frac{1}{\sigma_{TPRD}}}.TFA^{\frac{\sigma_{TPRD}-1}{\sigma_{TPRD}}} + \delta_{TPB}^{\frac{1}{\sigma_{TPRD}}}.TFB^{\frac{\sigma_{TPRD}-1}{\sigma_{TPRD}}} \\ + \delta_{TPC}^{\frac{1}{\sigma_{TPRD}}}.TFC^{\frac{\sigma_{TPRD}-1}{\sigma_{TPRD}}} + \delta_{TPD}^{\frac{1}{\sigma_{TPRD}}}.TFD^{\frac{\sigma_{TPRD}-1}{\sigma_{TPRD}}} \end{bmatrix} \tag{7.63}$$

Subject to zero profit condition:

$$TPRD.PTPRD = TPA.PTPA + TPB.PTPB + TPC.PTPC + TPD.PTPD \tag{7.64}$$

Where:

TPA = passenger transportation from 3-wheeler
TPB = passenger transportation from bus
TPC = passenger transportation from microbus
TPD = passenger transportation from taxi
PTPA = price of passenger transportation from 3-wheeler
PTPB = price of passenger transportation from bus
PTPC = price of passenger transportation from microbus
PTPD = price of passenger transportation from taxi
δ_{TPA}, δ_{TPB}, δ_{TPC}, δ_{TPD} = CES function share parameter associated with 3-wheeler, bus, microbus and taxi
σ_{TFRD} = elasticity of substitution for 3-wheeler, bus, microbus and taxi

As in the previous case, the demand for road passenger transportation from 3-wheeler, bus, microbus and taxi is obtained by the first order conditions for cost minimization as follows:

$$TPA = \delta_{TPA} \left(\frac{PTPRD}{PTPA} \right)^{\sigma_{TPRD}} TPRD \tag{7.65}$$

$$TPB = \delta_{TPB} \left(\frac{PTPRD}{PTPB} \right)^{\sigma_{TPRD}} TPRD \tag{7.66}$$

$$TPC = \delta_{TPC} \left(\frac{PTPRD}{PTPC} \right)^{\sigma_{TPRD}} TPRD \tag{7.67}$$

$$TPD = \delta_{TPD} \left(\frac{PTPRD}{PTPD} \right)^{\sigma_{TPRD}} TPRD \tag{7.68}$$

Similarly, PTPRD is derived from a equations 7.64, 7.65, 7.66, 7.67 and 7.68 as below.

$$PTPRD = \begin{bmatrix} \delta_{TPA}.PTPA^{1-\sigma_{TPRD}} + \delta_{TPB}.PTPB^{1-\sigma_{TPRD}} + \delta_{TPC}.PTPC^{1-\sigma_{TPRD}} \\ + \delta_{TPD}.PTPD^{1-\sigma_{TPRD}} \end{bmatrix}^{\frac{1}{1-\sigma_{TPRD}}} \tag{7.69}$$

c) Demand for Technology Specific Road Passenger Transport input

The technology specific road passenger transport output in terms of motive power generation is nested by the CES aggregation of internal combustion, full-electric, hybrid and fuel cell system in the fourth level. The technology and category specific road passenger transport demand is defined as below:

$$TPB = \begin{bmatrix} \delta_{TPB1}^{\frac{1}{\sigma_{TPB}}}.TPB1^{\frac{\sigma_{TPB}-1}{\sigma_{TPB}}} + \delta_{TPB2}^{\frac{1}{\sigma_{TPB}}}.TPB2^{\frac{\sigma_{TPB}-1}{\sigma_{TPB}}} + \delta_{TPB3}^{\frac{1}{\sigma_{TPB}}}.TPB3^{\frac{\sigma_{TPB}-1}{\sigma_{TPB}}} \\ + \delta_{TPB4}^{\frac{1}{\sigma_{TPB}}}.TPB4^{\frac{\sigma_{TPB}-1}{\sigma_{TPB}}} \end{bmatrix}^{\frac{\sigma_{TPB}}{\sigma_{TPB}-1}} \tag{7.70}$$

Subject to zero profit condition:

$$TPB.PTPB = TPB1.PTPB1 + TPB2.PTPB2 + TPB3.PTPB3 + TPB4.PTPB4 \tag{7.71}$$

Where:
TPB1 = passenger transportation from bus with internal combustion technology
TPB2 = passenger transportation from bus with hybrid technology
TPB3 = passenger transportation from bus with full-electric technology
TPB4 = passenger transportation from bus with fuel-cell technology
PTPB1 = price of transportation from bus with internal combustion technology
PTPB2 = price of transportation from bus with hybrid technology
PTPB3 = price of transportation from bus with full-electric technology
PTPB4 = price of transportation from bus with fuel-cell technology

δ_{TPBi} = CES function share parameter associated to bus with internal combustion, hybrid, full-electric and fuel-cell technologies
σ_{TPB} = elasticity of substitution for truck with internal combustion and hybrid technology

As in the previous case, the demand for road passenger transportation from specific technology of bus is obtained by the first order conditions for cost minimization as follows:

$$TPB1 = \delta_{TPB1}\left(\frac{PTPB}{PTPB1}\right)^{\sigma_{TPB}} TPB \tag{7.72}$$

$$TPB2 = \delta_{TPB2}\left(\frac{PTPB}{PTPB2}\right)^{\sigma_{TPB}} TPB \tag{7.73}$$

$$TPB3 = \delta_{TPB3}\left(\frac{PTPB}{PTPB3}\right)^{\sigma_{TPB}} TPB \tag{7.74}$$

$$TPB4 = \delta_{TPB4}\left(\frac{PTPB}{PTPB4}\right)^{\sigma_{TPB}} TPB \tag{7.75}$$

Similarly, PTPB is derived from a equations 7.71 to 7.75 as below.

$$PTPB = \begin{bmatrix} \delta_{TPB1}.PTPB1^{1-\sigma_{TPB}} + \delta_{TPB2}.PTPB2^{1-\sigma_{TPB}} \\ + \delta_{TPB3}.PTPB3^{1-\sigma_{TPB}} + \delta_{TPB4}.PTPB4^{1-\sigma_{TPB}} \end{bmatrix}^{\frac{1}{1-\sigma_{TPB}}} \tag{7.76}$$

The above Equation 7.70 to 7.76 is applicable for passenger transport with different technologies of 3-wheeler, microbus and taxi. The endogenous operation relation functions are used for the introduction of new (back stop) technology which is not available in the base year as discussed for electricity generation technology in the Section 7.3.1.1.

7.3.2 Income and Expenditure Module

In the Nepal-CGE model, four institutions are considered - household, government, production firm and RoW. The household owns labor and capital factors, receive its factors incomes and receive transfer from government (subsidies) and foreign institution (remittance). It expenses on the consumption of the final goods and services, tax payment to the government as well as retain saving for investment. Government earns income from direct and indirect taxes, import tariff, transfer from abroad. It spends its revenue on consumption of commodity and transfers to the household and foreign institution. The firm involves in the production of the good and services by using the factors rented by the households. It earns zero profit with all total revenue earned by selling the commodities it produced equals to total cost of all the input used in production process. Likewise, foreign institution receives revenue from import of commodities, expenses on the export of commodities and retain saving for investment. Institution wise description on income and expenditure is presented as follows:

7.3.2.1 Household Sector

a) Household Income

All the households in the country are represented by single representative household. Total household income consists of capital income, labor income, net transfer from the government and the foreign institution. Income of the firms and enterprises were also considered as household income (as used by Benjamin et al., 1989; Buehrer and di Mauro, 1993; Timilsina, 2001; Kim, 2004). Nepal introduced value added tax (VAT) in place of sales tax from November 1997 (Dahal, 2004). Unlike sales tax where government levied tax only at the point when commodity is sold to the final consumer, the VAT is levied during each transaction between producing firm to trader and between trader and final consumer based on the value added at each steps. As such representing the income of firm and household together avoid complication associated with representing VAT levied in each steps of commodity flow in the domestic market.

The total household income *(IH)* after tax is expressed as follows:

$$IH = (W.\, l_{TOT} + PC.\, C_{TOT}).(1 - hhtx) + [trhg + trhhw.ER] \tag{7.77}$$

Where:

$hhtx$	= direct tax on household's income
l_{TOT}	= total labor supply
C_{TOT}	= total capital supply
$trhg$	= transfer from the government to household
$trhhw$	= transfer from the foreign-ROW institutions to household
ER	= exchange rate (Nepalese Rupees per US$)

b) Household Saving

The household retain saving (SH) which is determined by fixed marginal propensity to saving (mps) as follows:

$$\boldsymbol{SH = mps\ .\ IH} \tag{7.78}$$

The household consumes commodities as much as can be purchased by its disposable income (IHD) represented as follows:

$$\boldsymbol{IHD = IH - SH} \tag{7.79}$$

c) Household Expenditure (Consumption)

In order to analyze the effects of the transport sector electrification and C-tax on household consumption and welfare, the household utility is disaggregated into five level nested consumption functions as shown in Figure 7.5. Household maximize its utility for each level of consumption. At the highest level, total utility function is represented by CES function of aggregated non-transport and aggregated transport consumption[35]. At the second level, the household non-transport consumption (HDNT) consists of energy consumption (HDE) and non-energy consumption (HDNE) nested by CES function. Energy consumption is further consists of electricity (HDEL) and non-electricity fuel composite (HDFS) consumption aggregated by CES function at the third level. In the same level, non-energy consumption is comprises of the individual non-energy consumptions excluding transport consumption. At the final level individual non-electricity fuels are aggregated by using CES function.

Similarly, in the second level, household transport consumption comprises of private transport (TRPR) and purchased transport (TRPU) consumptions which are aggregated by CES consumption function [36].

In the third level private transport is disaggregated into 2-wheeler (TR2W) and car (TRCR) categories of private transport consumption.[37] In the same level, purchased transport is disaggregated into air passenger transport (TAIR) and purchased land passenger transport (TLND).

In the fourth level, non-electric fuel (HDFS) consumption consists of nested aggregation of individual fuels (FS_i). The specific category of private transport (TR2W and TRCR) consists of CES nested aggregation of different technology based on motive power generation and fuel type (diesel IC, gasoline IC, diesel-hybrid, gasoline-hybrid and full-electric) under the same level. Further in the forth level, purchased land passenger transport (TLND) consists of nested CES consumption function of road passenger (TPRD), ropeway passenger (TPRW) and railway passenger (TPRL) transport modes.

In the fifth level, the individual private transport technology comprises of fuel consumption, service provided from the motor vehicles and commercial sectors combined in fixed proportion.

[35] Abrell (2010), Paltsev et al. (2004) and Schafer and Jacoby et al. (2006) have also disaggregated transport consumption separate from rest of the other consumption in the household consumption representation.

[36] Similar disaggregation of passenger transport demand into private and public passenger transport demand are considered by Abrell (2010), Schafer and Jacoby (2006a) and Paltsev et al. (2004).

[37] Karplus et al. (2009) have disaggregated private (own supplied) transport into plug-in hybrid electric vehicle transportation and conventional vehicle transportation. And used fixed factor input in the plug-in hybrid transport to control its penetration rate.

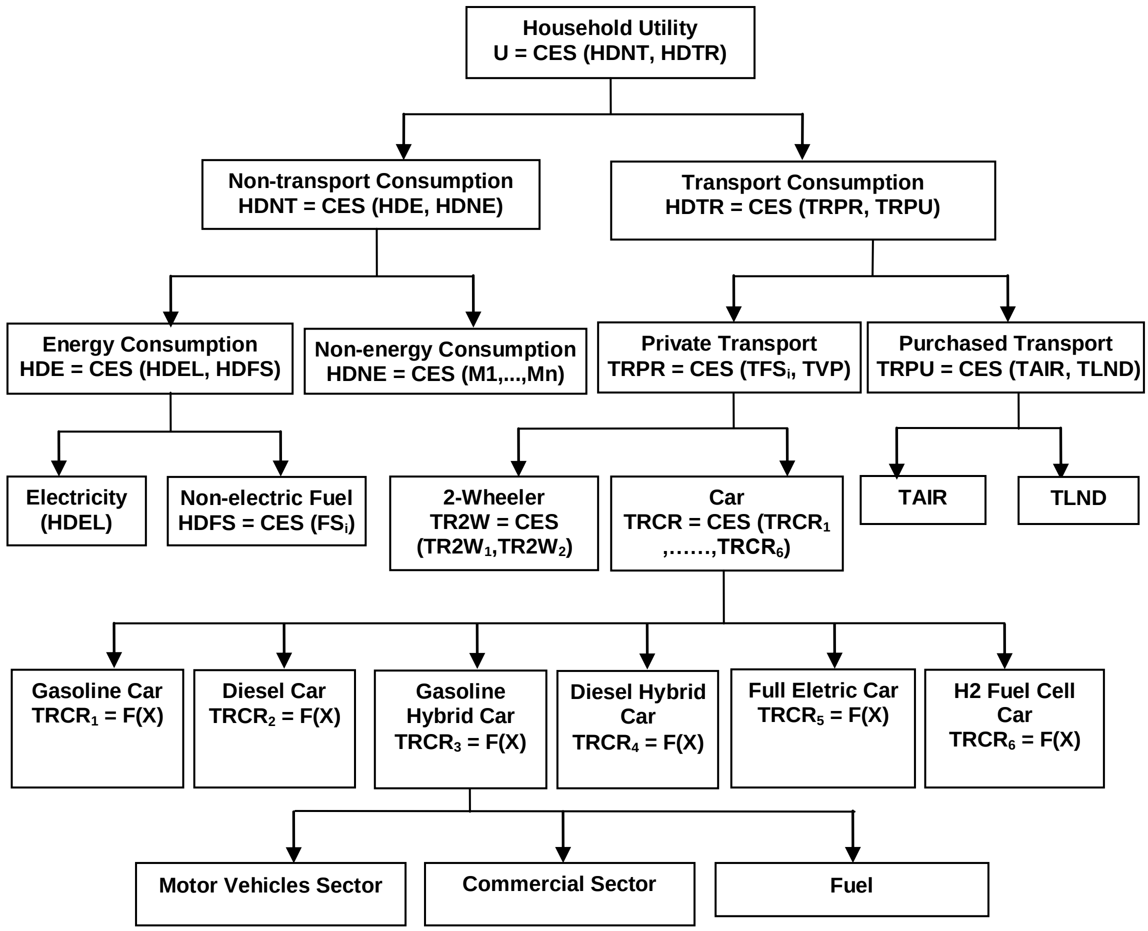


Figure 7.5: Nested household consumption structure

a) Household demand for nested transport and non-transport consumption

At the top of the hierarchy, the demand for total consumption by the household is based on maximization of the household utility function of nested consumption variables of transport composite and non-transport composite consumptions subject to the budget constraint.

The household utility function is considered to be represented by a standard CES function (U) (Shoven and Whalley, 1992) as follows:

$$\max U = \left[\delta_{HD}^{\frac{1}{\sigma_{HD}}} . HDTR^{\frac{\sigma_{HD}-1}{\sigma_{HD}}} + (1-\delta_{HD})^{\frac{1}{\sigma_{HD}}} . HDNT^{\frac{\sigma_{HD}-1}{\sigma_{HD}}} \right]^{\frac{\sigma_{HD}}{\sigma_{HD}-1}} \tag{7.80}$$

Where,
HDTR = household consumption of transport composite
HDNT = household consumption of non-transport composite
δ_{HD} = CES function share parameter associated with household consumption of transport composite and non-transport composite

σ_{HD} = elasticity of substitution between transport composite and non-transport composite household consumptions

The household trades off between Again, HDTR and HDNT to maximize its utility under the budget constraint as follows:

$$IHD = PHDTR\,.\,HDTR + PHDNT\,.\,HDNT \qquad (7.81)$$

Where:
PHDTR = price of transport composite demand
PHDNT = price of non-transport composite demand

Demand for transport composite consumption and non-transport composite consumption is obtained by the first order conditions of Lagrangian function for Equation 7.80 and 7.81 as given below[38]:

$$HDTR = \frac{\delta_{HD}.IHD}{PHDTR^{\sigma_{HD}}.\left[\delta_{HD}.PHDTR^{(1-\sigma_{HD})} + \left(1-\delta_{HD}\right).PHDTN^{(1-\sigma_{HD})}\right]}$$
(7.82)

$$HDNT = \frac{\left(1-\delta_{HD}\right).IHD}{PHDTN^{\sigma_{HD}}.\left[\delta_{HD}.PHDTR^{(1-\sigma_{HD})} + \left(1-\delta_{HD}\right).PHDTN^{(1-\sigma_{HD})}\right]} \qquad (7.83)$$

b) Household demand for nested transport consumption

At the second level of hierarchy, the demand for the transport composite consumption by the household is based on maximization of the household utility CES function of nested consumption of private and purchased transport as follows:

$$HDTR = \left[\delta_{HDTR}^{\frac{1}{\sigma_{HDTR}}}.TRPR^{\frac{\sigma_{HDTR}-1}{\sigma_{HDTR}}} + \left(1-\delta_{HDTR}\right)^{\frac{1}{\sigma_{HDTR}}}.TRPU^{\frac{\sigma_{HDTR}-1}{\sigma_{HDTR}}}\right]^{\frac{\sigma_{HDTR}}{\sigma_{HDTR}-1}} \qquad (7.84)$$

Where,
TRPR = household consumption of private transport
TRPU = household consumption of purchased transport service
δ_{HDTR} = CES function share parameter associated with private and purchased transport
σ_{HDTR} = elasticity of substitution between private and purchased transport consumptions

The household trades off between TRPR and TRPU to maximize its utility under the budget constraint as follows:

$$PHDTR\,.\,HDTR = PTRPR\,.\,TRPR + PTRPU\,.\,TRPU \qquad (7.85)$$

Where:

[38] The Lagrangian function is as following:

$$L = \left[\delta_{HD}^{\frac{1}{\sigma_{HD}}}.HDTR^{1-\frac{1}{\sigma_{HD}}} + \left(1-\delta_{HD}\right)^{\frac{1}{\sigma_{HD}}}.HDNT^{1-\frac{1}{\sigma_{HD}}}\right]^{\frac{1}{1-\frac{1}{\sigma_{HD}}}} + \lambda\left(I - PHDTR.HDTR - PHDNT.HDNT\right)$$

PTRPR = price of the private transport composite
PTRPU = price of the purchased transport composite

Demand for the private and purchased transport composite consumption is obtained by the first order conditions of Lagrangian function for Equation 7.84 and 7.85 as given below:

$$TRPR = \frac{\delta_{HDTR} \,.\, PHDTR \,.\, HDTR}{PTRPR^{\sigma_{HDTR}} \,.\, \left[\delta_{HDTR} \,.\, PTRPR^{(1-\sigma_{HDTR})} + \left(1-\delta_{HDTR}\right) . \, PTRPU^{(1-\sigma_{HDTR})}\right]} \tag{7.86}$$

$$TRPU = \frac{\left(1-\delta_{HDTR}\right) . \, PHDTR \,.\, HDTR}{PTRPU^{\sigma_{HDTR}} \,.\, \left[\delta_{HDTR} \,.\, PTRPR^{(1-\sigma_{HDTR})} + \left(1-\delta_{HDTR}\right) . \, PTRPU^{(1-\sigma_{HDTR})}\right]} \tag{7.87}$$

c) Household demand for nested non-transport consumption

Similarly, at the second level of hierarchy, the demand for the non-transport composite consumption by the household is based on maximization of the household utility CES function of nested consumption of energy composite and non-energy commodities consumption as follows:

$$HDNT = \left[\left\{\alpha_{HHEEI} \,.\, \delta_{HDNT}\right\}^{\frac{1}{\sigma_{HDNT}}} . \, HDE^{\frac{\sigma_{HDNT}-1}{\sigma_{HDNT}}} + \left(1-\delta_{HDNT}\right)^{\frac{1}{\sigma_{HDNT}}} . \, HDNE^{\frac{\sigma_{HDNT}-1}{\sigma_{HDNT}}} \right]^{\frac{\sigma_{HDNT}}{\sigma_{HDNT}-1}} \tag{7.88}$$

Where,
HDE = household consumption of energy composite
HDNE = household consumption of non-energy composite
α_{HHEEI} = energy efficiency improvement (EEI) factor for household energy consuming devices
δ_{HDNT} = CES function share parameter associated with energy composite and non-energy composite commodities consumptions
σ_{HDNT} = elasticity of substitution between energy composite and non-energy composite commodities consumptions

The household trades off between HDE and HDNE to maximize its utility under the budget constraint as follows:

$$PHDNT \,.\, HDNT = PHDE \,.\, HDE + PHDNE \,.\, HDNE \tag{7.89}$$

Where:
PHDE = price of the energy composite
PHDNE = price of the non-energy composite

Demand for the energy composite and non-energy composite consumption is obtained by the first order conditions of Lagrangian function for Equation 7.88 and 7.89 as given below:

$$HDE = \frac{\{\alpha_{HHEEI} \,.\, \delta_{HDNT}\}.\, PHDNT \,.\, HDNT}{PHDE^{\sigma_{HDNT}} \,.\, \left[\{\alpha_{HHEEI} \,.\, \delta_{HDNT}\}.\, PHDE^{(1-\sigma_{HDNT})} + (1-\delta_{HDNT})\,.\, PHDNE^{(1-\sigma_{HDNT})}\right]} \tag{7.90}$$

$$HDNE = \frac{(1-\delta_{HDNT}).\, PHDNT \,.\, HDNT}{PHDNE^{\sigma_{HDNT}} \,.\, \left[\{\alpha_{HHEEI} \,.\, \delta_{HDNT}\}.\, PHDE^{(1-\sigma_{HDNT})} + (1-\delta_{HDNT})\,.\, PHDNE^{(1-\sigma_{HDNT})}\right]} \tag{7.91}$$

d) Household demand for private transport consumption

At the third level, the demand for the private transport consumption by the household is based on maximization of the household utility CES function of nested consumption of transport service provided by 2-wheeler and car as follows:

$$TRPR = \left[\delta_{TRPR}^{\frac{1}{\sigma_{TRPR}}} .(TR2W.\, FCF_{TR2W})^{\frac{\sigma_{TRPR}-1}{\sigma_{TRPR}}} + (1-\delta_{TRPR})^{\frac{1}{\sigma_{TRPR}}} \,.(TRCR.\, FCF_{TRCR})^{\frac{\sigma_{TRPR}-1}{\sigma_{TRPR}}} \right]^{\frac{\sigma_{TRPR}}{\sigma_{TRPR}-1}} \tag{7.92}$$

Where,
TR2W = household consumption of transport service from 2-wheeler
TRCR = household consumption of transport service from car
δ_{TRPR} = CES function share parameter associated with 2-wheeler and car under private transport consumption
σ_{TRPR} = elasticity of substitution between 2-wheeler and car under private transport consumption

The household trades off between TR2W and TRCR to maximize its utility under the budget constraint as follows:

$$PTRPR\,.\,TRPR = PTR2W\,.\,TR2W + PTRCR\,.\,TRCR \tag{7.93}$$

Where:
PTR2W = price of the private transport service from 2-wheeler
PTRCR = price of the purchased transport service from car

Demand for the 2-wheeler and car transport service is obtained by the first order conditions of Lagrangian function for Equation 7.92 and 7.93 as given below:

$$(TR2W.\, FCF_{TR2W}) = \frac{\delta_{TRPR}.\, PTRPR \,.\, TRPR}{PTR2W^{\sigma_{TRPR}} \,.\, \left[\delta_{TRPR}.PTR2W^{(1-\sigma_{TRPR})} + (1-\delta_{TRPR})\,.PTRCR^{(1-\sigma_{TRPR})}\right]} \tag{7.94}$$

$$(TRCR.\, FCF_{TRCR}) = \frac{(1-\delta_{TRPR}).\, PTRPR \,.\, TRPR}{PTRCR^{\sigma_{TRPR}} \,.\, \left[\delta_{TRPR}.PTR2W^{(1-\sigma_{TRPR})} + (1-\delta_{TRPR})\,.PTRCR^{(1-\sigma_{TRPR})}\right]} \tag{7.95}$$

e) Household demand for purchased transport consumption

Similarly at the third level, the demand for the purchased transport consumption by the household is based on maximization of the household utility CES function of nested consumption of air transport service and aggregated land transport services as follows:

$$TRPU = \left[\delta_{TRPU}^{\frac{1}{\sigma_{TRPU}}} . TAIR^{\frac{\sigma_{TRPU}-1}{\sigma_{TRPU}}} + \left(1-\delta_{TRPU}\right)^{\frac{1}{\sigma_{TRPU}}} . TLND^{\frac{\sigma_{TRPU}-1}{\sigma_{TRPU}}} \right]^{\frac{\sigma_{TRPU}}{\sigma_{TRPU}-1}} \quad (7.96)$$

Where,
TAIR = household consumption of purchased air transport service
TLND = household consumption of purchased land transport service
δ_{TRPUi} = CES function share parameter associated with purchased air transport and purchased land transport services
σ_{TRPU} = elasticity of substitution between purchased air transport and purchased land transport services

The household trades off between purchased air transport and purchased land transport to maximize its utility under the budget constraint as follows:

$$PTRPU \,.\, TRPU = PTAIR\left(1+indt_{AIR}\right).TAIR + PTLND.TLND \quad (7.97)$$

Where:
PTAIR = price of the purchased air transport service
PTLND = price of the purchased land transport service
$indt_i$ = indirect tax on the purchased air transport service

Demand for the purchased air transport and purchased land transport services is obtained by the first order conditions of Lagrangian function for Equation 7.96 and 7.97 as given below:

$$TAIR = \frac{\delta_{TRPU} \,.\, PTRPU \,.\, TRPU}{\left[PTAIR\left(1+indt_{AIR}\right)\right]^{\sigma_{TRPU}} . \left[\begin{array}{l} \delta_{TRPU} . \left[PTAIR\left(1+indt_{AIR}\right)\right]^{\left(1-\sigma_{TRPU}\right)} \\ +\left(1-\delta_{TRPU}\right) . PTLND^{\left(1-\sigma_{TRPU}\right)} \end{array} \right]} \quad (7.98)$$

$$TLND = \frac{\delta_{TRPU} \,.\, PTRPU \,.\, TRPU}{PTLND^{\sigma_{TRPU}} . \left[\begin{array}{l} \delta_{TRPU} . \left[PTAIR\left(1+indt_{AIR}\right)\right]^{\left(1-\sigma_{TRPU}\right)} \\ +\left(1-\delta_{TRPU}\right) . PTLND^{\left(1-\sigma_{TRPU}\right)} \end{array} \right]} \quad (7.99)$$

f) Household demand for energy consumption

Following, in the third level, the demand for the energy consumption by the household is based on maximization of the household utility CES function of nested consumption of electricity and non-electric fuels as follows:

$$HDE = \left[\delta_{HDE}^{\frac{1}{\sigma_{HDE}}} . HDEL^{\frac{\sigma_{HDE}-1}{\sigma_{HDE}}} + (1-\delta_{HDE})^{\frac{1}{\sigma_{HDE}}} . HDFS^{\frac{\sigma_{HDE}-1}{\sigma_{HDE}}} \right]^{\frac{\sigma_{HDE}}{\sigma_{HDE}-1}} \tag{7.100}$$

Where,
HDEL = household consumption of electricity
HDFS = household consumption of non-electricity fuel
δ_{HDE} = CES function share parameter associated with electricity and non-electricity fuel consumption by household
σ_{HDE} = elasticity of substitution between electricity and non-electricity fuel consumption by household

The household trades off between HDEL and HDFS to maximize its utility under the budget constraint as follows:

$$PHDE \,.\, HDE = PHDEL \,.\, (1+indt_{el}) \,.\, HDEL + PHDFS \,.\, HDFS \tag{7.101}$$

Where:
PHDEL = price of the electricity
PHDFS = price of the non-electricity fuel composite
$indt_{el}$ = indirect tax on electricity

Demand for the electricity and non-electricity consumption is obtained by the first order conditions of Lagrangian function for Equation 7.100 and 7.101 as given below:

$$HDEL = \frac{\delta_{HDE} \,.\, PHDE \,.\, HDE}{[PHDEL.(1+indt_{el})]^{\sigma_{HDE}} . \left[\begin{array}{l} \delta_{HDE} . [PHDEL.(1+indt_{el})]^{(1-\sigma_{HDE})} \\ +(1-\delta_{HDE}).PHDFS^{(1-\sigma_{HDE})} \end{array} \right]} \tag{7.102}$$

$$HDFS = \frac{(1-\delta_{HDE}) . \, PHDE \,.\, HDE}{PHDFS^{\sigma_{HDE}} . \left[\begin{array}{l} \delta_{HDE} . [PHDEL.(1+indt_{el})]^{(1-\sigma_{HDE})} \\ +(1-\delta_{HDE}) . PHDFS^{(1-\sigma_{HDE})} \end{array} \right]} \tag{7.103}$$

g) Household demand for non-energy consumption

Additionally at the third level, the demand for the non-energy consumption by the household is based on maximization of the household utility CES function of nested consumption of non-energy material commodity consumption as follows:

$$HDNE = \left[\sum_i \delta_{HDNEi}^{\frac{1}{\sigma_{HDNE}}} . M_i^{\frac{\sigma_{HDNE}-1}{\sigma_{HDNE}}} \right]^{\frac{\sigma_{HDNE}}{\sigma_{HDNE}-1}} \tag{7.104}$$

Where,
M_i = household consumption of non-energy material commodity

δ_{HDNEi} = CES function share parameter associated with individual material commodity consumption
σ_{HDNE} = elasticity of substitution among individual material commodity consumption

The household trades off among different material commodities to maximize its utility under the budget constraint as follows:

$$\boldsymbol{PHDNE\ .\ HDNE = \sum_i PM_i\ .\left(1+indt_i\right).\ M_i} \tag{7.105}$$

Where:
MT_i = price of the particular material commodity
$indt_i$ = indirect tax on the consumption of particular material commodity

Demand for the particular material commodity consumption is obtained by the first order conditions of Lagrangian function for Equation 7.104 and 7.105 as given below:

$$M_i = \frac{\delta_{HDNEi}.\ PTRPU\ .TRPU}{\left\{PM_i.\left(1+indt_i\right)\right\}^{\sigma_{HDNEi}}.\left[\sum_i \delta_{HDNEi}.\left\{PM_i.\left(1+indt_i\right)\right\}^{(1-\sigma_{HDNE})}\right]} \tag{7.106}$$

h) Household demand for purchased land transport consumption

Similarly at the fourth level, the demand for the purchased land transport consumption by the household is based on maximization of the household utility CES function of nested consumption of road, rail and ropeway transport as follows:

$$\boldsymbol{TLND = \left[\sum_i cft_i\ .\ \delta_{TLNDi}{}^{\frac{1}{\sigma_{TLND}}}.T_i{}^{\frac{\sigma_{TLND}-1}{\sigma_{TLND}}}\right]^{\frac{\sigma_{TLND}}{\sigma_{TLND}-1}}} \tag{7.107}$$

Where,
T_i = household consumption of individual purchased land transport service
δ_{TLNDi} = CES function share parameter associated with individual purchased land transport service consumptions
σ_{TLND} = elasticity of substitution between individual purchased land transport service consumptions
cft_i =Counterfactual trend factor

Here, 'cft_i' is used to change share of individual purchased land transport in the counterfactual scenario case compared to the base case. In the base case, its value will be equal to '1'.

The household trades off among different mode of purchased land transport to maximize its utility under the budget constraint as follows:

$$PTLND.TLND = \sum_i PT_i\left(1+indt_i\right).T_i \tag{7.108}$$

Where:

PT_i	= price of the particular mode of purchased land transport
$indt_i$	= indirect tax on the particular mode of purchased land transport service

Demand for the particular mode of purchased land transport service consumption is obtained by the first order conditions of Lagrangian function for Equation 7.107 and 7.108 as given below:

$$T_i = \frac{(cft_i \,.\, \delta_{TLNDi}).\, PTLND \,.\, TLND}{PT_i^{(cft_i \,.\, \sigma_{TLNDi})} . \left[\sum_i (cft_i \,.\, \delta_{TLNDi}). PT_i^{(1-\sigma_{LND})} \right]} \tag{7.109}$$

i) Household demand for non-electricity fuel consumption

Additionally at the fourth level, the demand for the non-electricity fuel consumption by the household is based on maximization of the household utility CES function of nested consumption of non-electricity fuel consumption as follows:

$$HDFS = \left[\sum_i \delta_{HDFSi}^{\frac{1}{\sigma_{HDFS}}} . FS_i^{\frac{\sigma_{HDFS}-1}{\sigma_{HDFS}}} \right]^{\frac{\sigma_{HDFS}}{\sigma_{HDFS}-1}} \tag{7.110}$$

Where,

FS_i = household consumption of non-electricity fuel commodity

δ_{HDFSi} = CES function share parameter associated with individual non-electricity fuel consumption

σ_{HDFS} = elasticity of substitution among individual non-electricity fuel consumption

The household trades off among consumption of different non-electricity fuels to maximize its utility under the budget constraint as follows:

$$PHFS \,.\, HDFS = \sum_i PFS_i \,.\, (1 + indt_i + ctx) \,.\, FS_i \tag{7.111}$$

Where:

FS_i	= price of the non-electricity fuel
$indt_i$	= indirect tax on the consumption of particular non-electricity fuel
ctx	= carbon tax on consumption of fossil fuels

Demand for the particular non-electricity fuel consumption is obtained by the first order conditions of Lagrangian function for Equation 7.110 and 7.111 as given below:

$$FS_i = \frac{\delta_{HDFSi} .\, PHDFS \,.\, HDFS}{\{PFS_i .\, (1 + indt_i)\}^{\sigma_{HDFSi}} . \left[\sum_i \delta_{HDFSi} . \{PFS_i .\, (1 + indt_i)\}^{(1-\sigma_{HDFS})} \right]} \tag{7.112}$$

j) Household demand for Technology Specific Private Transport Consumption

At the fourth level, the demand for the category wise private transport consumption by the household is based on cost minimization of nested consumption of specific transport technologies (gasoline IC, diesel IC, gasoline hybrid, diesel hybrid, full electric and fuel-cell) as follows:

$$\boldsymbol{TRk = \left[\sum_i \delta_{TRki}{}^{\frac{1}{\sigma_{TRk}}} . TRk_i{}^{\frac{\sigma_{TRk}-1}{\sigma_{TRk}}} \right]^{\frac{\sigma_{TRk}}{\sigma_{TRk}-1}}} \tag{7.113}$$

Where,

TRk = household consumption of specific category (car and 2-wheelers) private transport service

TRk_i = household consumption of specific technology private transport service

δ_{TRki} = CES function share parameter associated with specific technology private transport service consumptions

σ_{TRki} = elasticity of substitution for specific technology private transport service consumptions

The household trades off among different technology of private transport to minimize its cost as follows:

$$PTRk \,.\, TRk = \sum_i PTRk_i \,.\, TRk_i \tag{7.114}$$

Where:

PTRk = price of the particular category of private transport service

$PTRk_i$ = price of the particular technology of private transport service

Demand for the particular technology of private transport service consumption is obtained by the first order conditions of Lagrangian function for Equation 7.113 and 7.114 as given below:

$$TRk_i = (\delta_{TRki}).\left(\frac{PTRk}{PTRk_i}\right)^{\sigma_{TRki}} .\, TRk \tag{7.115a}$$

The cost function of technology specific private transport consists of fixed ratio composition of service provided from commercial sector, motor vehicles sector and fuel consumption.

Similarly, PTRk is derived from equations 7.113, 7.114 and 7.115a as follows:

$$PTRk = \left[\sum_i \left(\delta_{TRk\,i} . PTRk_i{}^{1-\sigma_{TRki}} \right) \right]^{\frac{1}{1-\sigma_{TRki}}} \tag{7.115b}$$

Measurement of household welfare

Household or consumer welfare changed between the counter factual case and base case is measured by using equivalent variation in income (EV). Equivalent variation in income measures the extra income necessary to obtain a new utility level at old price. In this study, money metric indirect utility function approach (Varian, 1992) is used to measure the change in the household welfare due to policy intervention. The change in the consumer welfare is measured by following expression:

$$EV = \left[\frac{\sum_j \delta_j . P_{cf\,j}^{\;1-\sigma}}{\sum_j \delta_j . P_{0\,j}^{\;1-\sigma}} \right] I_{cf} - I_0 \qquad (7.116)$$

Where,

P_{cfj}, P_{cf0} = price of 'j' commodity in counterfactual case and base case

δ_j = CES function share parameter associated with consumption of 'j' commodity

σ = elasticity of substitution between any pair of commodities

I_{cfj}, I_{cf0} = household income in counterfactual case and base case

Considering price variables of composite commodity consumption in the top level of household utility function, the expression for equivalent variation of income is as follows**:**

$$EV = \left[\frac{\delta_{HD}.PHDTR_{cf}^{\;1-\sigma_{HD}} + (1-\delta_{HD}).PHDNT_{cf}^{\;1-\sigma_{HD}}}{\delta_{HD}.PHDTR_0^{1-\sigma_{HD}} + (1-\delta_{HD}).PHDNT_0^{1-\sigma_{HD}}} \right] IHD_{cf} - IHD_0$$

(7.117)

7.3.2.2 Government Sector

The government acts as a final consumer of commodity and provides services relating to the public administration, defense, social security and other public activities. Government consumption consists of commodity provided by public service sector (as used by Buehrer and di Mauro (1993), Bhattarai (2008), Acharya (2010)) and private transport demand (based on the share of the vehicle under Government ownership in 1999/2000 (WECS(2000)). It collects direct and indirect taxes, value added tax, import tariff and export tax. It makes net transfer and capital investment in the national economy and foreign markets.

a) Government Revenue and Spending

Total government revenue (IG) is represented as following:

$$IG = TTAX + (trgw - trwg) \qquad (7.118)$$

Where:

TTAX = total tax revenue

trgw = foreign aid and other financial transfer to government from ROW

trwg = financial transfer to ROW from government

The total tax revenue consists of different direct and indirect taxes as mentioned in the following expression.

$$TTAX = \left(hhtx.\left(W.\,l_{TOT} + PC.\,C_{TOT}\right)\right) + \sum_i \left[\left(HXD_i + GXD_i + IST_i\right).\,PXD_i.\,indt_i\right]$$
$$+ Z_i.\,PZ_i\,.\,tprd_i + \sum_i \left(p\exp_i.\,EXP_i.\,t\exp_i\right) + \sum_i \left(pmp_i.\,MP_i.\,trf_i\,.\,ER\right)$$

(7.134b)

Where :

$indt_i$ = indirect tax (value added tax) on commodity i sold in the domestic market
trf_i = tariff rate on commodity i imported from RoW
$texp_i$ = export tax on the commodity i exported to RoW
hhtx = household income tax
$tprd_i$ = production tax
HXD_i = household consumption of commodity i
GXD_i = government consumption of commodity i
$INP_{i,j}$ = intermediate consumption of commodity i in j production sector
IST_i = investment consumption of commodity i

The government consumption GXD_i consists of the other services related to the health, social work, defense, education, public administration. Other studies using CGE model for Nepal also considered the other services mentioned above to be solely consumed by the government (Acharya, 2010; Bhattarai, 1996; Sapkota and Cockburn, 2008).

The total government spending GXDTOT consists of total government consumption (IGD) and government transfer to the household. It is represented by following expression:

$$GXDTOT = IGD + trhg \qquad (7.119)$$

trhg = transfer from the government to the household

b) Government Saving

Government saving (SG) consists of total government revenue minus total government expenditure. Government saving acts as one of the variable sources of investment in the Nepalese economy.

$$SG = IG - GXDTOT \qquad (7.120)$$

7.3.2.3 Trade Sector

In Nepal-CGE model, there is import and export of commodities between the national economy and foreign economy (RoW). A small-country assumption is used in the model indicating the production and demand in the national economy will have no effect on the international market price of the commodity (Armington, 1969). Or, in other words, Nepalese economy is the price taker in both import and export market.

The summarized representation of traded commodities in production and consumption sectors is shown in the Figure 7.7. The aggregate domestic produced commodity output (XD_i) is consumed by export to RoW (EXP_i) and domestic market (XDD_i) governed by the constant elasticity of transformation (CET) function. Similarly, the domestic consumers acquire commodity i from import from RoW (MP_i) and domestic production (XDD_i) aggregated using the CES function.

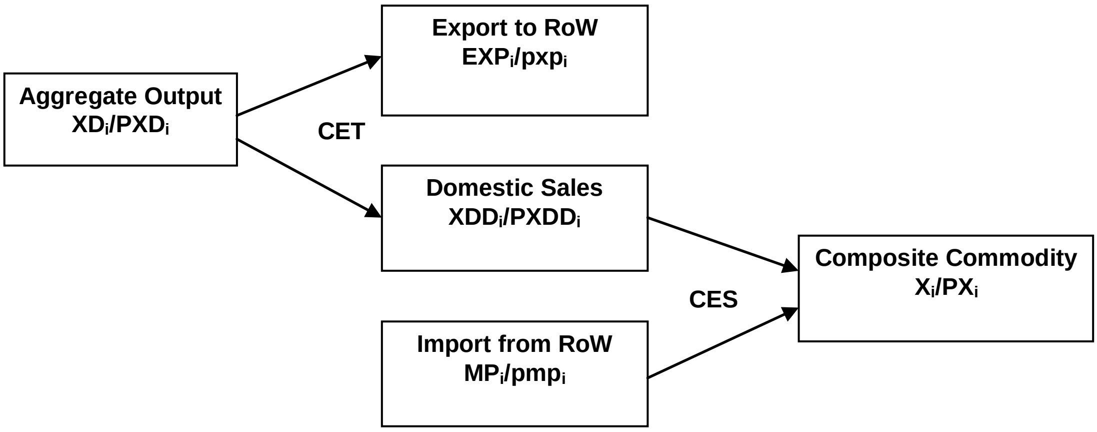


Figure 7.7: Representation of traded commodities in production and consumption sectors in the Nepal-CGE model

a) Supply of domestic consumption by import from ROW and domestic production

The domestic consumers use commodities supplied from domestic production and import. The total consumption of individual commodity 'cm' by domestic market consists of the composite commodity (X_{cm}) of domestic-produced commodity (XDD_{cm}) and imported commodity (MP_{cm}) nested by the CES function.

$$X_{cm} = \left[\delta_{Xcm}^{\frac{1}{\sigma_{Xcm}}} . MP_{cm}^{\frac{\sigma_{Xcm}-1}{\sigma_{Xcm}}} + \left(1-\delta_{Xcm}\right)^{\frac{1}{\sigma_{Xcm}}} . XDD_{cm}^{\frac{\sigma_{Xcm}-1}{\sigma_{Xcm}}} \right]^{\frac{\sigma_{Xcm}}{\sigma_{Xcm}-1}} \tag{7.121}$$

Where,
Xcm = total household consumption of commodity cm
MPcm = household consumption of commodity cm imported from RoW
XDDcm= household consumption of commodity cm from domestic production
δ_{Xcm} = CES function share parameter associated with consumption of commodity cm imported from RoW and domestic production
σ_{Xcm} = Armington elasticity of substitution between consumption of commodity cm imported from RoW and domestic production

Armington elasticity of substitution (low elasticity value) is used to differentiate the commodities imported from RoW and domestic production. The household trades off between MP_{cm} and XDD_{cm} based on minimization of cost function as follows:

$$PX_{cm} . X_{cm} = PMP_{cm} . \left(1+trf_{cm}\right). MP_{cm} + PXDD_{cm} . XDD_{cm} \tag{7.122}$$

Where:
PX_{cm} = price of the composite consumption of commodity cm imported from RoW and domestic production
PMP_{cm} = World market price in domestic currency of commodity cm imported from RoW
XDD_{cm} = household consumption of commodity cm from domestic production

Demand of the composite commodity i from import and domestic production is given by the first order conditions of Lagrangian function for Equation 7.121 and 7.122 as follows:

$$MP_{cm} = \delta_{Xcm}\left(\frac{PX_{cm}}{PMP_{cm}\left(1+trf_{cm}\right)}\right)^{\sigma_{Xcm}} X_{cm} \tag{7.123}$$

$$XDD_{cm} = \left(1-\delta_{Xcm}\right)\left(\frac{PX_{cm}}{PXDD_{cm}}\right)^{\sigma_{Xcm}} X_{cm} \tag{7.124}$$

Using equations 7.122, 7.123 and 7.124, the composite price of commodity cm is given by;

$$PX_{cm} = \left[\delta_{Xcm}.\left(PMP_{cm}\left(1+trf_{cm}\right)\right)^{1-\sigma_{Xcm}} + \left(1-\delta_{Xcm}\right).PXDD_{cm}{}^{1-\sigma_{Xcm}}\right]^{\frac{1}{1-\sigma_{Xcmi}}} \tag{7.125}$$

b) Domestic production for export to RoW and domestic market

The domestic production of commodities is mean for supplying to the domestic demand and RoW. The domestic producer allocates its production output between the export to RoW and domestic market based on the principle of profit maximization. The total production output including production tax (tprd) of commodity cm (XD_{cm}) is represented by constant elasticity of transformation (CET) demand function of the commodity produced for the export to RoW (EXP_{cm}) and domestic demand (XDD_{cm}) as follows:

$$XD_{cm} = \sum_i Z_i = \left[\delta_{XXcm}{}^{\frac{1}{\sigma_{XXcm}}}.EXP_{cm}{}^{\frac{\sigma_{XXcm}-1}{\sigma_{XXcm}}} + \left(1-\delta_{XXcm}\right)^{\frac{1}{\sigma_{XXcm}}}.XDD_{cm}{}^{\frac{\sigma_{XXcm}-1}{\sigma_{XXcm}}}\right]^{\frac{\sigma_{XXcm}}{\sigma_{XXcm}-1}} \tag{7.126}$$

Where,
EXP_{cm} = export of commodity cm to ROW
XDD_{cm}= household consumption of commodity cm from domestic production
XD_{cm} = composite of domestic consumption
tprd = production tax
texp = export tax
δ_{XXcm} = CET function share parameter associated with production of commodity cm exported to RoW and supply to domestic market
σ_{XXcm} = Armington elasticity of substitution between production of commodity cm exported to RoW and supply to domestic market

The producer allocates its production between EXP_{cm} and XDD_{cm} to minimize its cost of production (i.e., maximize its profit) as follows:

$$PXD_{cm} \,.\, XD_{cm} = PXP_{cm} \,.\, EXP_{cm}.(1+t\exp) + PXDD_{cm} \,.\, XDD_{cm} \qquad (7.127)$$

Where:
$PXDD_{cm}$= price of the commodity cm supplied to domestic market
PXP_{cm} = World market price in domestic currency of commodity cm exported to RoW

Demand of the production of the commodity for export to RoW and for supply to the domestic market is given by the first order conditions of Lagrangian function of Equations 7.126 and 7.127 for cost minimization as follows:

$$EXP_{cm} = \delta_{XD\,cm} \cdot \left(\frac{PXD_{cm}}{PXP_{cm}.(1+t\exp)} \right)^{\sigma_{XDcm}} XD_{cm} \qquad (7.128)$$

$$XDD_{cm} = \left(1 - \delta_{XD\,cm}\right). \left(\frac{PXD_{cm}}{PXDD_{cm}} \right)^{\sigma_{XDcm}} XD_{cm} \qquad (7.129)$$

The price of the domestic output with production tax of the commodity “cm” is obtained from Equations 7.127, 7.128 and 7.129 as follows:

$$PXD_{cm} = \left[\delta_{XD\,cm} \cdot \left(PXP_{cm}.(1+t\exp)\right)^{1-\sigma_{XDcm}} + 1 - \delta_{XD\,cm} \cdot \left(PXDD_{cm}\right)^{1-\sigma_{XDcm}} \right]^{\frac{1}{1-\sigma_{XDcm}}} \qquad (7.130)$$

The gross production output and its price with and without production tax are related by following Equations:

$$PXD_{cm} \,.\, XD_{cm} = PZ_i \,.(1+tprd) \,.\left(FCF_i \,.\, Z_i\right) \qquad (7.131)$$

Where,
tprd = production tax

In case of electricity, land freight transport and land passenger transport sectors, fixed conversion factor (FCFi) is used to convert physical unit (PJ, billion ton km and billion passenger km) into monetary unit (million NRs.).

$$XD_{cm} = FCF_i \,.\, Z_i \qquad (7.132)$$

Where,
FCF_i = fixed conversion factor from physical unit to monetary unit (PJ/million NRs, billion ton km/ million NRs and billion passenger km/ million NRs).

c) Foreign Saving

The current account balance in Nepalese economy is determined by accounting of the payments incoming and outgoing to RoW. The current account balance results from the flow of the foreign currency during net foreign trade, net foreign transfer and net foreign saving. The positive foreign saving occurs when outflow of the foreign currency is more than the inflow.

The foreign saving (FSAV) transaction of RoW is given by following expression:

$$FSAV = \left[pmp_{cm} \,.\, MP_{cm} - pxp_{cm} \,.\, EXP_{cm} - trgrw - trhhw\right].\, ER \qquad (7.133)$$

Where,
trgrw = net foreign transfer to government from RoW
trhhw = net foreign transfer to household from RoW

7.3.3 Investment Module

Investment module consists of macroeconomic financial balance in the model and activity specific allocation of capital goods in the model. Macroeconomic financial balance indicates how are the demands for capital goods needed for production of commodities are met? Similarly, activity specific allocation of capital goods indicates how are the total investment distributed among the production sectors in the economy?

7.3.3.1 Macroeconomic financial balance

A macroeconomic financial balance in the model (Macro-closure) is done by equating the total investment (INVTOT) with aggregate saving in the period. It is represented by the following expression:

$$INVTOT = SH + SG + FSAV \qquad (7.134)$$

As total investment (nominal investment) is expressed by the monetary value, real investment can be obtained by dividing it with the price of capital goods (Kim, 2004).

$$IT = \frac{INVTOT}{PI} \qquad (7.135a)$$

$$INV_c = dinvt_c \,.\, IT \qquad (7.135b)$$

$$PI = \sum_c dinvt_c \,.\, (1 + tvat_c) \,.\, PX_c \qquad (7.135c)$$

Where,
IT = real investment
PI = price of capital goods
INV_c = investment consumption of commodity c.
$dinvt_c$ = investment consumption distribution factor for commodity c.

7.3.4 Price Module

The price module consists of monetary relationship between national price and international price of traded commodities as well as consumer price index for the country. The import price and export price of traded commodities and the consumer price index (CPI) are derived as follows:

a) Import Price

The domestic price of the imported goods and services (expressed in Nepalese Rupees) is the price paid by the domestic consumers for that imported commodity including import tariff and transaction cost but excludes sales tax. The RoW foreign market price expressed in local currency is determined by the International market prices expressed in US dollars multiplied by exchange rate (Nepalese Rupees per US \$) as given in Equation 7.136.

$$PMP_{cm} = pwmp_{cm} \,.\, (1 + trf_{cm}) \,.\, ER \qquad (7.136)$$

Where:
$pwmp_{cm}$= c.i.f. import price in foreign currency of commodity cm imported from RoW
trf_{cm} = import tariff rate on commodity cm imported from RoW
ER = exchange rate (Nepalese Rupees per US\$)

b) Export Price

The domestic price of the exported commodity to RoW is expressed as follows:

$$PXP_{cm} = \frac{pwxp_{cm} \,.\, ER}{(1 + txep_{cm})} \qquad (7.137)$$

Where:
$pwxp_{cm}$= f.o.b. export price for RoW in US\$
$txep_{cm}$ = export tax on commodity cm

c) Consumer Price Index

The consumer price index (CPI) measures changes in the price level of consumer goods and services for a particular year with respect to the price level of the reference year. In the study Paasche type of CPI is used which considers the bundle of commodities using current prices and current quantities as the reference or numeraire. CPI is also used as numeraire for comparing the price of all the commodity and factors in the model. It is estimated by using following expression:

$$CPI = \frac{\dfrac{\sum_i \left[\left(HXD_i + GXD_i + INV_i \right) . PXD_i . \left(1 + tind_i \right) \right]}{\sum_i \left(HXD_i + GXD_i + INV_i \right)}}{\dfrac{\sum_i \left[\left(HXD0_i + GXD0_i + INV0_i \right) . PXD0_i . \left(1 + tind_i \right) \right]}{\sum_i \left(HXD0_i + GXD0_i + INV0_i \right)}} \qquad (7.139)$$

Where:
CPI = Consumer price index
PXD_i = price of commodity *i*
$PXD0_i$ = price of commodity *i* in the base year (benchmark equilibrium)

7.3.5 Macroeconomic closure and market clearing module

The model considers three macroeconomic and financial closure accounts consisting of current, government as well as saving and investment.

- The current account balance is reached with a flexible exchange rate adjustment to maintain the fixed level of foreign saving.
- In the government account balance (public expenditures equal receipts) with the direct and indirect tax rates as well as the real government consumption are held constant to maintain flexible government saving.
- The macroeconomic financial closure results with total investment equals with aggregate saving (see section 6.3.3.1). The foreign saving and household saving rate are held constant.

Market clearing results in the model with demand equals supply for commodity market as well as factor (capital and labor) markets.

The equilibrium in the commodity market takes pace with the sum of demands for household consumption, government consumption, investment consumption and intermediate inputs is equivalent to the supply of commodity i (X_i) in the economy.

$$X_i = HXD_i + GXD_i + INV_i + \sum_j INP_{i,j} \qquad (7.140)$$

Similarly, the equilibrium of capital market takes place with the total capital supply equals to sum of the capital demand required in all the production sectors.

$$\boldsymbol{\overline{CTOT} = \sum_i C_i} \qquad (7.141)$$

Where:
$\overline{CTOT}$ = total capital supply
C_i = capital demand in sector *i*

The equilibrating of labor market takes place with the total labor supply (exogenous) equals to the sum of the labor supply in each sector i.

$$\overline{\boldsymbol{LTOT}} = \sum_{i} \boldsymbol{L_i} \tag{7.142}$$

Where:

$\overline{LTOT}$ = total labor supply

L_i = labor demand in sector i

7.3.6 Gross Domestic Product

Nominal Gross Domestic Product based on consumption *(GDPNOMINL)* is defined as follows:

$$GDPNOMINL = IHD + IGD + INVTOT + \sum_i pwxp_i \,.\, XP_i \,.\, ER - \sum_i pwmp_i \,.\, MP_i \,.\, (1 + timp_i) \,.\, ER \tag{7.143a}$$

Real Gross Domestic Product based on consumption (GDPREAL) is defined as follows:

$$GDPREAL = {(IHD + IGD + INVTOT)}\big/{CPI} + \sum_i pwxp0_i \,.\, XP_i \,.\, ER0 - \sum_i pwmp0_i \,.\, MP_i \,.\, (1 + timp_i) \,.\, ER0 \tag{7.143b}$$

Where:

ER0 = exchange rate in the base year

pwxp0 = export price of commodity in foreign currency in the base year

pwmp0 = import price of commodity in foreign currency in the base year

Similarly, Nominal Gross Domestic Product based on income (GDPINCO) is defined as follows:

$$GDPINCO = LTOT.W + CTOT.PK + TTAX \tag{7.144}$$

7.3.7 Recursive Dynamic Module

In this model, recursive dynamic characteristic is applied to represent between period change in capital stock, labor supply and technological improvement. The several sequential equilibriums are determined (i.e., the first equilibrium in the sequence is given by the benchmark year) and the between-period specification is in equilibrium at the given conditions for the subsequent periods. The exogenous parameters relating to capital accumulation, demographical changes and technological improvement are used to reach within-period equilibrium.

7.3.7.1 Capital Accumulation

In the study, new capital is assumed to be homogeneous and moves freely across all sectors of the economy. The depreciated capital from all production sectors is not allowed to relocate to other sectors. The total capital stock available for the next period is given by the total capital stock in last year minus its depreciation plus part of the real investment in the previous year (IT) as follows:

$$CTOT_{t+1} = \sum_i C_{i,t} \,.\, (1 - rdep_i) + kratio.\, IT \quad (7.145)$$

Where:
$rdep_i$ = depreciation rate in sector i
kratio = capital allocation ratio

7.3.7.2 Growth of Labor Supply

The dynamic nature of total labor factor supply in the economy is represented by incorporating the growth rate in the annual supply of the labor. The population growth in the country is used to fix the growth rate of annual supply of labor in the economy.

$$\boldsymbol{LTOT_{t+1} = LTOT_t \,.\, (1 + grlabor)} \quad (7.146)$$

Where:
LTOT = total labor supply
grlabor= labor supply growth rate

7.3.7.3 Technological Improvement Parameters

Technological improvement in production sector due to increase in labor productivity over time is represented in the model by using progress rate in the labor productivity factor following Chuanyi (2009) as follows:

$$\alpha_{L\,i,t+1} = \alpha_{L\,i,t} \,.\, (1 + rtpg_t) \quad (7.147a)$$

Where,
α_{Li} = productivity factor of labor input of sector i and its value is 1 in the base year
$rtpg_t$ = progress rate of labor productivity factor in time t.

The annual energy efficiency improvement (AEEI) factor (Webster et,al., 2008) is given by following equations:

$$\alpha_{FS\,i,t+1} = \alpha_{FS\,i,t} \,.\, (1 + rfs_t) \quad (7.147b)$$

Where,

α_{AEEIi} = annual energy efficiency improvement (AEEI) factor associated with energy input of sector i in time t.

rfs_t = change in energy efficiency improvement factor in energy input of sector i in time t.

The energy efficiency improvement (EEI) factor for household energy consuming devices is given by following equations:

$$\alpha_{HHEEI\ t+1} = \alpha_{HHEEI\ t} \cdot (1 + rhe_t) \tag{7.148}$$

Where,

α_{HHEEI} = energy efficiency improvement (EEI) factor for household energy consuming devices.

rhe_t = change in energy efficiency improvement factor for household energy consuming devices in time t.

7.3.8 Energy and Emission Module

The energy consumption in engineering unit (PJ) and resulting GHG emissions consisting of CO_2, CH_4 and N_2O are estimated in the Nepal-CGE model by separate energy and emission module. The energy consumption in engineering unit (PJ) is determined by using fuel-specific energy conversion factor (i.e., 10^{12}NRs/PJ) as given in the following equation:

$$ENTOT_f = \frac{\sum_i ENIOPRD_{i,f}}{FF_f} + \frac{\sum_k ZTCH_k . ENIOTCH_{k,f}}{FF_f} + \frac{(HXD_f + GXD_f + INV_f)}{FF_f} \tag{7.149a}$$

Where,

$ENTOT_f$ = total consumption of “f” fuel in PJ

$ENIOPRD_{i,f}$ = consumption of “f” fuel as intermediate input for “i” production sector

FF_f = energy conversion factor for converting monetary unit into physical unit (10^{12}NRs/PJ)

$ENIOTCH_{i,f}$ = consumption of “f” fuel as intermediate input per unit physical unit output for “k” technology specific service production (land passenger, land freight and electricity sectors)

$ZTCH_{k,f}$ = physical unit based output by “k” technology specific service production (land passenger, land freight and electricity sectors)

The individual GHG emissions are calculated by using fuel-specific emission factor (thousand ton/PJ) for CO_2, while technology specific emission factors are used for CH_4 and N_2O emissions. Technology specific emission factors for the fuel are used the fuel consumed by the technology level production sub-sectors for land freight, land passenger and electricity sectors as used in Nepal-ESM model. For aggregated sectors whose technology level disaggregation is not available, emission factors for CH_4 and N_2O emissions are estimated by considering average emission factor for aggregated sectors estimated from the Nepal-ESM model analysis.

For C-tax scenario analysis, GHG emission tax is introduced in the counter factual simulation by imposing additional environmental tax based on the GHG emission and is given by following expression:

$$envtx = \left(\frac{EMM_f}{FF_f .} \right) . ctprice_f \qquad (7.149a)$$

The indirect tax would be changed from (1+indt) to (1+indt+envtx) in the counterfactual scenario of C-tax analysis.

Where,
envtx = C-tax on consumption of fossil fuel
ctprice = price of CO2e emission
EMMf = Emission factor for GHG emissions (10^3 ton/PJ)

7.4 Construction of Social Accounting Matrix of Nepal

A benchmark Social Accounting Matrix (SAM) of Nepal for the base year 2005 has been constructed for the purpose of this study based on the 2000/01 input-output table (IRPAD, 2007), national account (MOF, 2007; NRB, 2007) and national energy structure (WECS, 2006a).

The following procedure was followed in the construction of the new SAM for 2005:

a. The input-output structure of 2005 was considered as similar to that of 2000/01 (IRPAD, 2007). Following, Hosoe et al. (2010) and Acharya (2010), every entry in the cells of the domestic intermediate input, non-competitive imported intermediate input, production tax and import tariff were scaled up in proportion to the change in the gross output at constant prices.
b. The commodity wise export and import data were updated using NRB (2007) and FNCCI (2006).
c. National account data on, government investment, foreign investment, transfer to ROW from government and household were taken from MOF (2007) and FNCCI (2006). In order to achieve balance in the income and expenditure of institutions in SAM, the household investment, foreign transfer to government and household were adjusted (Acharya, 2010).
d. In order to represent energy sector effectively, electricity, lignite and fuel-wood were considered as separate activity in the production sector. The imported energy resources consisting of diesel, gasoline, kerosene, ATF, industrial grade coal, LPG were represented as individual imported fuel for intermediate input in

the production activity and commodity supplied to the domestic market. The sector wise disaggregation of the individual fuel account was done by using energy distribution ratio as reported in the energy balance of Nepal for 2005 (WECS, 2006a). The total cost of traded petroleum products, coal and electricity were estimated using WECS(2006a), FNCCI (2006) and NEA (2006).

e. Electricity is treated as separate commodity which is produced from the four power generation technologies (hydropower, diesel-fired power plant, wood gasification combined cycle power plant, and MSW-based power plant). The detail procedure for the disaggregation is mentioned in section 7.5.

f. The land transport sector is disaggregated into land freight and land passenger transport services. Following Schafer and Jacoby (2005) and Siddiqui (2007), the land freight transport service is considered as one of the components of domestic intermediate input, where as the land passenger transport service is considered as a component of household transport service consumption. The detail procedure for technology level disaggregation is mentioned in section 7.6.

Table 7.2: Aggregate SAM of Nepal for 2005 (Million Nepalese Rupees)

			Expenditure								
			Production		Factors		Institutions				
			Activities	Commodi Ties	Labor	Capital	House hold	Govern ment	Capital Account	Rest of World	Total
Receipt	Activities			914,088							914,088
	Commodities		258,234				458,737	60,040	187,803	85,245	1,051,059
	Factors	Labor	299,383								299,383
		Capital	270,302								270,302
	Institutions	Household			299,383	270,302		2,823		51,210	623,717
		Government	10,222	27,840			10,466			37,500	86,028
	Capital Account						150,907	17,213		19,683	187,803
	Rest of World		74,948	109,131			3,606	5,953			193,638
	Total		914,088	1,051,059	299,383	270,302	623,717	86,028	194,279	193,638	

Sources: FNCCI (2006), IRPAD (2007), MOF (2007), NEA (2006), NRB (2007), WECS (2006a)

Table 7.2 shows the aggregated SAM used in this study. It represents the summarized aggregated figures of different accounts and the role of different institutions in the circular flow of commodities and factors in the equilibrium condition of the economy (see section 7.2). The detail disaggregated SAM is given in the Appendix G.

7.5 Technology Options of Power Sector

In the Nepal-CGE model the electricity generation sector is disaggregated to the technology specific levels by following the procedure as used by Sue Wing (2008), Timilsina (2001) and Watcharejyothin (2010). There are four types of electricity generation technologies considered in the study; i.e., hydropower, diesel-fired power plant, wood gasification combined cycle power plant, and MSW-based power plant.

In this study, the electricity generation sector in a column of the SAM for Nepal is disaggregated corresponding to those generation technologies in the base year using capital distribution factor and generation distribution factor as used by Sue Wing (2008), Timilsina (2001) and Watcharejyothin (2010) underlining the limited data availability. The distribution of capital factor among the existing electricity generation technology is done based on the capital distribution factor and at the same time, the distribution of labor factor and intermediate input are based on the generation distribution factor (Table 7.3).

The estimation of the share of capital, labor, fuel and intermediate input per unit electricity generation (kWh) from each technology is done by adopting following assumptions (see McFarland et al. (2004) and Sue Wing (2008)):

- Annual cost of capital is taken as a levelized investment cost taking interest rate of 10% during its life time.
- Annual labor cost is considered as annual operation and maintenance (fixed and variable) costs.
- Annual fuel cost is taken as cost of inputs of fuel in a year.

Table 7.3: Electricity generation technology characteristics in the Nepal-CGE model

Technology characteristics	Electricity generation technologies			
(Electricity generation)	HYDRO	THDSL	THWOD	THMSW
Capacity in 2005 (MW)	552.3	40.8		
Capacity factor	0.44	0.68	0.80	0.80
Capacity cost ($/KW)	3379	680	2,208	1,829
Plant life (Yrs)[39]	50	25	30	30
Discount rate	10%	10%	10%	10%
Capital recovery factor[40]	0.101	0.110	0.106	0.106
Annual capital cost ($/KW/Yr)	341	75	234	194
Total capacity cost ($10^6$$/Yr)	188.2	3.1		
Capital distribution factor (in 2005)	0.99	0.01		
Generation distribution factor (in 2005)	0.98	0.02		
Capital cost share (%)	52%	4%	22%	23%
Labor cost share (%)	11%	4%	10%	25%
Fuel cost share (%)	0%	74%	26%	0%
Intermediate input share (%)	37%	19%	42%	52%

Note: hydropower (HYDRO); diesel-fired power plant (THDSL), wood gasification combined cycle power plant (THWOD), and MSW-based power plant (THMSW)

Source: MOE (2010), NEA (2005), Nepal-ESM model, USEPA (2006)

[39] The annual capital cost is very much dependent on the number of years considered during levelization. Some studies uses technology wise operational life as the levelization period (Timilsina, 2001; Watcharejyothin, 2010) where as other studies uses fixed levelization period for all the technologies (Sue Wing (2008).

[40] Adopted from Watcharejyothin (2010):
Capital distribution factor (CDF) = Annualized capital cost$_{GEN}$ ($/KW/Yr) / Total annualized capital cost ($/KW/Yr)

Total annualized capital cost ($) = $\sum_{GEN=1}^{4}$ Annualized capital cost$_{GEN}$ ($/KW/Yr) x Capacity$_i$ (MW)

Annualized capital cost ($/KW/Yr) = Capital cost$_{GEN}$ ($/KW) x Capital Recovery Factor (CRF)

$$CRF = \frac{Discount\ rate}{1 - \frac{1}{(1 + Discount\ rate)^n}}$$

In case of new technology not used in the base year, the per unit generation (kWh) for capital and labor are calculated by using the above assumptions. The cost of intermediate input per unit electricity generation is assumed to be the same as those of the aggregate electricty sector in the base year. The fuel cost is estimated by using efficiency and fuel cost data as used in the Nepal-ESM model. Based on the per unit generation cost distribution, the share of capital, labor, intermediate input and fuel are calculated. In order to harmonize the figure estimated for capital and labor as mentioned above with that given by the input output matrix of SAM, normalization ratio is multiplied to the capital and labor factors calculated for the new technology. The normalization ratio for capital consists of the total capital cost for aggregated electricity generation sector in the SAM divided by the total levelized investment cost of all the existing technologies in the base year. Similarly, the normalization ratio for labor factor consists of the total labor cost for aggregated electricity generation sector in the SAM divided by the total O&M cost per year for all the existing technologies in the base year. The detailed data used in the study is given in Table 7.3.

7.6 Technology Options of Transport Sector

The available input output table contains aggregated freight and passenger land transport sector. For better representation of the transport service sector in the Nepal-CGE model, it is disaggregated into the land freight transport and land passenger transport services. This study assumed that all the land transport service demand used as intermediate input for production sectors are from freight land transport sector and that used for the final consumption (household and government) are from passenger land transport sector (as used by Schafer and Jacoby (2005) and Siddiqui (2007)). Both the land freight transport and land passenger transport sectors provide service through three modes of transports: road, rail and ropeway. The road mode of transport further consists of technology specific disaggregation as mentioned in Table 7.4 and 7.5.

As in the electricity generation sector, the distribution of capital factor among the existing transport technology in the SAM is done by using capital distribution factor. In case of the distribution of labor factor and intermediate input, they are based on the demand distribution factor (Table 7.4). In case of new technology not used in the base year, the per unit transport demand (btkm and bpkm) for capital and labor are calculated by assuming above assumptions. The normalization ratios for capital and labor are used to harmonize the factor cost of the SAM and estimated factor cost (see section 7.5). The per unit transport intermediate input costs are assumed to be same as those of the aggregate land freight transport and land passenger transport sectors in the base year. The fuel cost is estimated by using efficiency and fuel cost data as used in the Nepal-ESM model. Based on the per unit cost distribution, the share of capital, labor, intermediate input and fuel were calculated.

In the household utility function, the transport consumption consists of the public transport demand produced by the land passenger transport sector and private transport demand produced by the household itself. The household produces private transport demand by purchasing transport vehicle from motor vehicles sector, maintenance service from commercial sector and fuel used in the vehicle from the fuel commodity market. The share of the vehicle and fuel costs for private passenger transport demand by household for final consumption is given in Table 7.6.

The analysis of transport electrification policy was carried out by following procedure:

a) First, the share of each transport technology in the final transport demand in each period under different transport electrification scenarios from Nepal-ESM model was obtained.
b) The technology wise transport service quantity demand under land freight transport, land passenger transport and private transport in the Nepal-CGE model was fixed.
c) The model was run to compare the macroeconomic and national welfare results between base case and counterfactual scenarios (transport electrification scenarios).
d) The effect of foreign direct investment was studied by introducing foreign owned capital to cover 25%, 50% and 100% of the additional capital investment required in the electricity sector and transport sector under selected transport electrification scenario as compared to the base case.

Similarly, the macroeconomic implications of C-tax in the consumption of fossil fuel was done by the following procedure:

a) Introduce the C-tax on the consumption of each fossil fuel based on the carbon content.
b) The effect of government transfer of C-tax revenue to household in different proportion (25%, 50% and 100% of the C-tax revenue).

7.7 Calibration of the Nepal-CGE Model

In the CGE model, the calibration in the benchmark year is done to determine the relevant parameters in the model that may reproduce the benchmark equilibrium in the base year. The parameters generally consist of the values related to the preferences of production factors and material inputs, consumer utility function, distribution of investment goods or any exogenous dynamic factors. Some parameters are directly estimated from the SAM, where as some parameters may be requireed to be estimated from time series data or adopted from literature reviews (e.g., elasticities of substitution).

Four types of the parameters are required for developing a Nepal-CGE model;

i) scale factors and share parameters,
ii) parameters that can be directly calculated from the benchmark dataset (i.e., direct and indirect taxes, import tariff rates, household saving ratio),
iii) elasticities of substitution that can be obtained from literature survey, and
iv) dynamic characteristic factors (i.e., population growth rate (for labor growth), technological progress rate (labor productivity), energy efficiency improvement rates).

These parameters are prepared either in a form of spread sheet (and transfer them to the model by using GAMS syntax called “XLIMPORT” in GAMS) or by input them directly into the model.

Table 7.4: Freight transport technology characteristics in the Nepal-CGE model

Technology characteristics (Freight transport)	Truck		Pick-up		Tractor	Train	Ropeway
	Diesel	D-Hybrid	Diesel	D-Hybrid	Diesel	Electricity	Electricity
Demand in 2005 (btkm)	1.8873		0.0089		0.3149	2.2111	0.0001
Capacity cost (M$/btkm)	127	228	217	356	178	30	5336
Levelization term (Yrs)	12	12	10	10	10	15	15
Interest rate	10%	10%	10%	10%	10%	10%	10%
Capital recovery factor	0.147	0.147	0.163	0.163	0.163	0.131	0.131
Annual capital cost (M$/btkm-Yr)	19	34	35	58	29	4	702
Capital distribution factor (in 2005)	0.7876		0.0070		0.2038		0.0016
Demand distribution factor (in 2005)	0.8535		0.0040		0.1424		0.0001
Capital cost share (%)	33%	30%	37%	35%	32%	21%	45%
Labor cost share (%)	24%	46%	25%	46%	21%	16%	47%
Fuel cost share (%)	27%	15%	29%	14%	37%	12%	7%
Intermediate input share (%)	16%	9%	10%	6%	12%	51%	0.6%

Source: IEA (2005, 2008); NIES (2007); TERI (2006); WECS (2000); Nepal-ESM model

Table 7.5: Public passenger transport technology characteristics in the Nepal-CGE model

Technology characteristics (Public passenger transport)	Bus					Micro-bus			3-Wheelers			Taxi				Train	Ropeway
	Diesel	D-Hybrid	Full-Electric	Fuel-cell	Mini-Bus	Diesel	LPG	Full-Electric	Diesel	LPG	Full-Electric	Gasoline	G-Hybrid	Full-Electric	Fuel-Cell	Electricity	Electricity
Demand in 2005 (bpkm)	12.5899				1.0946	0.2714	0.1232		0.5572	0.1406	0.2516	0.3366					0.0011
Capacity cost (M$/bpkm)	22	34	43	56	22	25	25	58	13	11	20	87	153	205	227	10	445
Levelization term (Yrs)	14	14	12	14	12	12	12	12	7	7	7	8	8	8	8	15	15
Interest rate	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
<u>Capital recovery factor</u>	0.136	0.136	0.147	0.136	0.147	0.147	0.147	0.147	0.205	0.205	0.205	0.187	0.187	0.187	0.187	0.131	0.131
Annual capital cost (M$/ bpkm/Yr)	3	5	6	8	3	4	4	9	3	2	4	16	29	38	43	1	58
Capital distribution factor (in 2005)	0.7404				0.0680	0.0196	0.0087		0.0284	0.0063	0.0201	0.1072					0.0013
Demand distribution factor (in 2005)	0.8193				0.0712	0.0177	0.0080		0.0363	0.0091	0.0164	0.0219					0.0001
Capital cost share (%)	37%	35%	38%	48%	34%	47%	46%	46%	31%	31%	29%	29%	35%	41%	53%	52%	51%
Labor cost share (%)	23%	42%	47%	35%	23%	15%	12%	39%	12%	13%	51%	45%	51%	53%	38%	24%	41%
Fuel cost share (%)	22%	11%	5%	7%	27%	19%	22%	7%	39%	34%	10%	24%	11%	5%	8%	11%	7%
Intermediate input share (%)	19%	12%	9%	10%	17%	20%	20%	8%	18%	22%	11%	3%	2%	2%	2%	12%	1%

Source: IEA (2005, 2008); NIES (2007); TERI (2006); WECS (2000); Nepal-ESM model

Table 7.6: Characteristics of the vehicle and fuel costs for private passenger transport demand by household for final consumption

Technology characteristics (Private transport demand)	Car						2-Wheelers	
	Diesel	Gasoline	D-Hybrid	G-Hybrid	Full-Electric	Fuel-Cell	Gasoline	Full-Electric
Demand in 2005 (bpkm)	0.4678	1.2151					3.7955	
Capacity cost (M$/bpkm)	127	180	259	285	376	474	53	71
Levelization term (Yrs)	8	8	8	8	8	8	7	7
Interest rate	10%	10%	10%	10%	10%	10%	10%	10%
Capital recovery factor	0.187	0.187	0.187	0.187	0.187	0.187	0.205	0.205
Annual capital cost (M$/bpkm/Yr)	24	34	49	53	71	89	11	15
Capital distribution factor (in 2005)	0.1197	0.4409					0.4394	
Transport vehicle cost share (%)	51%	49%	60%	57%	64%	73%	54%	54%
Operation and maintenence cost share (%)	13%	21%	24%	28%	30%	19%	9%	30%
Fuel cost share (%)	36%	30%	16%	15%	6%	8%	36%	17%

Source: IEA (2005, 2008); NIES (2007); TERI (2006); WECS (2000); Nepal-ESM model

a) Share Parameters

In this study, the CES functions are used for the formulation of composite commodities and composite factors of production. The share parameter in the CES function is derived following methods as mentioned in Kim (2004).

Let the common CES functional form be represented by following equation:

$$Y = \alpha \left[\sum_{1}^{n} \delta_i^{\frac{1}{\sigma}} . X_i^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \tag{7.150}$$

Where,
Y= dependent variable
X_i=independent variables
α = CES function shift parameter
δ_i = CES function share parameter of X_i
σ = elasticity of substitution

Considering first order condition of optimization, the ratio of marginal change in Y with respect to each Xi is the same as the ratio of their relative prices as given in Equation 7.151.

$$\frac{\partial Y / \partial X_i}{\partial Y / \partial X_1} = \left(\frac{\delta_i}{\delta_1} \right)^{\frac{1}{\sigma}} \cdot \left(\frac{X_1}{X_i} \right)^{\frac{1}{\sigma}} = \frac{P_i}{P_1}, \quad \text{for i=2,….,n} \tag{7.151}$$

Where, P_i = price of X_i

Rearranging Equation 7.150, we get,

$$\delta_i = \delta_1 \cdot \left(\frac{P_i}{P_1} \right)^{\sigma} \cdot \frac{X_i}{X_1}, \quad \text{for i=2,….,n} \tag{7.152}$$

As sum of shares of all the independent variables (δ_i) should make up to 1, we get the following relation:

$$\sum_{1}^{n} \delta_i = \delta_1 + \sum_{2}^{n} \delta_i = \delta_1 + \sum_{2}^{n} \left[\delta_1 \cdot \left(\frac{P_i}{P_1} \right)^{\sigma} \cdot \frac{X_i}{X_1} \right] = 1 \tag{7.153}$$

δ_i is estimated from above equation as follows:

$$\delta_i = \frac{1}{\left[\left(\frac{P_1}{P_1} \right)^{\sigma} \cdot \frac{X_1}{X_1} \right] + \sum_{2}^{n} \left[\left(\frac{P_i}{P_1} \right)^{\sigma} \cdot \frac{X_i}{X_1} \right]} = \frac{1}{\sum_{1}^{n} \left[\left(\frac{P_i}{P_1} \right)^{\sigma} \cdot \frac{X_i}{X_1} \right]} = \frac{P_1^{\sigma} . X_1}{\sum_{i}^{n} P_i^{\sigma} . X_i} \tag{7.154}$$

Following expression in Equation 7.153, representing condition for sum of share of all the related independent variables, share parameter can be calculated for all composite CES function used in the study. Following Kim (2004), for the convenience of calculation, price index is used in the model assigning price of the base year fixed as 1 (P_i = 1). Then, the share parameter is the ratio of production factor (Xi) to the total input of the production factors ($\sum_1^n X_i$).

b) Scale Parameters

The zero profit condition of production function represented by Equation 7.150 is given by following:

$$\boldsymbol{P_y Y = \sum_1^n P_i . X_i} \tag{7.155}$$

Demand for Xi is obtained by the first order conditions for cost minimization of the Lagrangian function of Equations 7.150 and 7.155.

$$X_i = \alpha^{\sigma-1}\, \delta_i \left(\frac{P_y}{P_i} \right)^{\sigma_i} Y \tag{7.156}$$

From Equations 7.150 and 7.155, the scale parameter is calculated by following expression:

$$\alpha = \frac{\left[\sum_1^n \delta_i \,.\, P_i^{1-\sigma} \right]^{1/1-\sigma}}{P_y} \tag{7.157}$$

If price of Xi and Y is considered as 1 following price index approach, the value of scale parameter (α) is always 1.

c) Other exogenous parameters

In the study, values of elasticities of substitution are taken from the literature survey or modeler’s own judgment as practiced in most of the study for developing countries (Buehrer and di Mauro, 1993; Chuanyi, 2009; Kim, 2004; Siddiqui, 2007; Watcharejyothin, 2010). The labor supply growth, technology progress rate, energy efficiency improvement parameters, depreciation rate considered during 2005-2050 are given in Appendix H.

To get the desired outputs of the demand and price by solving in the model all the equations defined in this chapter are not required. Those equations actually used for solving in the model are given in Appendix I. A software package called “General Algebraic Modeling System (GAMS)” is used with selection of GAMS/PATH solver as it is appropriate to solve both linear and non-linear complex nested structure functions (Paltsev et al., 2005, Watcharejyothin, 2010).

Different blocks of equations to be solved are written in GAMS programming language. It starts with declaration and definition of sets of parameters, variables and equations. It is followed by assignment of the data to represent those parameters and variables. Then initial bench mark values of the variables, model statements, control commands and specific formats for output generation are set in the model. This is followed by employing zero iteration limits to check whether there are any infeasible and redefined results as well as check whether the model cans reproduce the benchmark equilibrium. Finally, the model is solved to generate the simulation results for further interpretation.

7.8 Conclusion

This chapter described the development of a multi-sector, single region recursive dynamic computable general equilibrium model of Nepal for analyzing economy-wide implications under transport electrification and carbon tax policies. It comprises the production and consumption structure, institutions and commodity trade structure. The procedure to develope the social accounting matrix has been presented. The technology options considered and provision of backstop technology for the transport and power sectors were discussed. Finally, calibration of the model has been presented in the Chapter.

Chapter 8

Macroeconomic Effects of Transport Electrification Policy

The electrification of the transport sector is considered as one of the promising options for persuing the Low Carbon Development path by the global communities which emphasize the need for adaptation of the sustainable economic development in the 21st century. But long term macroeconomic consequences of such policies is very much country specific due to the variations in the availability and tapping potential of indigenous clean energy resources, access to the clean technologies, affordability and acceptability of such technologies, and so on. This chapter is devoted to the fulfillment of Objective 2 of the present research work. It studies the macroeconomic consequences of introducing the electrified mass transport systems and electric vehicles in Nepal on the long term basis. This study develops and uses a multi-sector, single region, recursive dynamic computable general equilibrium model of Nepal (Nepal-CGE) with technology level disaggregation in the transport and electricity sectors for analyzing the economy-wide implications of undertaking transport sector electrification. The study of the economy-wide implications was focused to determine the structural change in GDP, national consumer welfare, energy and emission intensities of GDP. Other effects in terms of energy system development, energy system costs, energy security, GHG and local pollutant emissions of the transport electrification policy has been discussed in Chapter 5.

8.1 Modeling of the Transport Electrification Policy

The macroeconomic consequences of transport electrification policy in Nepal is analyzed in the study by using multi-sector, single region recursive dynamic general equilibrium model developed for the country (Nepal-CGE) as discussed in Chapter 7. The transport sector electrification policy is represented in the model by exogenously introducing different levels of electrified transportation systems in the total transport service demand for the land freight, land passenger public transport services and private owned transport facilities. The model is developed by using monetary unit as well as non-monetary units following Sands and Fawcett (2005). ‘PJ’ is used as the initial unit for the electricity generation sector, ‘billion passenger km’ for land passenger public and private owned transport demand and ‘billion ton km’ for land freight transport demand. Later, all non-monetary units are converted into the monetary unit at the stage of final commodity supplied to the market by multiplying the physical unit with fixed conversion factor (monetary unit per physical unit). The use of non-monetary unit for demand would facilitate the technology level selection based on per unit cost of service demand in physical unit (non-monetary). The planning horizon of the study is 2005 to 2050.

The dynamic function equations are used to represent the future total stocks of labor and capital supply as mentioned in Chapter 7. Upper limits on the electricity generation for the non-hydropower electricity generation are set in agreement with the limits set in the Nepal-ESM model. The annual energy efficiency improvement (AEEI) factor in the production sectors and energy efficiency improvement (EEI) factor in household end-use energy consumption are assumed to be in the range of 0.002 to 0.009. The labor productivity growth rate is considered to be in the range of 0.005 to 0.01

(details given in Appendix H). These values are within the range of as used in other studies (Brenkert et al., 2004; Paltsev et al., 2005; Watcharejyothin, 2010; Webster, et al., 2008). Emission factors for CO2 emission from carbon intensive fuels are based on IPCC (2006). For non-CO_2 GHG emissions (i.e., CH_4 and N_2O), technology specific fuel emission factors are used for electricity generation, land freight transport sector, land passenger transport sector, and private transport based on IPCC (2006). For other sectors which are not disaggregated into the level of technology and for household consumption in the Nepal-CGE model, emission factors are estimated by using sector specific non-CO2 emission factor for each source estimated by using the outputs of Nepal-ESM model under the base case scenario following Sands and Fawcett (2005).

The analysis of transport electrification policy was carried out by following procedure:

a) First, the technology wise final transport demands for land freight transport (truck, tractor, pickup, ropeway and railway), land passenger public transport (bus, microbus, 3-wheelers, taxi, ropeway and railway) and private owned transport (car and 2-wheelers) in each period were obtained from Nepal-ESM model output and was used as exogenous input in the Nepal-CGE model. The projected land transport service demand for Nepal during 2005 to 2050 is given in Table 4.3.
b) The technology wise transport service demands in physical unit of the individual land transport services from production sectors and privately owned transports were introduced exogenously in the Nepal-CGE model.
c) The model was run with exogenously introduced technology wise distribution of transport service demands for the base case and different transport electrification cases.
d) The analysis was carried out by comparing and interpreting the results from the base case and counterfactual scenarios (transport electrification scenarios) to determine macroeconomic implications in terms of GDP distribution, consumer welfare, energy intensity and emission intensity.
e) Then effect of foreign direct investment in the policy scenario was studied by exogenously introducing foreign capital consisting of 25%, 50% and 100% of additional investment required under selected transport electrification scenario as compared to the base case during 2020 to 2050.

Altogether six scenarios were used for analyzing macroeconomic effects of transport sector electrification as follows:

(i) Base case: The base case scenario is defined as the business-as-usual case without any transport sector electrification policy being introduced. In order word no electrified mass transport and electric vehicles are allowed to penetrate during the study period. The future labor factor growth is assumed to follow population growth in future. It is assumed that the population growth during 2005 to 2020 would be same as mentioned in (CBS, 2003b) and then after it would follow the medium variant growth rate as mentioned in UNPD (2009) during 2020 to 2050 (Discussed in Chapter 4). The future total capital factor is determined by the depreciated total capital and new real investment of the previous year. The level of total gross investment was varied through iteration method to maintain the level of energy consumption as close to the one obtained from the Nepal-ESM model analysis.

(ii) EMT10: a shift of 10% of the road transport demand to the electric mass transport system from 2020 onwards and all other things remaining the same as in the base case as shown in Figure 8.1.

(iii) EMT20: a shift of 10% of the road transport demand to the electric mass transport system in 2020 and gradually increase the shift to 20% by 2050.

(iv) EMT30: a shift of 10% of the road transport demand to the electric mass transport system in 2020 and gradually increase the shift to 30% by 2050.

(v) EMT20+EV10: a shift of 20% of the road transport demand to the electric mass transport system as in the EMT20 and shift of another 5% of the demand to electric vehicles in 2015 with gradually increase in the shift of electric vehicles to 10% by 2050.

(vi) EMT20+EV15: a shift of 20% of the road transport demand to the electric mass transport system as in the EMT20 and shift of another 5% of the demand to electric vehicles in 2015 with gradually increase in the shift of electric vehicles to 15% by 2050.

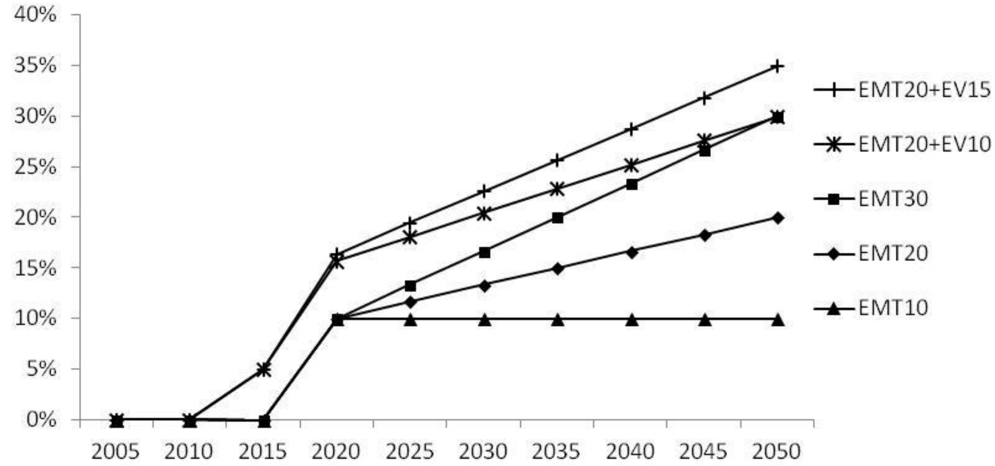
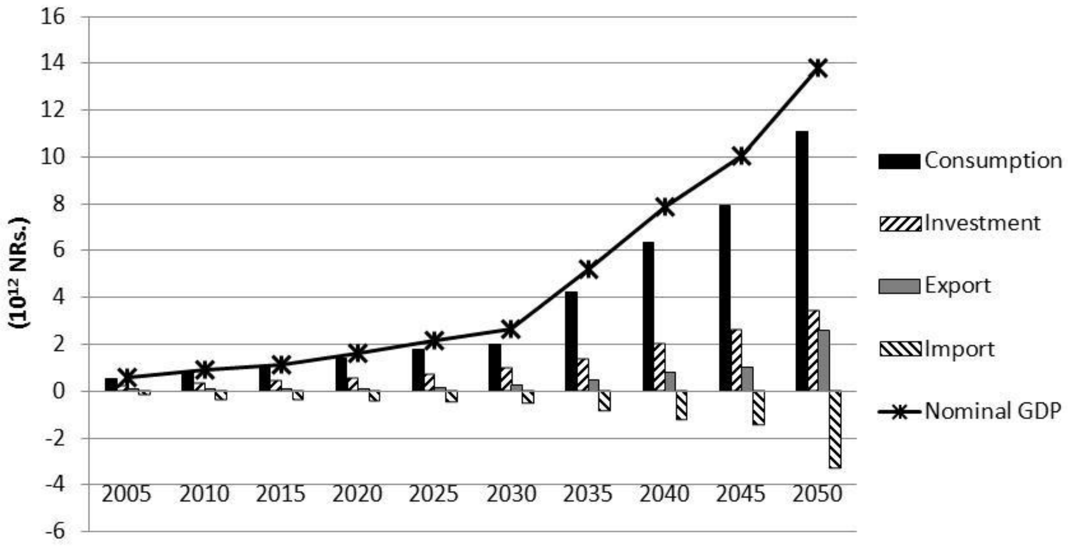


Figure 8.1: Share of electric transport system in the total road transport demand during 2005 to 2050

In addition, other three scenarios were developed for analyzing the effect of foreign direct investment by exogenously introducing foreign capital consisting of 25%, 50% and 100% of additional investment required under 30% transport electrification (EMT30) scenario as compared to the base case during 2020 to 2050.

8.2 Analysis of the Base Case Scenario

This section discusses the evolution of economic growth, GDP distribution, energy intensity, emission intensity of the country during the period 2005 and 2050. In order to study the macroeconomic implications of the transport electrification policy in Nepal, a reference plausible baseline path of economic development, energy consumption and GHG emissions has been established under the CGE-frame work during the study horizon. Following the procedures as mentioned above, the nominal GDP of Nepal is estimated to grow at an annual compounding growth rate (ACGR) of 7.19% from NRs. 0.60 trillion in the base year 2005 to NRs. 13.80 trillion by 2050 as shown in Figure 8.2. The share of consumption demand from household and government, fixed investment demand, export and import of commodities as the percentage of GDP would change during the study periods as shown in Table 8.1. The consumption demand accounts for the major share (over 76%) in the national GDP during 2005 to 2050. The contribution of investment demand in GDP lies between 24.7% to 36.5% during 2005 – 2050, while that of the trade deficit as percentage of GDP is gradually decreased from 16.2% in 2005 to 5.0% by 2050.



Note: trend line represent Nominal GDP growth path

Figure 8.2: Estimated GDP of Nepal under the base case scenario (BASE3) during 2005-2050

Table 8.1: The estimated macro-economic parameters of Nepal under the base case scenario for selected years

Parameter	2005	2020	2030	2040	2050
GDP (10^{12}NRs)	0.61	1.64	2.64	7.88	13.80
Consumption (% of GDP)	85.55	86.16	76.38	80.51	80.26
Investment (% of GDP)	30.65	32.78	36.49	25.07	24.75
Exports (% of GDP)	13.68	7.49	9.20	10.21	18.97
Imports (% of GDP)	29.87	26.43	22.07	15.78	23.98
Equivalent variation (welfare) [a]		0.05	0.42	0.89	1.09
Exchange Rate[b]	1.00	0.78	0.72	1.33	2.78

[a] Measured in terms of equivalent variation (EV) in income
[b] Measured in with reference to the base year value as 1.

The value of equivalent variation (EV) in income is estimated to increase significantly in later period indicating improvement in the national household welfare as compared to the base year condition. This indicates that real income of the national household relative to its income in the base year have increased during the study period. This can also be attributed to the estimated higher growth rates for GDP and private consumption (ACGR of 7.02% during 2005 to 2050) as compared to the growth rate of the population during the study periods (ACGR of 1.48% during the study period). The exchange rate would initially appreciate but depreciate after 2030.

The study shows that total gross output from production sectors of the country increases 21 folds from NRs. 0.97 trillion to NRs. 20.76 trillion (Table 8.2). There would be a major growth in the electricity sector (11.0%), service sector (7.3%) and agriculture sector (7.0%). The sectoral composition of national total gross output changes with major increase in the share of service sectors and electricity sector while there would be decrease in other sectors during 2005 to 2050.

Table 8.2: The share of sectoral gross output under the base case scenario

Sector	2005	2020	2030	2040	2050	ACGR[a]
Agriculture and Forestry (%)	26.40	27.56	26.65	29.23	25.62	6.98
Manufacturing (%)	24.89	19.81	18.20	12.00	18.11	6.30
Electricity (%)	1.96	5.61	7.02	8.16	10.18	11.04
Others[b] (%)	1.51	0.77	0.63	0.82	0.63	4.98
Transport (%)	10.76	8.23	7.93	7.85	7.33	6.14
Service (%)	34.49	38.02	39.57	41.95	38.13	7.29
Total gross output (10^{12} NRs)	0.97	2.27	3.39	10.32	20.76	7.05

[a] Annual compounding growth rate of the total gross output during 2005 to 2050 in %
[b] Other sectors consists of wood and lignite sectors

Table 8.3: Share of gross value added (capital and labor) by sector under the base case scenario

Sector	2005	2020	2030	2040	2050	ACGR[a]
Agriculture and Forestry (%)	33.21	32.97	32.17	33.69	31.13	7.12
Manufacturing (%)	14.91	10.54	8.09	5.93	6.60	5.34
Electricity (%)	2.03	5.90	7.22	6.40	8.89	10.85
Others[b] (%)	2.44	1.09	0.87	0.99	0.66	4.19
Transport (%)	4.16	5.20	6.65	7.88	9.07	9.15
Service (%)	43.26	44.29	45.00	45.10	43.64	7.29
Total gross value added (10^{12} NRs)	0.57	1.50	2.31	7.46	13.41	7.27

[a] Annual compounding growth rate of the total gross output during 2005 to 2050 in %
[b] Other sectors consists of wood and lignite sectors

Table 8.4 Energy and emission intensities under the base case during 2000-2050

Parameter	2005	2020	2030	2040	2050
Energy intensity (MJ/$10^3$2005NRs)	554.82	292.16	206.84	78.95	52.73
Electricity intensity (MJ/ $10^3$2005NRs)	15.37	30.42	19.85	8.59	10.19
GHG intensity (kg/ $10^3$2005NRs)	9.47	6.91	6.15	2.88	1.86
CO_2 intensity (kg / $10^3$2005NRs)	5.31	5.18	5.04	2.52	1.65
CH_4 intensity (kg / $10^3$2005NRs)	0.141	0.058	0.037	0.012	0.007
N_2O intensity (kg / $10^3$2005NRs)	0.0021	0.0010	0.0006	0.0002	0.0001

The findings show that the total gross value asses due to capital and labor employment grows by 22 times from NRs. 0.57 trillion to NRs. 13.41 trillion during 2005 to 2050. There would be a significant growth in the electricity sector (10.9%) and transport sector (9.1%). Service sector and agriculture sectors continue to dominate in the contribution of gross value added of the economy in the long run as shown in Table 8.3.

In the long run, the country's economy is expected to be oriented towards the service sectors. This is a reasonable trend that can be expected for a developing country like Nepal which is still in the phase of industrialization and commercialization. This is also reasonable in the sense that Nepal possesses numerous numbers of natural and historical sites for tourism development, and of course has huge hydropower resource yet to be exploited.

The study also shows that the country would proceed towards less energy and emission intensive economy in the long run as shown in the Table 8.4. The energy intensity of GDP would decrease significantly from 555 MJ/10^3 2005NRs to 53 MJ/10^3 2005NRs during 2005 to 2050. The electricity intensity of GDP would increase initially and decrease in the later period of the study period. The GHG emission intensity shows decreasing trend but not as fast as energy intensity. This is because, as the future energy consumption is expected to compose of considerable amount of carbon intensive fuel as cleaner and renewable energy resources are relatively more expensive. Besides, some renewable energy resource like fuel wood and municipal solid waste are available in limited amounts.

8.3 Macroeconomic effects of Transport Sector Electrification

A number of interesting questions arise: What would be the economic effects due to the electrification of the transport sector in the medium and long terms? How would it affect on the other production sectors? What would be the effects on the household welfare due to the policy? Will there be any Dutch disease effects under the policy? How would it change the energy intensity and GHG emission intensity of the economy? These issues are discussed in the following sections for five different scenarios of transport sector electrification.

8.3.1 Effects on Macroeconomic and Welfare Indicators

The study shows that an electrification of transport sectors would have positive effects on the national economy with increase in GDP of the country as compared to the base case. This change in the GDP is attributed to the change in the GDP distribution due to the reallocation of the factors of production, intermediate inputs among all domestic production sectors from supply side and change in the level of consumption and net trade in demand side. The percentage change in the GDP of transport electrification cases from the base case value lies in the range of 7.7% under EMT10 to 11.0% under EMT20+EV10 in 2030 (Table 8.5a). In 2050, there would be increase in GDP due to the transport electrification in the range of 1.3% under EMT20 to 4.5% under EMT30(Table 8.5b). This results is in agreement with other related studies by Chuanyi et al. (2010), Estache et al. (2008) and Gilbert and Banik (2010). Chuanyi et al. (2010) found that there would be increase in GDP when the scale of investment in energy sectors is increased in case of Shaanxi Province of China. Estache et al. (2008) found that investment in road and electricity infrastructures would increase GDP in case of 6 Sub Saharan African countries (Tanzania, Uganda, Senegal, Mali, Benin and Cameroon). Gilbert and Banik (2010) mentioned increase in GDP as investment flows in international land transport infrastructure in case of South Asian countries (Pakisthan, Bangladesh, India, Sri lanka and Nepal). The cumulative undiscounted real GDP at 2005 price during 2005 to 2050 would be 197.4 trillions in the base case (Figure 8.3a). There would be increase in the cumulative real GDP by 2.8% under EMT10, 2.6% under EMT20, and 3.1% under EMT30 as compared to the base case. In case of EMT20+EV10 and EMT20+EV15, the cumulative real GDP would increase by 2.9% and 2.5% respectively.

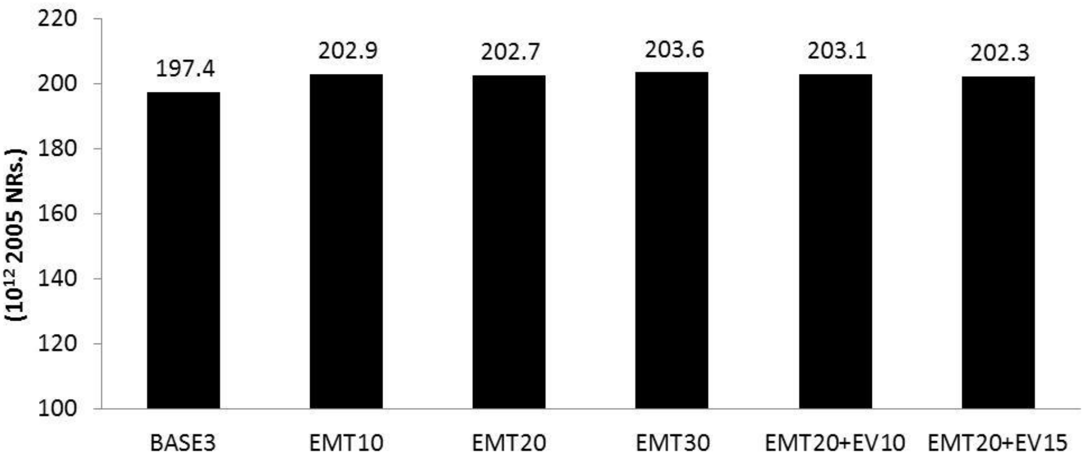


Figure 8.3a: Estimated cumulative undiscounted real GDP at 2005 price during 2005-2050

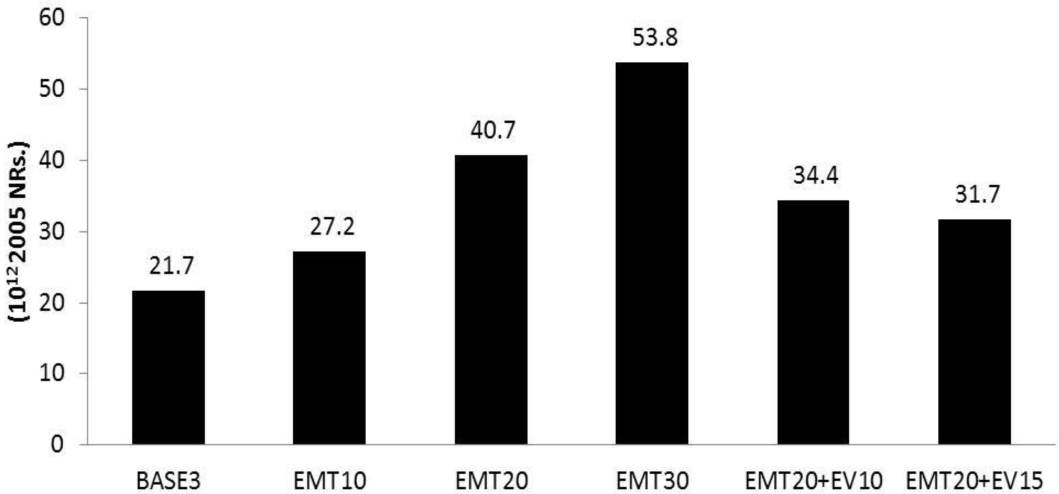


Figure 8.3b: Estimated cumulative household welfare during 2005-2050

The consumption would increase in the range of 10.1% under EMT10 to 14.2% under EMT20+EV10 in 2030 due to the transport sector electrification. In 2050, the increase in the level of consumption would be in the range of 0.6% under EMT10 to 4.3% under EMT30 as compared to the BASE3. Chuanyi et al. (2010) reported that there would be an increase in the household consumption when the scale of investment in energy sectors is increased. The investment does not increase under the transport electrification policy analysis as compared to the BASE3. For a comparative analysis, the gross investment of the base case is set as a lower level for the investment in the electrification scenarios.

Table 8.5a: Estimated macro-economic implications of transport electrification in 2030

Deviation from BASE3, %	EMT10	EMT20	EMT30	EMT20 +EV10	EMT20 +EV15
GDP	7.70	9.24	9.68	10.99	10.14
Consumption	10.11	12.35	12.80	14.16	13.37
Investment	0.00	0.00	0.00	0.00	0.00
Exports	5.05	4.96	0.82	(7.50)	(1.50)
Imports	2.20	2.93	0.76	(3.91)	(0.29)
Equivalent variation (welfare) [a]	24.34	3.33	(31.24)	(91.42)	(55.60)
Exchange Rate[b]	19.27	12.41	7.28	0.45	5.75

[a] The absolute value of equivalent variation (EV) in income under BASE3 is 0.42.
[b] The value of exchange rate in BASE3 is 1.91.
[c] Figure inside parenthesis indicates % decrease in value compared to the value in BASE3.

The volume of trade would increase in 2030 but would decrease in 2050 under all the transport electrification scenarios. The exchange rate would depreciate in 2030 but appreciate in 2050 under all the transport electrification scenarios as compared to the base case. This indicates the presence of Dutch disease effects under this policy with detrimental effects on other non-transport based export oriented industries in later period of the study. The detail effects are mentioned in the Section 8.3.2. Estache et al. (2008) found that investment in road and electricity infrastructures would decrease nominal exchange rate with slight Dutch disease effects (i.e., negative impact on the export sectors) in case of 6 Sub Saharan African countries. The household welfare would increase under EMT10 and EMT20 but decrease under other scenarios as compared to the BASE3 in 2030. However, in 2050 there would be increase in the household welfare under all transport electrification scenarios as compared to the base case. The cumulative household welfare during 2005 – 2050 would increase under all the transport electrification scenarios as shown in Figure 8.3b.

Table 8.5b: Estimated macro-economic implications of transport electrification in 2050

Deviation from BASE3, %	EMT10	EMT20	EMT30	EMT20 +EV10	EMT20 +EV15
GDP	1.73	2.96	4.52	3.80	2.60
Consumption	0.59	2.03	4.31	2.65	1.24
Investment	0.00	0.00	2.75	0.00	0.00
Exports	(44.77)	(49.07)	(6.69)	(64.51)	(61.52)
Imports	(40.66)	(44.35)	(6.88)	(58.00)	(55.34)
Equivalent variation (welfare)[a]	323.14	176.35	642.55	373.14	274.23
Exchange Rate[b]	(22.29)	(43.35)	(2.10)	(54.60)	(54.11)

[a] The absolute value of equivalent variation (EV) in income under BASE3 is 1.09.
[b] The value of exchange rate in BASE3 is 4.64.
[c] Figure inside parenthesis indicates % decrease in value compared to the value in BASE3.

The relative lower improvement in mixed electric mass transport plus electric vehicle based scenarios (EMT+EV) compared to electric mass transport based scenarios (EMT) is mostly due to the higher cost of household spending on privatly owned electric transportation facilities. Estache et al. (2008) found that investment in road and electricity infrastructures would increase household welfare in case of 6 Sub Saharan African countries. Gilbert and Banik (2010) mentions increase in household welfare as investment flows in international land transport infrastructure in case of five South Asian countries.

8.3.2 Effects on the Domestic Production Sectors and Trade of Commodities

a) Impacts on Gross Output of Domestic Production Sectors

The study shows that the gross production outputs would increase under all scenarios of transport electrification as compared to the base case in 2030 (Table 8.6a). In 2050, there would be decrease in the gross production outputs in the range of 0.9% under EMT20+EV10 and 5.3% under EMT20+EV15 except in case of EMT30 where it increases by 6.1% as compared to the base case (Table 8.6b). There would be a major shift of resources from other sectors to the transport sector to achieve the stated level of electrification in the transport sector.

Table 8.6a: Estimated effects of transport electrification on gross domestic output in 2030, %

Deviation from BASE3[a], %	EMT10	EMT20	EMT30	EMT20 +EV10	EMT20 +EV15
Agriculture and Forestry	33.60	9.14	8.93	0.90	4.14
- Manufacturing	4.48	(12.50)	(13.49)	(22.60)	(18.38)
- Electricity	35.21	42.17	37.02	65.57	60.53
- Others	25.04	88.15	88.11	108.53	101.97
Transport	111.11	105.69	109.19	113.47	112.90
Service	33.34	7.79	7.49	9.10	8.62
Total gross output (10^{12} NRs)[b]	34.40	15.14	14.70	14.01	15.01

[a] Figure inside parenthesis indicates % decrease in value compared to the value in BASE3.
[b] Total gross output value in monetary term in BASE3 is 3.39 10^{12} NRs.

Table 8.6b: Estimated effects of transport electrification on gross domestic output in 2050, %

Deviation from BASE3[a], %	EMT10	EMT20	EMT30	EMT20 +EV10	EMT20 +EV15
Agriculture and Forestry	(16.20)	(28.42)	(3.98)	(37.15)	(28.07)
Manufacturing	(34.28)	(61.67)	(20.85)	(72.20)	(70.41)
Electricity	(47.38)	9.15	(36.90)	17.98	(7.63)
Others	0.44	20.86	8.22	31.52	24.77
Transport	167.26	231.92	238.89	307.30	244.23
Service	(3.39)	(4.41)	(7.63)	(7.45)	(6.88)
Total gross output (10^{12} NRs) [b]	(4.20)	(2.06)	6.11	(0.87)	(5.27)

[a] Figure inside parenthesis indicates % decrease in value compared to the value in BASE3.
[b] Total gross output value in monetary term in BASE3 is 20.76 10^{12} NRs.

b) Impacts on Gross Value Added (Capital and Labor) by Production Sectors

The study shows that the gross value added would rise under all transport electrification scenarios as compared to the base case (Table 8.7a). In 2050, the gross value added would increase under EMT30, while it nominally decreases under other transport electrification scenarios as compared to the base case. The transport, electricity and service sectors would experience increase in the gross value added under all transport electrification scenarios in 2030. In 2050, only transport sector would experience increase in gross value add under all transport electrification scenarios compared to BASE3 as shown in Table 8.7b. The capital investment at 2005 price in the transport and electricity sectors would increase under all the transport electrification scenarios as compared to the BASE3 in 2030 and 2050 as shown in Figure 8.4. This indicates the additional new capital investment would divert mostly to the transport and elecicity sectors under all the transport electrification scenarios as compared to the base case.

Table 8.7a: Estimated effects of transport electrification on Gross Value Added in 2030, %

Deviation from BASE3[a], %	EMT10	EMT10	EMT30	EMT20 +EV10	EMT20 +EV15
Agriculture and Forestry	34.97	1.88	2.17	(4.86)	(2.76)
Manufacturing	6.17	12.83	10.47	(0.97)	2.62
Electricity	33.89	19.07	18.18	45.80	37.87
Others	24.88	68.84	58.94	94.95	71.36
Transport	114.41	90.07	100.16	114.52	111.98
Service	34.37	2.57	2.75	5.56	4.04
Gross Value Added (10^{12} NRs) [b]	37.49	10.77	11.28	12.66	11.99

[a] Figure inside parenthesis indicates % decrease in value compared to the value in BASE3.
[b] Total Gross Value Added in monetary term in BASE3 is 2.31 10^{12} NRs.

Table 8.7b: Estimated effects of transport electrification on Gross Value Added in 2050, %

Deviation from BASE3[a], %	EMT10	EMT10	EMT30	EMT20 +EV10	EMT20 +EV15
Agriculture and Forestry	(12.86)	(29.73)	(9.49)	(36.14)	(28.41)
Manufacturing	(23.60)	(48.35)	(5.88)	(82.15)	(72.66)
Electricity	(39.13)	13.96	(35.31)	4.68	(2.65)
Others (%)	(6.35)	3.34	(24.86)	37.63	13.29
Transport	104.80	141.19	165.11	189.06	168.06
Service	(0.96)	(5.64)	(13.46)	(4.98)	(6.76)
Gross Value Added (10^{12} NRs) [b]	(0.05)	(0.82)	2.41	(1.03)	(1.49)

[a] Figure inside parenthesis indicates % decrease in value compared to the value in BASE3.
[b] Total Gross Value Added in monetary term in BASE3 is 13.41 10^{12} NRs.

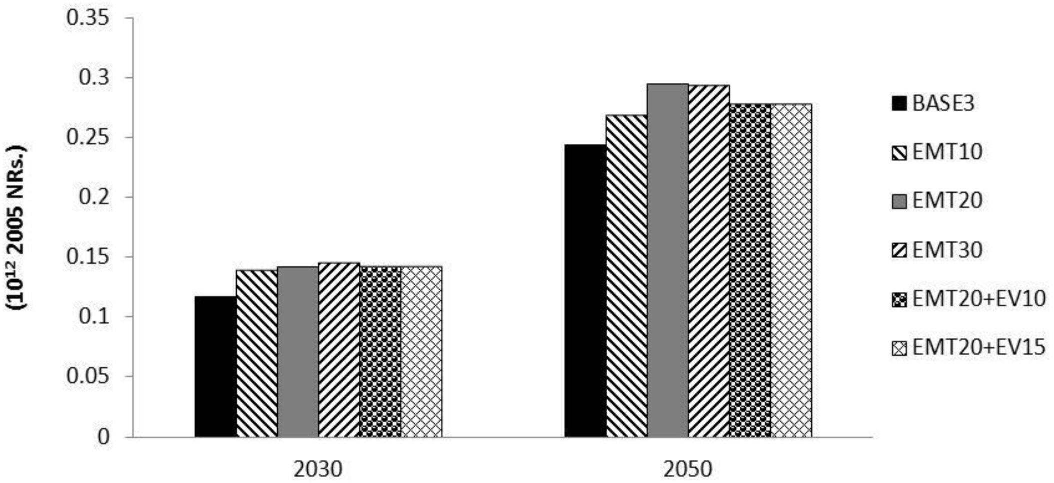


Figure 8.4: Estimated capital investment in transport and electricity sectors

c) Impacts on Imports of Individual Goods and Services

The total import of commodities decrease under EMT20+EV10 and EMT20+EV15, while in other transport electrification scenarios it would increase. Import of manufacturing based commodities decrease under EMT30, EMT20+EV10 and EMT20+EV15, import of commercial service under EMT30 and fossil fuel under EMT10 in 2030 as compared to BASE3 (Table 8.8a). In 2050, there would be decrease in the import of most of the commodities except, agriculture and foresrtry based commodities under fossil fuels under EMT10 and EMT30 and increase under other transport electrification scenarios as compared to BASE3. However, there would be decrease in the import of all the commodities under all the scenarios except agriculture and forestry based commodities under EMT30, EMT20+EV10 and EMT20+EV15, non-competitive intermediate input products under EMT20 and EMT30 as compared to the BASE3(Table 8.8b).

Table 8.8a: Estimated effects of transport electrification on commodity imports in 2030, %

Deviation from BASE3[a], %	EMT10	EMT20	EMT30	EMT20 +EV10	EMT20 +EV15
Agriculture and Forestry	12.10	37.15	29.58	15.55	25.38
Manufacturing	1.39	(10.60)	(10.12)	(16.65)	(14.06)
Electricity	2.94	12.41	7.28	0.45	5.75
Transport	2.94	12.17	7.05	1.99	7.37
Service	2.89	11.00	5.93	(4.58)	0.46
Imported fossil fuels [b]	(0.62)	65.28	53.62	71.05	75.46
Others [c]	5.45	13.49	7.96	0.57	6.54
Total commodity import [d]	2.20	2.93	0.76	(3.91)	(0.29)

[a] Figure inside parenthesis indicates % decrease in value compared to the value in BASE3.
[b] Imported petroleum products consist of gasoline, diesel, aviation turbine fuel, kerosene, LPG and coal.
[c] Others include non-competitive imported intermediate input in the production sectors.
[d] Total commodity import in monetary term in BASE3 is 0.58 10^{12} NRs.

Table 8.8b: Estimated effects of transport electrification on commodity imports in 2050, %

Deviation from BASE[a], %	EMT10	EMT20	EMT30	EMT20 +EV10	EMT20 +EV15
Agriculture and Forestry	(10.21)	33.26	110.92	29.89	47.62
Manufacturing	(41.52)	(49.60)	(8.46)	(62.22)	(59.18)
Electricity	(43.16)	(43.35)	(2.10)	(54.60)	(54.11)
Transport	(79.98)	(80.09)	(65.59)	(83.76)	(83.59)
Service	(43.19)	(44.11)	(3.42)	(56.98)	(56.52)
Imported fossil fuels [b]	(34.74)	(27.35)	(38.94)	(51.95)	(57.71)
Others [c]	(34.54)	(32.05)	4.80	(49.82)	(47.13)
Total commodity import [d]	(40.66)	(44.35)	(6.88)	(58.00)	(55.34)

[a] Figure inside parenthesis indicates % decrease in value compared to the value in BASE3.
[b] Imported petroleum products consist of gasoline, diesel, aviation turbine fuel, kerosene, LPG and coal.
[c] Others include non-competitive imported intermediate input in the production sectors.
[d] Total commodity import in monetary term in BASE3 is 3.31 10^{12} NRs.

d) Impacts on Exports of Individual Goods and Services

There would be increase in the export of all commodities except agriculture and forestry sector and service sector under all the scenarios as compared to the base case in 2030 (Table 8.9a). There would be decrease in the export of agriculture and forestry based commodities under all transport electrification scenarios except EMT10 and decrease in export of transport service under EMT30, EMT20+EV10 and EMT20+EV15 as compared to BASE3 in 2030. However, in 2050 there would be decrease in the export of commodities from agriculture and forestry, manufacturing and service sectors and increase in the export of electricity and transport based industries (Table 8.9b). As agriculture and forestry and manufacturing sectors are the major export oriented industries in the country, decrease in the export of these industries indicates the presence of Dutch Disease effects in the later period of the study due to the transport electrification policy. This is also supported by the appreciation of the exchange rate under transport electrification scenarios as compared to the base case as discussed under the Section 8.3.1.

Table 8.9a: Estimated effects of transport electrification on export of commodities in 2030, %

Deviation from BASE3[a], %	EMT10	EMT20	EMT30	EMT20 +EV10	EMT20 +EV15
Agriculture and Forestry	(1.59)	(4.62)	(10.63)	(25.16)	(15.70)
Manufacturing	2.94	12.51	7.37	0.54	5.85
Electricity	1.30	1.27	0.11	1.10	3.04
Transport	26.77	17.36	12.70	0.11	8.60
Service	0.15	(3.37)	(8.86)	(24.36)	(15.75)
Total commodity export[b]	5.05	4.96	0.82	(7.50)	(1.50)

[a] Figure inside parenthesis indicates % decrease in value compared to the value in BASE3.
[b] Total commodity export in monetary term in BASE3 is 0.24 10^{12} NRs.

Tabe 8.9b: Estimated effects of transport electrification on export of commodities in 2050, %

Deviation from BASE3[a], %	EMT10	EMT20	EMT30	EMT20 +EV10	EMT20 +EV15
Agriculture and Forestry	(56.86)	(59.05)	(21.21)	(73.97)	(70.67)
Manufacturing	(62.23)	(66.82)	(28.75)	(76.45)	(76.86)
Electricity	23.80	22.33	(4.53)	18.86	22.24
Transport	57.58	50.04	180.80	0.34	12.43
Service	(56.40)	(61.11)	(22.27)	(75.52)	(72.21)
Total commodity export[b]	(44.77)	(49.07)	(6.69)	(64.51)	(61.52)

[a] Figure inside parenthesis indicates % decrease in value compared to the value in BASE3.
[b] Total commodity export in monetary term in BASE3 is 2.62 10^{12} NRs.

8.3.3 Effects on Energy Consumption and Environment

There would be nominal increase in the energy consumption under EMT10 and EMT20+EV15 and decrease under all other transport electrification scenarios as compared to the base case in 2030. However, the energy intensity and electricity intensity decreases significantly under all the scenarios as compared to the base case in 2030 (Table 8.10a). In 2050, both total energy consumption and energy intensity would decrease indicating improvement in the energy efficiency of the economy under transport electrification policy (Table 8.10b). The share of fossil fuel would decrease under all scenarios except EMT10 and EMT20+EV15 as compared to the BASE3. The average energy intensity of GDP during 2005 to 2050 would be 237.2 MJ/$10^3$2005 NRs under the base case (Figure 8.5). The value of average energy intensity of GDP would be decreased by 3.8% under EMT10, 4.1% under EMT20 and 3.1% under EMT30. In case of EMT20+EV10 and EMT20+EV15, the average energy intensity would decrease by 2.7% and 3.1% respectively.

Table 8.10a: Change in estimated energy consumption and energy intensity in 2030

Parameter	BASE3	EMT10	EMT20	EMT30	EMT20 +EV10	EMT20 +EV15
Total Final Energy Consumption (TFEC) (PJ)	539.43	536.10	539.16	520.03	538.51	548.69
Electricity share in TFEC (%)	9.60	9.66	9.61	10.03	10.24	10.00
Fossil fuel share in TFEC (%)	32.69	32.27	32.41	29.85	31.71	33.02
Biomass fuel share in TFEC (%)	57.71	58.07	57.98	60.11	58.05	56.97
Electricity intensity (MJ/10^3 2005 NRs)	19.85	15.08	18.07	18.19	19.22	19.13
Energy intensity (MJ/10^3 2005 NRs)	206.84	156.07	187.94	181.27	187.71	191.26

Table 8.10b: Change in estimated energy consumption and energy intensity in 2050

Parameter	BASE3	EMT10	EMT20	EMT30	EMT20 +EV10	EMT20 +EV15
Total Final Energy Consumption (TFEC) (PJ)	753.13	734.47	542.58	629.67	577.34	579.64
Electricity share in TFEC (%)	19.32	17.06	18.31	22.22	14.52	15.52
Fossil fuel share in TFEC (%)	39.34	40.56	39.24	28.34	31.56	30.78
Biomass fuel share in TFEC (%)	41.34	42.39	42.45	49.45	53.92	53.70
Electricity intensity (MJ/10^3 2005 NRs)	10.19	8.70	6.87	9.40	5.78	6.27
Energy intensity (MJ/103 2005 NRs)	52.73	50.99	37.53	42.29	39.82	40.41

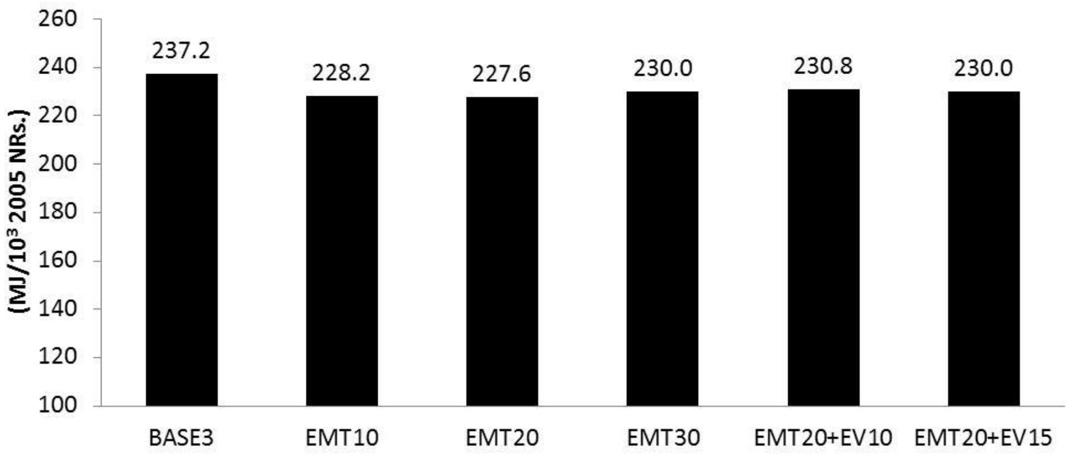


Figure 8.5: Estimated average energy intensity of GDP during 2005-2050

There would be a significant decrease in the total GHG emission under all the transport electrification scenarios except negligible increase under EMT20+EV15 in 2030. However, GHG intensity decreases in all the transport electrification scenarios as compared to BASE3. In 2050, Total GHG emission and GHG emission intensity under all the scenarios as compared to BASE3 (Table 8.11b). The average GHG intensity during the study period would be 6.12 kg CO2e/ $10^3$2005 NRs under BASE3 (Figure 8.6). The average GHG intensity would be decreased by 4.7% under EMT10, 5.3% under EMT20 and 7.1% under EMT30. The average GHG intensity would decrease by 6.9% and 7.7% under EMT20+EV10 and EMT20+EV15 respectively. This indicates transport electrification policy could be one of the effective tools to pursue low carbon development path in the country.

Table 8.11a: Change in estimated GHG emission in Nepal in 2030

Parameter	BASE3	EMT10	EMT20	EMT30	EMT20 +EV10	EMT20 +EV15
GHG emission (10^3 tons)	16029	15652	15817	13878	15043	16076
CO_2 intensity (kg / $10^3$2005 NRs)	5.04	3.72	4.51	3.84	4.24	4.61
CH_4 intensity (kg / $10^3$2005 NRs)	0.037	0.028	0.033	0.033	0.033	0.033
N_2O intensity (kg / $10^3$2005 NRs)	0.0006	0.0005	0.0006	0.0006	0.0006	0.0006
GHG intensity (kg/$10^3$2005 NRs)	6.15	4.56	5.51	4.84	5.24	5.60

Table 8.11b: Change in estimated GHG emission in Nepal in 2050

Parameter	BASE3	EMT10	EMT20	EMT30	EMT20 +EV10	EMT20 +EV15
GHG emission (103 tons)	26623	26718	17717	15842	16115	15809
CO2 intensity (kg / $10^3$2005 NRs)	1.65	1.65	1.07	0.87	0.91	0.90
CH4 intensity (kg / $10^3$2005 NRs)	0.007	0.007	0.005	0.006	0.007	0.007
N2O intensity (kg / $10^3$2005 NRs)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
GHG intensity (kg/$10^3$2005 NRs)	1.86	1.85	1.23	1.06	1.11	1.10

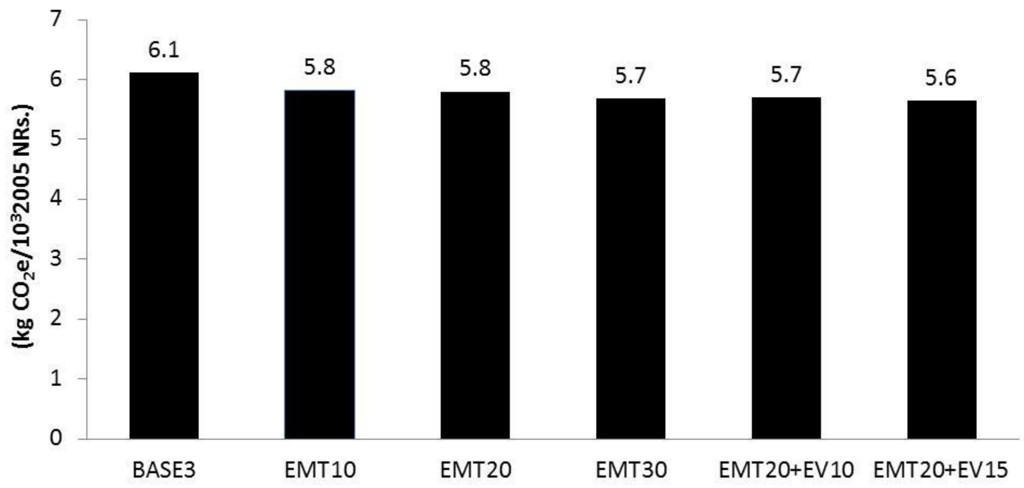


Figure 8.6: Estimated average GHG intensity of GDP during 2005-2050

8.4 Effects of Foreign Direct Investment

The role of foreign direct investment is very crucial to the economic development of developing country, due to their limited domestic possession and access to the much needed capital. The electrification of transport sector is expected to required significant amount of capital investment mostly in the transport and electricity sectors. However, there might be negative effects associated with the flow of foreign investment in the national economy (Ahmed and O'Donoghue, 2010; Barry, 2009; Dhungel,1996; Kyophilavong and Toyoda ,2008). Ahmed and O'Donoghue (2010) analysed the effects of foreign investment growth in the form of increase in the level of exogenous foreign saving. This would, however, not reflect the actual flow of foreign direct investment in the national economy as total capital accumulation is owned by the national household and there is no direct role of foreign institution in the ownership of total capital formation in the national CGE model. Besides, additional capital accumulation from the increase in the foreign saving comes at the cost of forced increment in the negative trade balance (i.e., increase in import and decrease in export to compensate additional amount of foreign saving). In order to investigate the effects of FDI more accurately, a global economic model with the country under study as sub-region is required with provision of substitution between domestic capital and foreign capital. As the present study use national economic model without global market interaction, endogenous introduction of FDI is not possible. Here, the effect of FDI is investigated indirectly by exogenously introducing new additional capital which is owned by the foreign institution. Government would charge income tax on the earning from FDI to the foreign institution. The introduction of the FDI in the model is carried out by modifying the equations for capital market clearance (Equation 7.141), current account balance (7.133), and government revenue (7.118).

$$\overline{CTOT} + CFDI = \sum_i C_i \qquad (7.141B)$$

Where:

$\overline{CTOT}$ = total capital supply

C_i = capital demand in sector i

CFDI = capital investment from foreign direct investment

$$FSAV = \left[pmp_{cm}\,.\,MP_{cm} - pxp_{cm}\,.\,EXP_{cm} - trgrw - trhhw\right].\,ER + CFDI.PC.(1-th)$$

(7.133B)

Where,
trgrw = net foreign transfer to government from RoW
trhhw = net foreign transfer to household from RoW

EXP_{cm} = export of commodity cm to ROW

MP_{cm} = import of commodity cm to ROW

pmp_{cm} = World market price in foreign currency of commodity cm imported from RoW
pxp_{cm} = World market price in foreign currency of commodity cm imported from RoW

PC = price of capital

$$IG = TTAX + (trgw - trwg) + th.\,CFDI.PC \qquad (7.118B)$$

Where:
TTAX = total tax revenue
trgw = foreign aid and other financial transfer to government from ROW
trwg = financial transfer to ROW from government

Here three scenarios are considered for analyzing the effects of FDI under selected transport electrification scenario, i.e., EMT30, as follows:

i) Introduction of FDI capital equal to 25% of the additional investment required in the transport and electricity sectors under EMT30 as compared to the base case (Here after "FDI25").

ii) An addition of FDI equal to 50% of the additional investment required under EMT30 as compared to the base case (Here after "FDI50").

iii) Introduction of FDI equal to 100% of the increase in the additional investment required under EMT30 (Here after "FDI100").

8.4.1 Effects on Macroeconomic Indicators

The study shows that increasing the level of FDI would increase GDP in the range of 6.26% under FDI100 to 6.97% under FDI25 as compared to the EMT30 in 2030 as shown in the Table 8.12. However, in 2050, there would be nominal increase by 0.14% under FDI25, 0.64% under FDI100 and a decrease by 0.04% under FDI50. The cumulative undiscounted real GDP at 2005 price during 2005 to 2050 would increase 5.6% under FDI25, 9.8% under FDI50 and 11.0% under FDI100 as compared to EMT30 without FDI (Figure 8.7a). Dhungel (1996) mentioned that there would be an increase in GDP due to flow of FDI during development of hydropower projects (Itaipu and Yacyreta) in Paraguay. Similar results have been reported by Kyophilavong and Toyoda (2008) for Lao PDR with an increase in GDP due to foreign capital inflow in the mining and hydropower sectors.

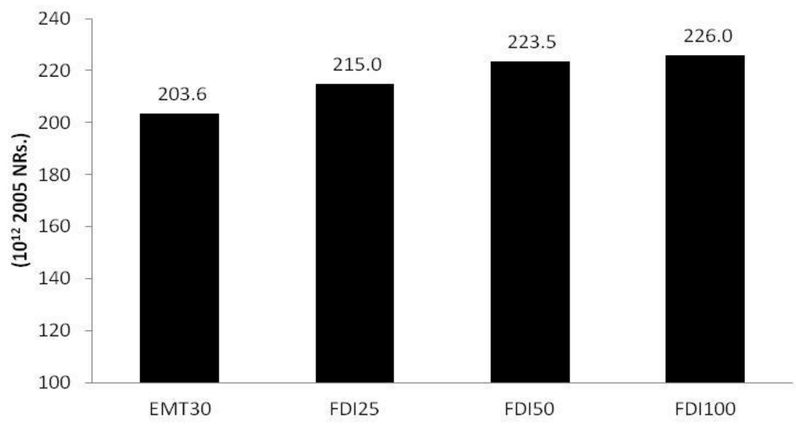


Figure 8.7a: Estimated cumulative undiscounted real GDP at 2005 price during 2005-2050

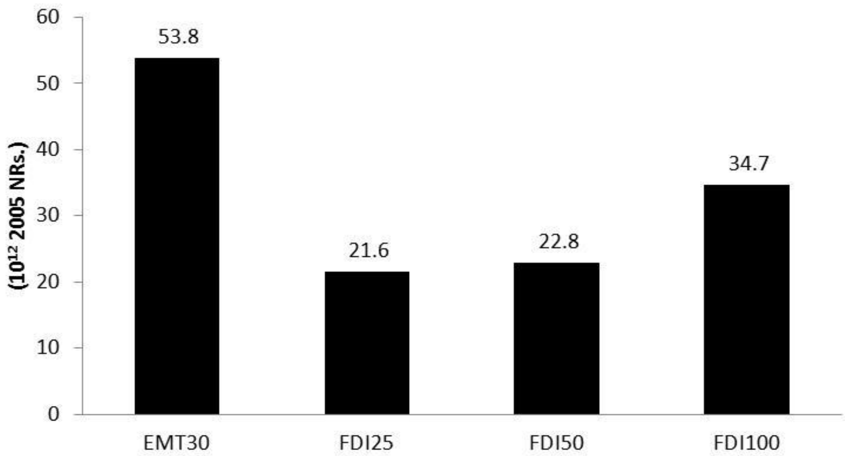


Figure 8.7b: Estimated cumulative household welfare during 2005-2050

Table 8.12: Estimated macro-economic implications of foreign direct investment

Deviation from EMT30[a], %	2030			2050		
	FDI25	FDI50	FDI100	FDI25	FDI50	FDI100
GDP	6.97	5.32	6.26	0.14	(0.04)	0.64
- Consumption	7.59	4.81	3.35	(0.05)	(0.09)	0.22
- Investments	2.21	4.42	8.84	0.36	0.73	1.45
- Exports	24.34	56.11	58.68	(4.92)	5.96	25.18
- Imports	8.80	23.07	21.08	(4.33)	5.40	19.46
Equivalent variation (welfare) [b]	(52.48)	(96.79)	(61.30)	(59.00)	(99.74)	(78.99)
Exchange rate [c]	15.11	40.43	29.96	0.95	18.00	19.52

[a] Figure inside parenthesis indicates % decrease in value compared to the value in EMT30.
[b] The value of equivalent variation (EV) in income under EMT30 is 0.29 in 2030 and 8.08 in 2050.
[c] The value of exchange rate under EMT30 is 0.78 in 2030 and 2.72 in 2050.

The consumption and investment would increase under all scenarios as compared to BASE3 in 2030. In 2050, the scale of change in consumption is below 1%. However the role of investment becomes dominant with respect to the scale of FDI increment. The national economy changes from consumption based economy to investment based economy. The volume of trade increases under all the scenarios in 2030. However in 2050, there would be decrease in volume of trade under FDI25 and increase under FDI50 and FDI100. Household welfare would decrease under all the FDI scenarios as compared to EMT30 in 2050. The cumulative household welfare during 2005 – 2050 would decrease under all the FDI scenarios as shown in Figure 8.7b. This indicates increasing the role of FDI in the economy may not necessarily improve the welfare of the national household. The exchange rate depreciates unser all scenarios as compared to EMT30 in 2030 and 2050 as shown in Table 8.12.

8.4.2 Effects on the Domestic Production Sectors and Trade

a) Impacts on Gross Sectoral Production

There would be increase in the gross output under all the FDI scenarios in the range of 6.5% under FDI100 to 7.4% under FDI50 as compared to EMT30 in 2030. However, there would be a nominal decrease below 1% under FDI25 and FDI100 and a decrease by 4.3% under FDI50. Interestingly, agriculture and forestry, manufacturing and transport sectors would benefit most from FDI in 2030. In 2050, manufacture and transport would benefit from FDI as compared to scale of gross output under EMT30. This would change the level of export as discussed in the following section.

Table 8.13: Estimated effects of Foreign Direct Investment on sectoral output

Sector[a]	2030			2050		
	FDI25	FDI50	FDI100	FDI25	FDI50	FDI100
Agriculture and Forestry	7.4	5.0	7.3	(4.9)	(10.8)	(5.0)
Manufacturing (%)	22.1	45.9	42.8	(4.1)	14.0	34.8
Electricity (%)	(15.8)	(24.7)	(30.9)	19.7	(23.4)	(27.3)
Others (%)	(6.3)	(30.6)	(39.2)	(7.4)	(34.0)	(30.1)
Transport (%)	7.4	14.0	13.6	2.2	2.0	1.7
Service (%)	6.2	0.6	(0.6)	(2.1)	(7.7)	(7.5)
Total gross output (10^{12} NRs) [b]	6.9	7.4	6.5	(0.8)	(4.3)	(0.4)

[a] Sector wise deviations relative to the EMT30 (%).
[b] Total gross output value in monetary term under EMT30 is 3.88 10^{12} NRs in 2030 and 22.03 10^{12} NRs in 2050.

b) Impacts on Imports of Individual Goods and Services

There would be increase in the import of all commodities except fossil fuels under all FDI scenarios as compared to EMT30 in 2030. In 2050, there would be a significant increase in the import of all the commodities except the agriculture and forestry and manufacturing based commodities as compared that under EMT30 without FDI (Table 8.14).

Table 8.14: Estimated effects of FDI on commodity imports

	2030			2050		
Deviation from EMT30[a], %	FDI25	FDI50	FDI100	FDI25	FDI50	FDI100
Agriculture and Forestry	10.18	16.99	8.27	(45.37)	(44.89)	(44.18)
Manufacturing	19.15	28.32	28.06	(10.19)	(0.41)	18.31
Electricity	15.11	40.43	29.96	0.95	18.00	19.52
Transport	17.60	40.63	30.15	3.14	18.26	19.69
Service	16.85	42.57	31.94	2.59	19.91	21.46
Imported fossil fuels [b]	(43.67)	(31.94)	(25.94)	61.95	57.51	107.34
Others [c]	14.82	45.92	35.41	12.50	25.02	24.04
Total commodity import [d]	8.80	23.07	21.08	(4.33)	5.40	19.46

[a] Figure inside parenthesis indicates % decrease in value compared to the value in BASE3.
[b] Imported petroleum products consist of gasoline, diesel, aviation turbine fuel, kerosene, LPG and coal.
[c] Others include non-competitive imported intermediate input in the production sectors.
[d] Total commodity import in monetary term under EMT30 is 0.63 10^{12} NRs in 2030 and 2.61 10^{12} NRs in 2050.

c) Impacts on Exports of Individual Goods and Services

There would be an increase in the export of all commodities under all FDI scenarios as compared to EMT30 without FDI in 2030 (Table 8.15). However in 2050, there would be a decrease in the export of all the commodities under FDI25. Similarly in 2050, there would be decrease in the export of agriculture and forestry and electricity based commodities under FDI50 and a reduction in the export of electricity under FDI100 as compared to that in BASE3. This indicates increasing the level of FDI would help to improve negative effects on other non-transport export oriented industries (mainly, agriculture and forestry and manufacturing industries) due to transport electrification process. Or in other words FDI helps to reduce the Dutch disease effects observed under EMT30 by depreciating currency and increasing the volume of non-transport based commodities.

Table 8.15: Estimated effects of transport electrification on export of commodities, %

	2030			2050		
Deviation from EMT30[a], %	FDI25	FDI50	FDI100	FDI25	FDI50	FDI100
Agriculture and Forestry	42.87	90.52	107.14	(7.80)	(2.46)	9.47
Manufacturing	15.40	42.91	34.31	(4.47)	14.41	54.26
Electricity	12.47	25.82	26.41	(0.33)	(14.14)	(18.91)
Transport	29.76	65.20	76.17	(8.57)	0.31	22.31
Service	39.74	91.20	99.21	(2.21)	11.27	22.89
Total commodity export[b]	24.34	56.11	58.68	(4.92)	5.96	25.18

[a] Figure inside parenthesis indicates % decrease in value compared to the value in BASE3.
[b] Total commodity import in monetary term under EMT30 is 0.28 10^{12} NRs in 2030 and 2.02 10^{12} NRs in 2050.

8.4.3 Effects on the Energy Consumption and Environment

The study shows that foreign investment would result in a decrease in energy and GHG emission intensities of GDP under all FDI scenarios as compared to the BASE3 in

2030 (Table 8.16a and 8.17a). However, the energy and GHG emission intensities of GDP increase in all FDI scenarios in 2050 (Table 8.16b and 8.17b). The average energy intensity of GDP during 2005 to 2050 would be 230.7 MJ/$10^3$2005 NRs under EMT30 without FDI (Figure 8.8). The value of average energy intensity of GDP would be decreased by 3.7% under FDI25, 3.3% under FDI50 and 1.9% under FDI100. Similarly, the average GHG intensity during the study period would be 5.70 kg CO_2e/ $10^3$2005 NRs under EMT30 without FDI (Figure 8.9). The average GHG intensity would be decreased by 4.3% and 1.0% under FDI25 and FDI50, where as it would increase by 2.7% under FDI100.

Table 8.16a: Effects on estimated energy consumption and energy intensity due to Foreign Direct Investment in Nepal in 2030

Parameter	EMT30	FDI25	FDI50	FDI100
Total Final Energy Consumption (TFEC) (PJ)	520.03	479.67	492.70	529.63
Electricity share in TFEC (%)	10.03	10.65	11.16	10.38
Fossil fuel share in TFEC (%)	29.85	24.44	25.65	30.84
Biomass fuel share in TFEC (%)	60.11	64.90	63.19	58.78
Electricity intensity (MJ/$10^3$2005 NRs)	18.05	16.33	17.58	17.56
Energy intensity (MJ/$10^3$2005 NRs)	179.92	153.27	157.43	169.23

Table 8.16b: Effects on estimated energy consumption and energy intensity due to Foreign Direct Investment in Nepal in 2050

Parameter	EMT30	FDI25	FDI50	FDI100
Total Final Energy Consumption (TFEC) (PJ)	629.67	655.67	702.90	747.74
Electricity share in TFEC (%)	22.22	20.21	20.94	21.85
Fossil fuel share in TFEC (%)	28.34	32.31	34.78	42.96
Biomass fuel share in TFEC (%)	49.45	47.48	44.28	35.18
Electricity intensity (MJ/$10^3$2005 NRs)	9.70	8.90	9.87	10.91
Energy intensity (MJ/$10^3$2005 NRs)	43.67	44.02	47.13	49.93

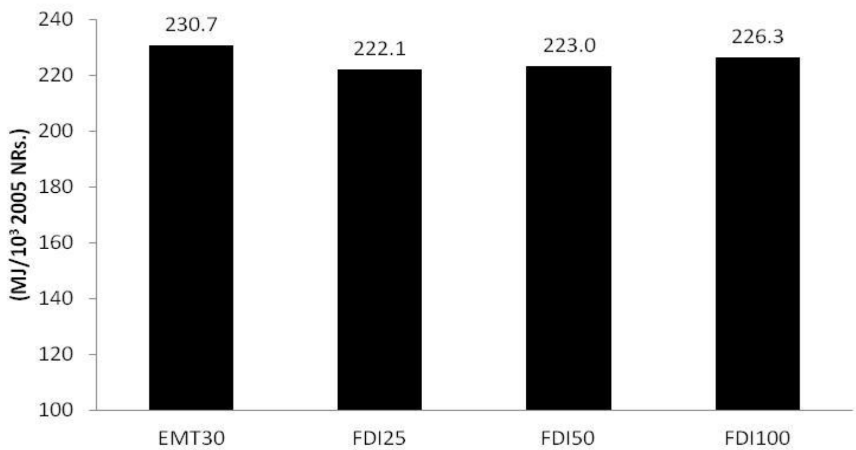


Figure 8.8: Estimated average energy intensity of GDP during 2005-2050

Table 8.17a: Change in estimated GHG emission due to Foreign Direct Investment in Nepal in 2030

Parameter	EMT30	FDI25	FDI50	FDI100
GHG emission (10^3 tons)	13878	11453	12222	14954
CO_2 intensity (kg / $10^3$2005 NRs)	3.84	2.75	3.00	3.87
CH_4 intensity (kg / $10^3$2005 NRs)	0.033	0.030	0.030	0.030
N_2O intensity (kg / $10^3$2005 NRs)	0.0006	0.0005	0.0005	0.0005
GHG intensity (kg/$10^3$2005 NRs)	4.84	3.66	3.91	4.78

Table 8.17b: Change in estimated GHG emission due to Foreign Direct Investment in Nepal in 2030

Parameter	EMT30	FDI25	FDI50	FDI100
GHG emission (10^3 tons)	15842	18869	22315	29178
CO_2 intensity (kg / $10^3$2005 NRs)	0.87	1.07	1.30	1.78
CH_4 intensity (kg / $10^3$2005 NRs)	0.006	0.006	0.006	0.005
N_2O intensity (kg / $10^3$2005 NRs)	0.0001	0.0001	0.0001	0.0001
GHG intensity (kg/$10^3$2005 NRs)	1.06	1.27	1.50	1.95

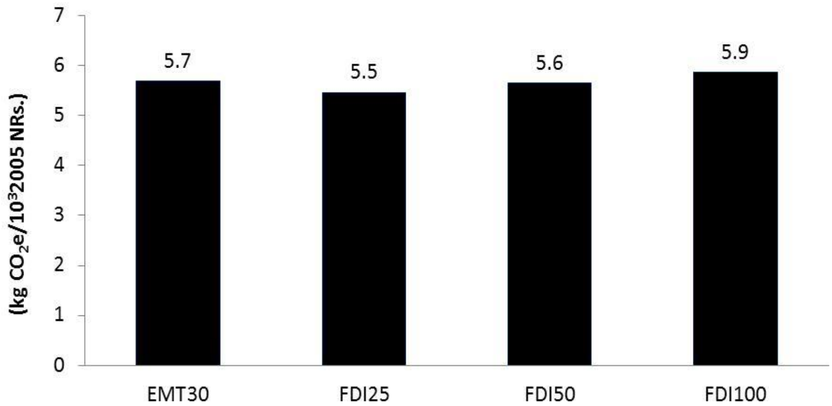


Figure 8.9: Estimated average GHG intensity of GDP during 2005-2050

8.5 Sensitivity Analyses

The effect of transport sector electrification is expected to results changes in the production composition of intermediate inputs and value additions. It results shifting of the factors of production (capital and labor) among transport sectors and non-transport sectors and the change on the consumption of transport services and other non-transport intermediate inputs due to change in their prices. As such, elasticity of substitution parameter of nested CES production function for intermediate inputs consisting of transport service inputs and other non-transport inputs are important parameters for determining the changes in their composition in the sectoral production after the application of transport electrification policy. In this study, sensitivity analysis has been carried out for elasticity of substitution for domestic intermediate inputs (consisting of transport services and non-transport intermediate inputs) "σ_{DMi}" by varying its value by 10% in both direction (i.e., ±10% from base year value).

In case of demand side, this policy is expected to change the composition of the consumption of aggregate transport and aggregate non-transport commodities nested by CES utility function due to the change in the transport service price. Considering this, sensitivity analysis has been done for elasticity of substitution between transport composite and non-transport composite household consumptions "σ_{HD}" with variation in the range of 10% deviation from initial value.

Table 8.18: Effects of variation in elasticity of substitution for domestic intermediate input "σ_{DMi}" in the production function in selected years

Deviation from BASE3 σ_{DMi}=0.5	2015		2030		2050	
	σ_{DMi} =0.45	σ_{DMi} =0.55	σ_{DMi} =0.45	σ_{DMi} =0.55	σ_{DMi} =0.45	σ_{DMi} =0.55
GDP (% change)	(0.28)	(0.21)	38.29	21.90	1.31	1.95
Energy Consumption (% change)	5.02	5.80	(5.18)	11.14	(9.14)	(11.79)
GHG Emission (% change)	18.16	21.49	(16.13)	36.33	(23.70)	(22.63)
Equivalent variation (welfare)[a]	0.06	0.06	0.28	0.40	2.22	2.94

[a] Measured in terms of equivalent variation (EV) in income as compared to the base year

The analysis shows the change in the value of the elasticity of substitution for domestic intermediate input "σ_{DMi}" in the production function would result moderate change in the macroeconomic, welfare parameters, energy and environment parameters (Table 8.18). Change in these parameters is comparatively smaller in 2015 1nd 2050 as compared to 2030.

Table 8.19: Effects of variation in elasticity of substitution between transport composite and non-transport composite household consumptions "σ_{HD}" in selected years

Deviation from BASE3 σ_{HD} =0.3	2015		2030		2050	
	σ_{HD} =0.27	σ_{HD} =0.33	σ_{HD} =0.27	σ_{HD} =0.33	σ_{HD} =0.27	σ_{HD} =0.33
GDP (% change)	(0.01)	(0.01)	25.27	26.59	1.66	1.94
Energy Consumption (% change)	5.08	(0.30)	21.36	3.75	17.20)	(6.03)
GHG Emission (% change)	18.09	(1.13)	30.92	5.84	(21.62)	(8.25)
Equivalent variation (welfare)[a]	0.06	0.06	0.74	0.31	2.82	2.42

[a] Measured in terms of equivalent variation (EV) in income as compared to the base year

The change in the value of elasticity of substitution between transport composite and non-transport composite household consumptions "σ_{HD}" would result moderate change in the macroeconomic, welfare parameters, energy and environment parameters. Change in these parameters is comparatively larger in 2030 compared to those in 2015 and 2050 (Table 8.19). This indicates that the results given by this study is subject to change if the value of elasticity is altered in the middle of the study period.

8.6 Conclusion and Policy Implications

The study in this chapter indicates that Nepal would benefit from the implementation of the transport sector electrification in the long run with an increase in GDP and household welfare in most of the transport electrification scenarios. Besides, the transport electrification would promote energy efficiency improvement and cleaner economic development with a significant reduction in the energy and greenhouse gas intensities of GDP. This highlights the importance of the transport sector electrification as one of the desirable options in achieving the low carbon development path in the country. It also indicates that the transport sector electrification would result in the appreciation of the national currency triggering reduction in the export of other non-transport and non-electricity related commodities produced in the country (i.e., the presence of Dutch disease kind of effect).

Altogether, five transport electrification scenarios were considered in the study. First three scenarios consist of a shift of 10% of the road transport demand to the electric mass transport system in 2020 and maintain at 10% (EMT10) till 2050, or gradually increase the shift to 20% (EMT20) and 30% (EMT30) by 2050. Two other scenarios consists of EMT20 with additional 5% shift of the demand to electric vehicles in 2015 and gradually increase in the shift of electric vehicles to 10% (EMT20+EV10) and 15% (EMT20+EV15) by 2050.

The study shows that GDP would increase in the range of 7.7% under EMT10 to 11% under EMT20+EV10 in 2030 as compared to the GDP in the base cases and it would increase in the range of 1.34% under EMT20 to 4.52% under EMT30 in 2050. The cumulative undiscounted real GDP at 2005 price during the study period would increase in the range of 2.5% under EMT20+EV15 to 3.1% under EMT30 as compared to the base case. The household welfare would increase under all the transport electrification scenarios with an increase in the value of the cumulative equivalent variation in income during 2005-2050.

The study shows that the national economy shifts towards the energy efficient path under the transport electrification policy with a decrease in energy intensity of GDP. The average energy intensity of GDP during 2005 to 2050 would be 237.2 MJ/$10^3$2005 NRs under the base case. The value of the average energy intensity would be decreased under all the transport electrification scenarios in the range of 2.7% under EMT20+EV10 to 4.1% under EMT20 as compared to the base case.

The study also indicates that the transport electrification policy would help the country to pursue a low carbon development path in the long run thus supporting the effective implementation of national climate change policy 2010. The average GHG intensity during the study period would be 6.12 kg CO_2e/ $10^3$2005 NRs under the base case. The average GHG intensity would be decreased in all the transport electrification scenarios in the range of 4.7% under EMT10 to 7.7% under EMT20+EV15 as compared to the base case value.

Interestingly, the analysis of this study shows that the transport electrification policy would results in the Dutch disease kind of effect in the later period as shown by the appreciation of the exchange rate and a decrease in the export of other non-transport and non-electricity related commodities produced in the country.

Introducing Foreign Direct Investment (FDI) to cover different share of the additional investment required in the transport and electricity sectors under 30% transport sector electrification (EMT30) scenario would increase the GDP. The cumulative undiscounted real GDP at 2005 price during 2005 to 2050 would increase in the range of 5.6% under FDI sharing 25% of additional investment in transport and electricity sectors (FDI25) to 11.0% under FDI sharing 100% of additional investment as compared to EMT30 without FDI. Interestingly, FDI helps to improve symptoms of

Dutch disease effects observed under EMT30 by increasing the export of non-transport commodities and depreciating the national currency. However, household welfare decreases under FDI scenarios.

Considering the above results, this study comes out with the recommendations for the national and international policy makers and related stakeholders as follows:

- Transport sector electrification program would be a promising option for fulfilling the objectives of the climate change policy, hydropower development policy and national transport policy of Nepal. The national policy makers should give special emphasis on the implementation of transport electrification program due to the multi-faceted benefits of its implementation. There is a need for studying the elaborate inter-relationship among the policies related to energy, climate change and transport so as to develop the effective and sustainable policy in an integrated framework in the long run.
- The government should create an enabling environment by developing and implementing effective policies to attract Foreign Direct Investment (FDI) as it would increase national economy growth and control Dutch disease effects observed under transport electrification policy. However, there is the need for studies of the additional mechanism to improve household welfare under increasing role of FDI (such as transferring the tax revenue from FDI to household).
- The study indicates that transport sector electrification in the country with substantial affordable renewable energy resources would be a promising option to mitigate global green house gas emissions and thus help to minimize the adverse effects of the global climate change in the long-run. As such international communities should support the renewable energy based transport sector electrification program in the developing country through the financial support (with allocation of different GHG mitigation funds under international cooperation) and the proper technology transfer.
- Successful implementation of the transport sector electrification and realization of its multi-faceted benefits depends on many factors. This study is focused on the macroeconomic effects in terms of GDP distribution, consumer welfare, energy intensity, GHG intensity only in this Chapter and energy system development, energy system costs, energy security, GHG and local pollutant emission in Chapter 5. Further studies on the transport electrification policy can be done in the issues not covered in this study, such as implications of incorporating different national and international financing mechanisms; effects of integration of the transport electrification policy with other policies; development of global model incorporating the country under study as a sub region for better understanding of effects of foreign direct investment etc.

Chapter 9

Macroeconomic Effects of Carbon Tax Policy

A justifiable accounting of the environmental externalities from the use of carbon intensive fossil fuels is a big challenge for the present world suffering from the impacts of climate change. Market pricing based environmental policy instrument like Carbon tax (C-tax) has been already used mostly in the developed countries to curb the unsustainable use of carbon intensive fuels and protect local and global environment. Most developed countries are well adapted to imposing such price based instruments due to the scale of their economy which can absorb any distortionary effects resulting from introduction of such taxes. However, in case of developing countries, where most of the population relies on these fossil fuels for sustaining the basic needs of their life, introduction of any new tax has to be well studied and understood from all aspects of the socio-economy to avoid negative effects on the livelihood of the major population. As such, if other benefits, relating to improvement in energy security, reeducation of environmental pollution, increase in the energy efficiency, possible recycling of the C-tax revenue to favor the socio-economic efficiency were considered, C-tax may be a promising tool to leapfrog from carbon-intensive conventional development path to Low Carbon Development (LCD) path.

This chapter is devoted to addressing the objective 4 of the present research work. It studies the macroeconomic consequences of introducing C-tax in Nepal on a long term basis. This study uses a multi-sector, single region, recursive dynamic computable general equilibrium model of Nepal (Nepal-CGE) with provision for imposing fuel and sector specific annual C-tax accounting for the study period. The study of the macroeconomic implications was focused to determine the structural change in GDP, national household welfare, energy intensity of GDP and emission intensity of GDP. The macro-economic implications of the recycling of the C-tax revenue to the national household was studied to address issues related to economic efficiency of the tax. Other effects in terms of energy system development, energy system costs, energy security, GHG and local pollutant emissions of the C-tax policy have been discussed in Chapter 6.

9.1 Modeling of the Carbon Tax Policy

This study used multi-sector, single region recursive dynamic general equilibrium model developed for Nepal to analyze the macroeconomic consequences of introducing C-tax to the carbon intensive fuels. A detail on the formulation for analyzing the C-tax policy was discussed in Chapter 7. The main difference in the development of the model for analyzing the C-tax policy from the one developed for analyzing the transport electrification policy (Chapter 8) lies in terms of the provision for the endogenous selection of technology level of demand of public passenger transport service, freight transport service, and privately owned vehicles. Another additional modification is the incorporation of additional C-tax in the price of the carbon intensive fuel based commodities in the country.

The analysis of C-tax policy was carried out by using the following procedure:

a) Firstly, the base case scenario was developed without any provision for imposing C-tax.
b) The base case was run to obtain the overview of the overall economy of the country in terms of sectoral GDP distribution, household welfare, energy intensity and emission intensity etc.
c) Different levels of C-tax were introduced in three different counter factual scenarios followed by running of the scenarios.
d) The analysis was carried out by comparison and interpretation of the results from the base case and counterfactual scenarios (C-tax scenarios) to determine the macroeconomic implications in terms of sectoral GDP distribution, household welfare, energy intensity and emission intensity.
e) Then effect of government transfer of C-tax revenue to the national household was analysed by adopting the lump-sum government transfer of the tax revenue to the household.

Altogether, four scenarios were considered for analyzing macroeconomic effects of introducing C-tax in the country. They are as follows:

(i) Base case: The base case scenario (BASE4 hereafter) is considered as the reference case without any environment or energy policy restrictions on GHGs emission. The assumptions are the same as in the base case (BASE3) of Chapter 8 (for analyzing the effects of transport sector electrification). BASE4 also consider the availability of electric railway from 2020. The railway based electrified mass transport (EMT) is assumed to serve 10% of land transport demand in 2020 and gradually increases to 20% by 2050 to reflect the recent government plan of introducing electric railway system in the country (RITES/SILT, 2010). Further, non-fossil fuel based transport options including full-electric, hybrid with battery storage and fuel cell technology based vehicles are also made available in BASE2. Among the electric vehicle (EV), the hybrid and full-electric options are made available from 2015 and the fuel cell vehicle options are made available from 2020 only. All other assumptions including the future labor factor growth, the future total capital factor, AEEI, etc. are the same as given in Chapter 8. The level of the annual total gross investment was varied iteratively to maintain the level of annual total energy consumption as close to the one obtained from the Nepal-ESM model based analysis on C-tax (Chapter 6).

(ii) CT-LOW: introduction of carbon tax starts at US\$ 3/tCO_2e in 2015 which would gradually increase to US\$ 20/tCO_2e by 2050. All other assumptions remaining the same as in the BASE4,

(iii) CT-MED: introduction of carbon tax starts at US\$ 13/tCO_2e in 2015 which would gradually increase to US\$ 100/tCO_2e by 2050, and

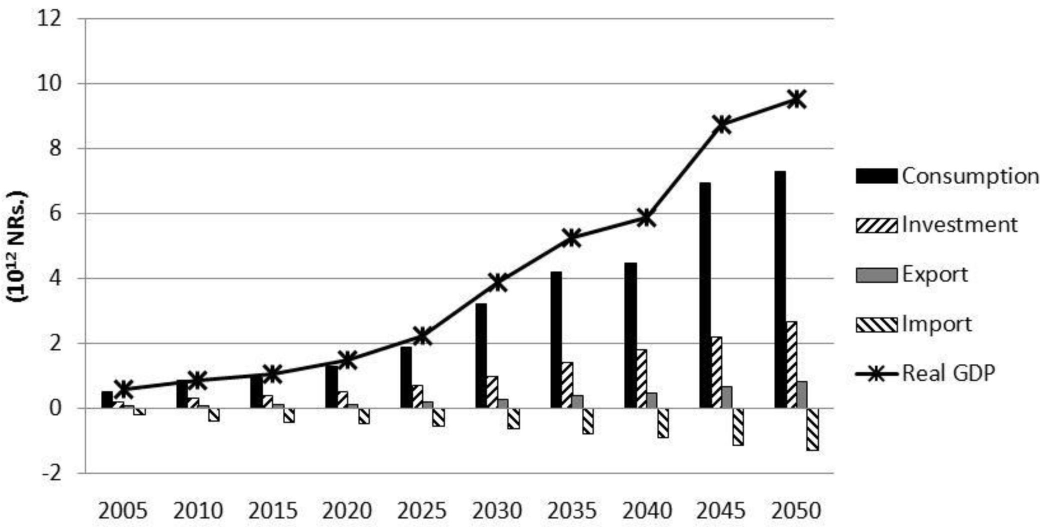
(iv) CT-HIG: introduction of carbon tax starts at US\$ 32/tCO_2e in 2015 which would gradually increase to US\$ 200/tCO_2e by 2050.

In addition, other three scenarios were developed for analyzing the effects of lump-sum transfer of the revenue from C-tax to the national household. The transfer of C-tax revenue under CT-HIG is carried out considering three different level consisting of 25%, 50% an 100% of CT-revenue being transferred to the household during 2015 to 2050.

9.2 Analysis of the Base Case Scenario

This section discusses the evolutions of economic growth, GDP distribution, energy intensity, emission intensity of the country during 2005 and 2050. In order to study the macroeconomic implications of the transport electrification policy in Nepal, a reference plausible baseline path of economic development, energy consumption and GHG emissions has been established under the CGE-frame work during the study period. Following the procedure mentioned earlier, the nominal GDP of Nepal is estimated to grow at an annual compound growth rate (ACGR) of 6.31% from NRs. 0.60 trillion in the base year 2005 to NRs. 9.54 trillion by 2050 as shown in Figure 9.1. The share of consumption demand from household and government, fixed investment demand, export and import of commodities as the percentage of GDP would change during the study periods as shown in Table 9.1. The consumption demand would contribute a major share in the national GDP with its value as percentage of GDP remaining over 76% during 2005 to 2050. The share of the investment demand in GDP lies between 25.1% to 37.26% during the study period. The net trade remains negative throughout the study period and the trade deficit as percentage of GDP decreases gradually from 16.2% in 2005 to 4.67% by 2050.

The value of equivalent variation (EV) in income is estimated to increase significantly during the study period indicating improvement in the national household welfare as compared to the base year condition. This indicates that real income of the national household relative to its income in the base year have increased during the study period. This can also be attributed to the estimated higher growth rates for GDP and private consumption (ACGR of 6.06% during 2005 to 2050) as compared to the growth rate of the population during the study periods (ACGR of 1.48% during the study period).



Note: trend line represent GDP growth path

Figure 9.1: Estimated GDP of Nepal under the base case (BASE4) scenario during 2005-2050

Table 9.1: The estimated macro-economic parameters of Nepal under BASE4 scenario for selected years

Parameter	2005	2020	2030	2040	2050
Real GDP (10^{12}NRs)	0.61	1.52	3.89	5.87	9.54
Consumption (% as of GDP)	85.54	86.45	83.43	76.10	76.60
Investment (% as of GDP)	30.64	34.29	25.42	30.46	28.07
Exports (% as of GDP)	13.69	9.60	7.19	8.50	8.66
Imports (% as of GDP)	29.87	30.34	16.05	15.05	13.34
Equivalent variation (welfare) [a]	0.00	0.15	1.02	1.76	3.56
Exchange Rate [b]	1.00	0.88	0.87	0.84	0.93

[a] Measured in terms of equivalent variation (EV) in income.
[b] Measured with respect to the base year value taken as 1.

Table 9.2: The share of sectoral gross output under BASE4 scenario

Sector	2005	2020	2030	2040	2050	ACGR[a]
Agriculture and Forestry (%)	26.32	25.41	24.61	21.86	21.69	5.49
Manufacturing (%)	24.92	22.52	10.87	9.19	7.37	3.11
Electricity (%)	1.96	5.73	10.95	11.59	9.99	9.84
Others[b] (%)	1.52	0.61	0.74	0.63	0.55	3.56
Transport (%)	10.79	10.21	12.86	17.73	20.72	7.49
Service (%)	34.49	35.52	39.98	39.01	39.68	6.27
Total gross output (10^{12} NRs)	0.97	2.20	5.22	7.81	12.98	5.94

[a] Annual compounding growth rate of the total gross output during 2005 to 2050 in %
[b] Other sectors are wood and lignite sectors

Table 9.3: The share of gross value added (capital and labor) by sector under BASE4 scenario

Sector	2005	2020	2030	2040	2050	ACGR[a]
Agriculture and Forestry (%)	33.10	31.46	29.35	25.74	25.81	5.59
Manufacturing (%)	14.92	12.19	5.42	5.40	3.49	2.80
Electricity (%)	2.03	6.15	9.06	10.88	10.03	10.01
Others[b] (%)	2.45	0.82	1.02	0.70	0.51	2.53
Transport (%)	4.24	6.26	9.97	12.75	15.68	9.30
Service (%)	45.71	43.94	46.20	45.22	45.00	6.24
Total gross value added (10^{12} NRs)	0.57	1.37	3.57	5.12	8.44	6.17

[a] Annual compounding growth rate of the total gross output during 2005 to 2050 in %
[b] Other sectors consists of wood and lignite sectors

The study shows that total gross output from the production sectors of the country would increase by more than 13 folds from NRs. 0.97 trillion in 2005 to NRs. 12.98 trillion in 2050 (Table 9.2) in BASE4. There would be a major growth in the electricity sector (9.8%), transport sector (7.5%) and service sector (6.3%). The sectoral composition of national total gross output changes with major increase in the share of electricity sector, transport sector and service sector, while there would be decrease in the share of other sectors during 2005 to 2050. The total gross value added due to capital and labor employment grows by nearly 14 times from NRs. 0.57 trillion to NRs. 8.44 trillion during 2005 to 2050. There would be a significant growth in the gross value added of the electricity sector (10.0%), transport sector (9.3%) and service sector (6.2%). The service sector continues to dominate in the gross value added of the economy in the long run while agriculture sector shows declining share. The shares of agriculture and forestry sectors as well as manufacturing sector gradually decrease while the shares of electricity sector and transport sector in gross value added increase significantly during the study period as shown in Table 9.3.

The results indicate that the country's economy is expected to shift from an agrarian economy to a more service sector oriented economy in the long run. This is a reasonable trend to be expected for a developing country like Nepal which is still in the phase of industrialization and commercialization. The government of Nepal has already highlighted the need for emphasis on these sectors for long term economic development of the country as the country possesses numerous natural and historical sites for tourism development and a huge hydropower resource that is yet to be exploited.

Table 9.4 The energy and emission intensities under BASE4 during 2000-2050

Parameter	2005	2020	2030	2040	2050
Energy intensity (MJ/$10^3$2005NRs)	554.04	314.64	139.61	113.64	81.33
Electricity intensity (MJ/ $10^3$2005NRs)	15.41	35.31	16.68	10.38	5.50
GHG intensity (kg/ $10^3$2005NRs)	9.45	7.46	3.74	3.95	3.19
CO_2 intensity (kg / $10^3$2005NRs)	5.29	5.62	3.01	3.45	2.88
CH_4 intensity (kg / $10^3$2005NRs)	0.141	0.062	0.025	0.017	0.010
N_2O intensity (kg / $10^3$2005NRs)	0.0021	0.0010	0.0004	0.0003	0.0002

The results also show that the country would proceed towards less energy and emission intensive economy in the long run as shown in the Table 8.4. The electricity intensity of GDP would increses initially and decreases in the later period during 2005 - 2050. The energy intensity of GDP would decrease significantly from 554 MJ/10^3 2005NRs to 81 MJ/10^3 2005NRs during 2005 to 2050. This is due to the improvement of the production efficiency (AEEI) and growing share of electricity in the national energy consumption. The GHG emission intensity shows decreasing trend as compared to the base year. It has been estimated that, the decrease in the level of GHG intensity is slower than the decrease in the level of energy intensity. This is because the future energy demand is expected to be supplied from carbon intensive fuel as penetration of some cleaner and renewable energy supply are controlled by higher cost (like hydropower) without considering environmental cost and use of some renewable energy resources are limited by nature (like fuel wood and municipal solid waste).

9.3 Macroeconomic effects of Carbon Tax

Many policy related questions that may arise when introducing Carbon tax in the country, such as, What would be the macro-economic effects due to the pricing of GHG emission from the use of carbon intensive fuels in the medium and long term? How would it affect on the other production sectors? What would be the effect on the consumer welfare due to this policy? What would be the effect on the commodity trade of the country? How would it change the energy and GHG emission intensities of the economy? These are discussed in this section for three different scenarios of introducing various level of C-tax on the emission intensive fuels.

9.3.1 Effects on Macroeconomic and Welfare Indicators

The study shows that introduction of C-tax on the price of emission intensive fuels results in distortionary effects on the economy with a decrease in GDP and household welfare.

This decrease in GDP and loss of household welfare is associated with the higher price to be paid for the carbon intensive fossil fuels and its spillover effects on the overall national consumption and production of the economy (see Tables 9.10a and 9.10b). The percentage decrease in GDP under C-tax cases with respect to BASE4 lies in the range of 0.5% under CT-LOW to 8.4% under CT-HIG in 2030 (Table 9.5). In 2050, there would be a reduction in GDP due to the C-tax in the range of 2.6% under CT-LOW to 10.8% under CT-HIG (Table 9.5). The cumulative undiscounted real GDP at 2005 price during 2005 to 2050 would be 173.4 trillions in the base case (Figure 9.2a). There would be decrease in the cumulative real GDP by 2.3% under CT-LOW, 4.9% under CT-MED, and 8.1% under CT-HIG as compared to the base case. The phenomenon of GDP loss due to the distortinary effects of the C-tax is well documented in several other similar studies (Siriwardana et al., 2011; Quasem et al., 2008; Van Heerden et al., 2006; Xu, 2010; Zhong, 1998; Zhou et al., 2011).

The end-use consumption would decrease in the range of 2.0% under CT-LOW to 3.6% under CT-HIG in 2030 as compared to BASE4. In 2050, there would be decrease in the level of consumption by 1.9% under CT-MED, reduce by 5.2% under CT-HIG but moderately increase by 1.1% in case of CT-LOW as compared to the BASE4. The investment would decrease significantly under all the C-Tax scenarios as compared to BASE4 as shown in Table 9.5.

Table 9.5: Estimated macro-economic implications of C-tax

Deviation from BASE4, %	2030			2050		
	CT-LOW	CT-MED	CT-HIG	CT-LOW	CT-MED	CT-HIG
GDP	(0.47)	(3.10)	(8.37)	(2.55)	(6.02)	(10.83)
- Consumption	(0.63)	(2.84)	(7.64)	2.31	(1.23)	(6.10)
- Investments	(1.26)	(4.12)	(8.36)	(17.31)	(19.97)	(23.66)
- Exports	(16.56)	(15.06)	(2.09)	(38.25)	(33.30)	(34.21)
- Imports	(9.78)	(8.70)	(1.78)	(28.89)	(25.54)	(25.85)
Equivalent variation (welfare) [a]	(46.62)	(43.60)	(35.04)	(41.40)	(50.30)	(56.81)
Exchange Rate[b]	(22.61)	(18.64)	(1.06)	(27.33)	(30.63)	(15.08)

[a] The value of equivalent variation (EV) in income under BASE4 is 1.02 in 2030 and 3.56 in 2050.
[b] The value of exchange rate in BASE4 is 0.87 in 2030 and 0.93 in 2050.

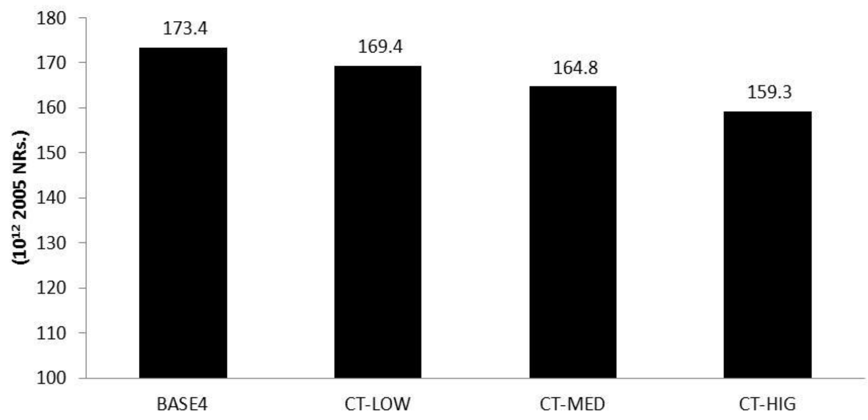


Figure 9.2a: Estimated cumulative undiscounted real GDP at 2005 price during 2005-2050

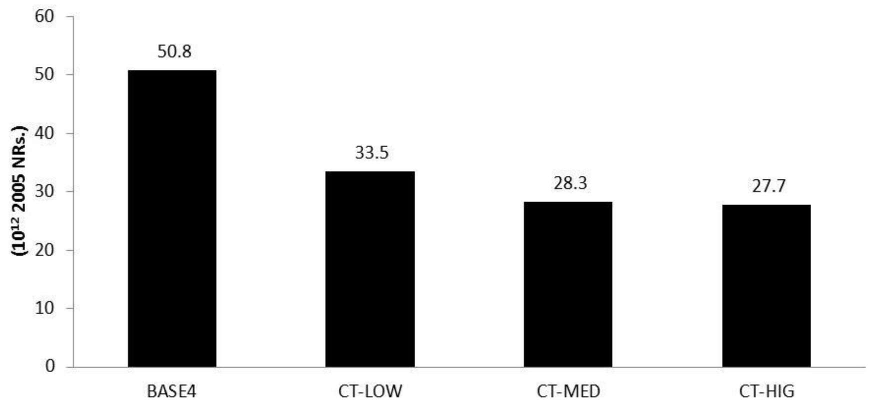


Figure 9.2b: Estimated cumulative household welfare during 2005-2050

The volume of trade would decrease under all C-tax scenarios except minor increase of export under CT-LOW in 2030 as compared to the base case. The exchange rate would appreciate in all cases of C-tax scenarios both in 2030 and 2050 as compared to the base case under the C-tax scenarios. The detail effects in the trade of commodities are discussed in Section 9.3.2.

The household welfare would decrease under all the C-tax scenarios in 2030 and 2050. This is evident from the decrease in the value of equivalent variation in income for all the C-tax scenarios as compared to BASE4 (Table 9.5). The cumulative household welfare during the study period would reduce in all the C-tax scenarios as shown in Figure 9.2b. It is in aggrement with several other studies (Siriwardana et al., 2011; Quasem et al., 2008; Van Heerden et al., 2006; Xu, 2010; Zhong, 1998; Zhou et al., 2011) which report there would be a decrease in the household welfare under the C-tax.

9.3.2 Effects on the Domestic Production Sectors and Trade of Commodities

a) Impacts on Gross Output of Domestic Production Sectors

The study found that the gross output of domestic production would decrease under all C-tax scenarios as compared to the base case in 2030 and 2050 (Table 9.6). In 2030, there would be a decrease in the gross output in the range of 9.40% under CT-MED to 11.3%% under CT-HIG as compared to BASE4. However, in 2050, the decrease in the value would be in the range of 0.5% under CT-LOW to 10.5% under CT-HIG. The sectoral gross output from the electricity, transport and service sectors decrease under all C-tax scenarios in 2030. In case of agriculture and forestry sector, there would be a decrease in gross output under CT-MED and CT-HIG. The gross output from other transport sector decrease under CT-LOW and CT-MED and the output from other sectors would decrease under CT-HIG in 2030. In 2050, there would be a major decrease in the gross output of agriculture and forestry, manufacturing and service sectors under all C-tax scenarios.

Table 9.6: Estimated effects of C-Tax on gross domestic output in 2030, %

Deviation from BASE4[a], %	2030			2050		
	CT-LOW	CT-MED	CT-HIG	CT-LOW	CT-MED	CT-HIG
Agriculture and Forestry	2.10	(12.90)	(11.57)	(24.60)	(9.68)	(20.90)
Manufacturing	(14.71)	(6.57)	7.16	(34.93)	(38.40)	(28.91)
Electricity	(58.81)	(21.67)	(20.89)	46.08	10.59	43.42
Others	48.06	30.45	(39.15)	46.83	38.73	29.64
Transport	(23.00)	(5.35)	(11.92)	19.82	(4.34)	(10.84)
Service	(1.21)	(5.73)	(12.88)	(4.02)	(6.58)	(15.24)
Total gross output (10^{12} NRs)[b]	(10.61)	(9.02)	(11.33)	(0.54)	(7.17)	(10.45)

[a] Value in parenthesis indicates percentage decrease relative to the base case value.
[b] Total gross output value in monetary term in BASE4 is 5.22 10^{12} NRs in 2030 and 12.98 10^{12} NRs in 2050.

b) Impacts on Gross Value Added (Capital and Labor) by Production Sectors

The study shows that the total gross value added would decrease under all C-tax scenarios in 2030 and 2050 as compared to that in the base case. There would be a major decrease in the gross value added in the transport, electricity, manufacturing and service sectors under CT-LOW; agriculture and forestry and service sectors under CT-MED and in agriculture and forestry, manufacturing , transport, service and other sectors under CT-HIG as compared to BASE4 in 2030 (Table 9.7). In 2050, there would be a decrease in the value added in agriculture and forestry and manufacturing sectors under all the C-tax scenarios. The capital investment at 2005 price in the electricity sectors would increase nominally under CT-LOW and CT-MED but would increase significantly under CT-HIG as compared to the BASE4 in 2030 and 2050 as shown in Figure 9.3. This indicates the additional new capital investment would divert significantly to the elecicity sectors under higher rate of the C-tax.

Table 9.7: Estimated effects of C-Tax on Gross Value Added (Capital and Labor), %

Deviation from BASE4[a], %	2030			2050		
	CT-LOW	CT-MED	CT-HIG	CT-LOW	CT-MED	CT-HIG
Agriculture and Forestry	1.20	(8.46)	(10.41)	(21.63)	(5.31)	(17.13)
Manufacturing	(13.00)	11.24	45.90	(64.71)	(66.39)	(41.38)
Electricity	(56.29)	4.89	0.07	(2.94)	(11.77)	8.89
Others	48.41	31.66	(39.49)	128.56	116.31	101.95
Transport	(34.66)	0.10	(12.12)	19.99	0.79	(5.58)
Service	(1.27)	(1.99)	(11.46)	0.98	(2.39)	(11.68)
Gross Value Added (10^{12} NRs) [b]	(9.48)	(1.95)	(7.41)	(3.05)	(5.01)	(10.31)

[a] Value in parenthesis indicates percentage decrease relative to the base case value.
[b] Total Gross Value Added in monetary term in BASE4 is 3.63 10^{12} NRs in 2030 and 8.77 10^{12} NRs in 2050.

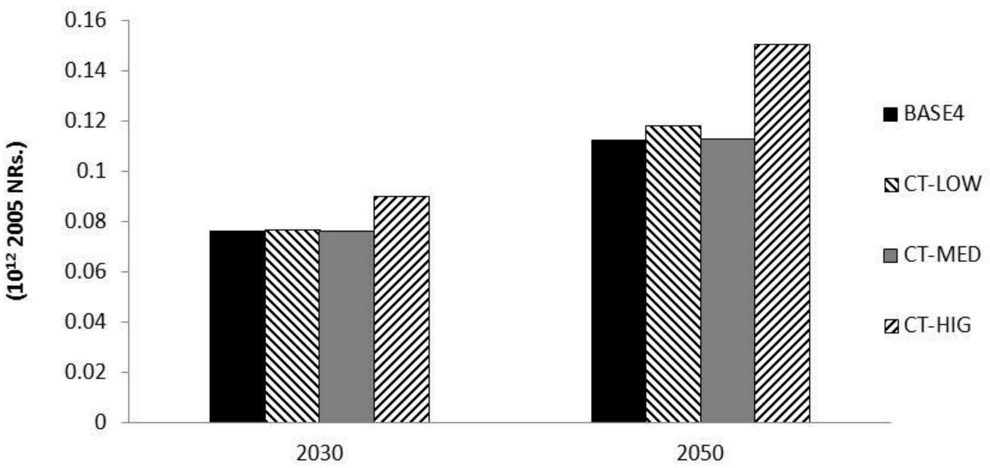


Figure 9.3: Estimated capital investment in transport and electricity sectors

c) Impacts on Imports of Individual Goods and Services

C-tax would result in a decrease in the import of fossil fuels and electricity under all C-tax scenarios in 2030(Table 9.8). In 2050, there would be a decrease in the import of all the commodities except those based on agriculture and forestry and service sectors under all C-tax scenarios (Table 9.8).

Table 9.8: Estimated effects of C-Tax on commodity imports, %

Deviation from BASE4[a], %	2030			2050		
	CT-LOW	CT-MED	CT-HIG	CT-LOW	CT-MED	CT-HIG
Agriculture and Forestry	56.14	(2.68)	(14.54)	28.65	106.00	15.31
Manufacturing	2.46	11.85	15.01	(22.43)	(11.54)	(16.14)
Electricity	(22.61)	(18.64)	(1.06)	(27.33)	(30.63)	(15.08)
Transport	(24.31)	6.40	5.20	(22.93)	(9.28)	(9.71)
Service	(7.33)	2.63	5.54	(12.55)	17.54	0.06
Imported fossil fuels [b]	(57.81)	(69.59)	(59.86)	(52.27)	(80.96)	(67.58)
Others [c]	(16.63)	(20.07)	1.30	(39.42)	(46.51)	(24.70)
Total commodity import [d]	(9.78)	(8.70)	(1.78)	(28.89)	(25.54)	(25.85)

[a] Positive value indicates percentage increase and negative value indicates percentage decrease relative to the base case value.
[b] Imported petroleum products consist of gasoline, diesel, aviation turbine fuel, kerosene, LPG and coal.
[c] Others include non-competitive imported intermediate input in the production sectors.
[d] Total commodity import value in monetary term under BASE4 is 0.63 10^{12} NRs in 2030 and 1.27 10^{12} NRs in 2050.

The import of fossil fuel would decrease significantly in all C-tax scenarios both in 2030 and 2050 highlighting the effectiveness of C-tax in reducing the use of carbon intensive fossil fuels.

d) Impacts on Exports of Individual Goods and Services

There would be a major decrease in the export of commodities based on agriculture and forestry as well as manufacturing sectors under all the C-tax scenarios as compared to BASE4 in 2030 (Table 9.9).

Table 9.9: Estimated effects of C-Tax on export of commodities, %

Deviation from BASE4[a], %	2030			2050		
	CT-LOW	CT-MED	CT-HIG	CT-LOW	CT-MED	CT-HIG
Agriculture and Forestry	(37.12)	(25.05)	(24.60)	(47.18)	(37.98)	(50.63)
Manufacturing	(36.98)	(33.75)	(2.13)	(40.83)	(43.51)	(15.99)
Electricity	28.15	11.93	2.63	(20.00)	(15.28)	(18.71)
Transport	(17.29)	(1.76)	(3.13)	(41.16)	(33.53)	(42.43)
Service	(26.54)	(21.24)	0.51	(45.31)	(39.22)	(44.98)
Total commodity export [b]	(16.56)	(15.06)	(2.09)	(38.25)	(33.30)	(34.21)

[a] Positive value indicates percentage increase and negative value indicates percentage decrease relative to the base case value.
[b] Total commodity export in monetary term in BASE4 is 0.28 10^{12} NRs in 2030 and 0.83 10^{12} NRs in 2050.

However, the export of electricity would increase in all C-tax scenarios and the export of commercial service would increase under CT-HIG as compared to BASE4 in 2030. There would be a decrease in the export of all the commodities produced in the country under all C-tax scenarios in 2050 (Table 9.9). This decrease in the value of commodities is partially compensated by the appreciation of the currency as discussed in Section 9.3.1.

9.3.3 Effects on Energy Consumption and Environment

There would be decrease in the energy consumption under all C-tax scenarios as compared to the BASE4 in 2030. The energy intensity decreases under all the C-tax scenarios in 2030 (Table 9.10a). In 2050, both total energy consumption and energy intensity would decrease indicating improvement in the energy efficiency of the economy under C-tax policy (Table 9.10b). The electricity intensity of GDP would decrease under CT-LOW and CT-MED in 2030. But there would be an increase in the value of electricity intensity under all C-tax scenarios in 2050 as compered to BASE4.

The average energy intensity of GDP during 2005 to 2050 would be 244.0 MJ/$10^3$2005 NRs under the BASE4 (Figure 9.4).

Table 9.10a: Change in estimated energy consumption and energy intensity in Nepal in 2030

Parameter	BASE4	CT-LOW	CT-MED	CT-HIG
Total Final Energy Consumption (TFEC) (PJ)	544.95	473.67	488.09	496.51
Electricity share in TFEC (%)	11.95	8.20	12.05	12.75
Fossil fuel share in TFEC (%)	30.93	26.08	23.94	24.32
Biomass fuel share in TFEC (%)	57.13	65.72	64.01	62.93
Electricity intensity (MJ/$10^3$2005NRs)	16.68	10.15	15.72	17.56
Energy intensity (MJ/$10^3$2005NRs)	139.61	123.81	130.44	137.77

Table 9.10b: Change in estimated energy consumption and energy intensity in Nepal in 2050

Parameter	BASE4	CT-LOW	CT-MED	CT-HIG
Total Final Energy Consumption (TFEC) (PJ)	774.04	685.12	670.39	563.62
Electricity share in TFEC (%)	6.76	9.38	12.23	13.86
Fossil fuel share in TFEC (%)	52.85	45.18	41.33	30.94
Biomass fuel share in TFEC (%)	40.39	45.44	46.44	55.19
Electricity intensity (MJ/$10^3$2005NRs)	5.50	6.96	9.24	9.16
Energy intensity (MJ/$10^3$2005NRs)	81.33	74.26	75.50	66.10

The value of average energy intensity of GDP would be decreased by 5.0% under CT-LOW, 3.1% under CT-MED and 2.4% under CT-HIG. Similarly, average electricity intensity of GDP would be 18.3 MJ/1032005 NRs under BASE4. There would be decrease in the value of average electricity intensity by 19.6% under CT-LOW and increase by 1.3% under CT-MED, while there would be increase in the average electricity intensity by 7.3% under CT-HIG. The share of fossil fuel would decrease and combined share of electricity and biomass would increase under all C-tax scenarios as compared to the BASE4. This indicates the existance of co-benefits of C-tax policy to promote the development of indigenous hydropower potential in the country under medium and high level of C-tax.

There would be a significant decrease in the total GHG emission and GHG emission intensity under all the C-tax scenarios as compared to BASE4 in both 2030 and 2050 (Table 9.11a and 9.11b). The cumulative GHG emission during 2005-2050 would be 753 million tons of CO2e. The mitigation of GHG emission under C-tax scenarios consists of 10.6% under CT-LOW, 17.0% under CT-MED and 31.3% under CT-HIG. The average GHG intensity during the study period would be 6.42 kg CO_2e/ $10^3$2005 NRs under BASE4 (Figure 9.5). The average GHG intensity would be decreased by 6.2% under CT-LOW, 9.3% under CT-MED and 13.7% under CT-HIG. This indicates that C-tax policy could be one of the effective tools to pursue a low carbon development path in the country.

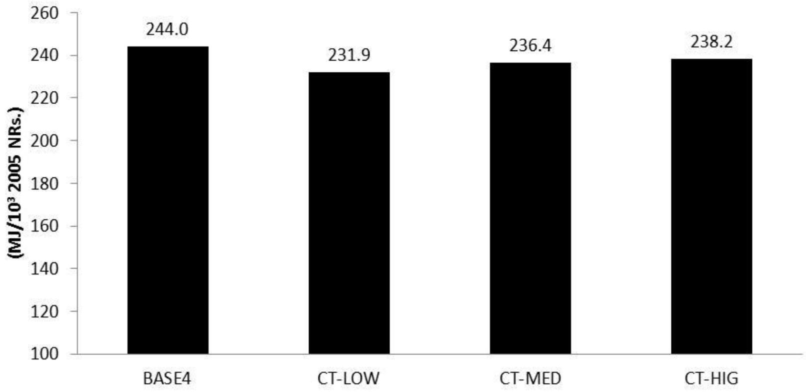


Figure 9.4: Estimated average energy intensity of GDP during 2005-2050

Table 9.11a: Change in estimated GHG emission in Nepal in 2030

Parameter	BASE4	CT-LOW	CT-MED	CT-HIG
GHG emission (10^3 tons)	14584	13065	11882	11543
CO_2 intensity (kg / $10^3$2005NRs)	3.01	2.67	2.41	2.40
CH_4 intensity (kg / $10^3$2005NRs)	0.025	0.025	0.026	0.027
N_2O intensity (kg / $10^3$2005NRs)	0.0004	0.0004	0.0004	0.0005
GHG intensity (kg/$10^3$2005NRs)	3.74	3.41	3.18	3.20

Table 9.11b: Change in estimated GHG emission in Nepal in 2050

Parameter	BASE4	CT-LOW	CT-MED	CT-HIG
GHG emission (10^3 tons)	30360	26120	23435	15417.46
CO2 intensity (kg / $10^3$2005NRs)	2.88	2.50	2.30	1.46
CH4 intensity (kg / $10^3$2005NRs)	0.010	0.011	0.011	0.011
N2O intensity (kg / $10^3$2005NRs)	0.0002	0.0002	0.0002	0.0002
GHG intensity (kg/$10^3$2005NRs)	3.19	2.83	2.64	1.81

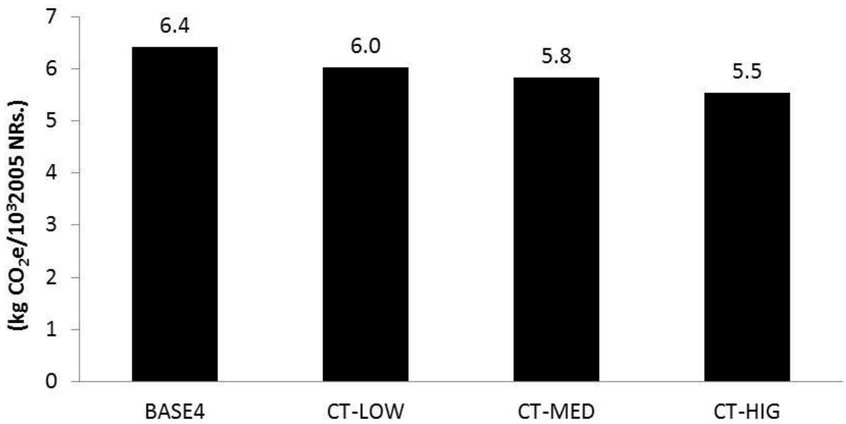


Figure 9.5: Estimated average GHG intensity of GDP during 2005-2050

9.4 Effects of C-Tax Revenue Recycling

Contraction of the economy and loss of household welfare due to the imposition of C-tax is well known phenomenon (Devarajan et al., 2009). However, if the revenue generated under C-tax policy is recycled back to the household in the form of lump-sum transfer, subsidy, reduction in other taxes, there is possibility of reduction in such effects as well as additional gain in the form of reduction in the environmental emissions, improvement of local environment, and other co-benefits. It is also called double dividend or multiple dividend based on the number of benefit parameters considered for comparison. There are several studies which analysed such benefits of C-tax revenue recycling (Devarajan et al., 2009; Timilsina and Shrestha, 2007; Van Heerden et al., 2006; Yusuf and Resosudarmo, 2007).

In this study, effects of C-tax revenue recycling were carried out by formulating three additional scenarios mentioned below:

i) Lump-sum government transfer of 25% of C-tax revenue under CT-HIG to the household (Here after “CTR25”).

ii) A 50% of C-tax revenue under CT-HIG being transferred to the household by the government (Here after “CTR50”).

iii) A lump-sum government transfer of 100% C-tax revenue under CT-HIG to the household (Here after “CTR100”).

9.4.1 Effects on Macroeconomic Indicators

The study shows that recycling of the revenue generated from C-tax to the household through lump-sum transfer would reduce GDP loss and improve household welfare in the long run. There would be a slight decrease in the GDP under CTR25 and an increase in GDP under CTR50 and CTR100 in 2030, where as, there would be an increase in the GDP in 2050 under all the C-tax recycling scenarios (Table 9.12). The cumulative undiscounted real GDP at 2005 price during 2005 to 2050 would be 159.2 trillions in CT-HIG (Figure 9.6a). There would be a nominal increase in the cumulative real GDP by 0.014% under CTR25, 0.015% under CTR50, and 0.036% under CTR100 as compared to CT-HIG. Similar recovery of GDP loss under C-tax revenue recycling scheme has been reported in case of Indonesia by Yusuf and Resosudarmo (2007).

However, household welfare would increase under CTR50 and CTR100 scenarios in 2030 and would increase significantly under all CTR scenarios in 2050. The cumulative household welfare during 2005 - 2050 would increase under all the CTR scenarios as shown in Figure 9.6b. This indicates the lump-sum transfer of C-tax revenue to household is effective policy tool to reduce negative effects of C-tax on the household welfare in the long run. Similar improvement in the household welfare loss under C-tax revenue recycling scheme has been reported by Devarajan et al. (2009) in case of South Africa, and by Timilsina and Shrestha (2007) in case of Thailand. The exchange rate would appreciate under all CTR25 in 2030. In 2050, the exchange rate would appreciate under all CTR scenarios as compared to CT-HIG.

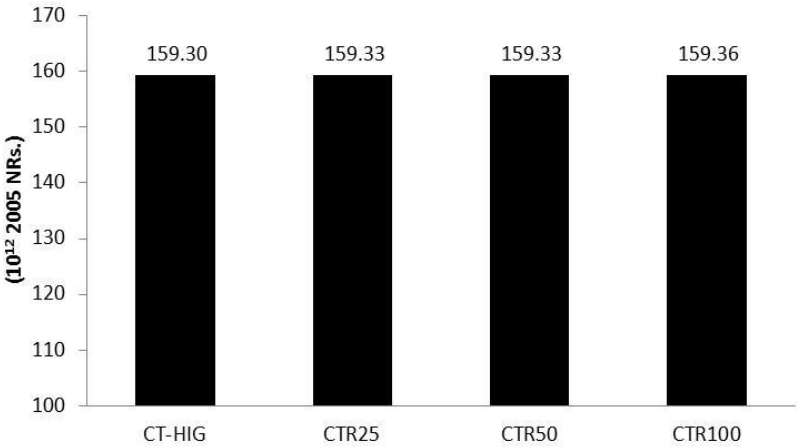


Figure 9.6a: Estimated cumulative undiscounted real GDP at 2005 price during 2005-2050

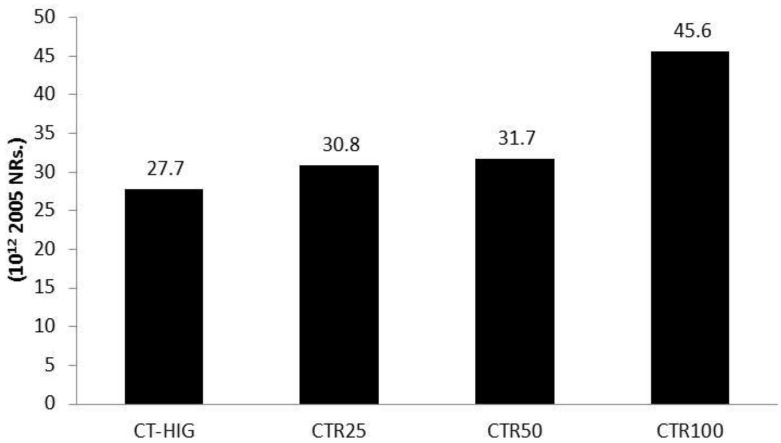


Figure 9.6b: Estimated cumulative household welfare during 2005-2050

Table 9.12: Estimated macro-economic implications of C-Tax Revenue Recycling in 2030 and 2050

Deviation from CT-HIG, %	2030			2050		
	CTR25	CTR50	CTR100	CTR25	CTR50	CTR100
GDP	(0.17)	5.25	0.66	0.89	0.81	2.10
- Consumption	(0.17)	4.46	0.40	0.94	0.82	1.96
- Investments	0.25	3.91	1.17	0.42	0.32	1.13
- Exports	(2.86)	(31.11)	(8.49)	(0.88)	(3.59)	(24.99)
- Imports	(0.74)	(16.83)	(3.92)	(0.74)	(2.74)	(16.68)
Equivalent variation (welfare) [a]	21.99	(34.15)	48.60	11.51	96.68	178.61
Exchange Rate[b]	(2.88)	13.47	0.11	(4.43)	(5.52)	(2.44)

[a] The value of equivalent variation (EV) in income under CT-HIG is 0.71 in 2030 and 1.18 in 2050.
[b] Measured with respect to the base year value as 1 and its value in CT-HIG is 0.56 in 2030 and 0.65 in 2050.

9.4.2 Effects on the Domestic Production Sectors

a) Impacts on Gross Sectoral Production

There would be decrease in the gross output under CTR25 while there would be increase under CTR50 and CTR100 as compared to the CT-HIG in 2030 and 2050. Agriculture and forestry, service and other sectors would gain under all the CTR scenarios, electricity sector would gain under CTR50, and transport sector would gain under CTR50 and CTR100 in 2030. In 2050, the gross output would be decrease under CTR25 and increase under CTR50 and CTR100 as swhon in Table 9.13. The service sector would gain under all CTR scenarios, whereas, other sector shows mixed effects under different CTR scenarios as compared to the EMT30 in 2050.

Table 9.13: Estimated effects of C-Tax Revenue Recycling on sectoral output in 2030, %

Sector [a], %	2030			2050		
	CTR25	CTR50	CTR100	CTR25	CTR50	CTR100
Agriculture and Forestry	9.66	13.69	13.86	14.01	4.45	(4.24)
Manufacturing	(3.54)	(35.93)	(10.21)	(11.85)	(16.36)	(19.31)
Electricity	(50.04)	7.47	(6.62)	(16.39)	21.52	7.97
Others [b]	12.62	133.25	89.80	0.90	(0.90)	4.75
Transport	(44.89)	12.52	7.24	(4.65)	12.23	42.01
Service	1.27	9.78	4.59	1.87	1.76	6.72
Total gross output (10^{12} NRs)[c]	(8.15)	5.48	4.60	(0.88)	6.52	10.56

[a] Sector wise deviations relative to CT-HIG (%).
[a] Others include wood and lignite mining industry.
[c] Total gross output value in CT-HIG is 4.89 10^{12} NRs in 2030 and 11.10 10^{12} NRs in 2050.
[d] Value in parenthesis indicates percentage decrease relative to the base case value.

b) Impacts on Imports of Individual Goods and Services

The total commodity import would be decrease under all the CTR scenarios compared to CT-HIG in 2030 as well as in 2050. Intrestingly, there would be major increase in the import of commodities related to agriculture and forestry sector while there would be mixed effects in the the import of commodities related to other remaining sectors in 2030 and 2050 as compared to CT-HIG as shown in Table 9.14.

Table 9.14: Estimated effects of C-Tax Revenue Recycling on commodity imports

Deviation from CT-HIG[a], %	2030			2050		
	CTR25	CTR50	CTR100	CTR25	CTR50	CTR100
Agriculture and Forestry	1.90	138.33	31.61	50.64	43.64	75.84
Manufacturing	(0.10)	(17.87)	(5.00)	5.89	2.83	(18.94)
Electricity	3.03	(39.90)	(5.37)	(11.71)	(18.54)	(35.84)
Transport	(3.36)	(43.90)	(9.46)	(17.19)	(23.96)	88.29
Service	(0.61)	(9.57)	(10.87)	(3.87)	11.36	0.46
Imported fossil fuels [b]	(4.85)	(32.17)	4.39	(33.97)	(33.62)	(44.46)
Others [c]	(1.73)	(36.08)	(7.68)	(23.45)	(24.78)	(42.13)
Total commodity import [d]	(0.74)	(16.83)	(3.92)	(0.74)	(2.74)	(16.68)

[a] Figure inside parenthesis indicates % decrease in value compared to the value in CT-HIG.

[b] Imported petroleum products consist of gasoline, diesel, aviation turbine fuel, kerosene, LPG and coal.
[c] Others include non-competitive imported intermediate input in the production sectors.
[d] Total commodity import in monetary term in CT-HIG is 0.54 10^{12} NRs in 2030 and 0.93 10^{12} NRs in 2050.

c) Impacts on Exports of Individual Goods and Services

There would be a decrease in the total commodity export under all CTR scenarios compard to CT-HIG in 2030 and 2050 (Table 9.15). In 2030, there would be an increase in export of electricity under all CTR scenarios, increase of agriculture and forestry based commodities under CTR25 and CTR100, and increase in export of transport service under CTR100. In 2050, there would be a major decrease in the export of commodities from manufacturing sector under CTR25 and CTR50, and there would be decrease in the export of all commodities under CTR100 as compared to the BASE4.

Table 9.15: Estimated effects of C-Tax Revenue Recycling on export of commodities

	2030			2050		
Deviation from CT-HIG[a], %	CTR25	CTR50	CTR100	CTR25	CTR50	CTR100
Agriculture and Forestry	22.50	(39.90)	11.14	18.05	15.94	(13.31)
Manufacturing	(16.86)	(51.23)	(24.50)	(26.66)	(33.33)	(48.22)
Electricity	9.03	14.90	3.90	3.03	1.62	(15.45)
Transport	(4.07)	(34.59)	4.53	5.96	7.39	(18.42)
Service	(0.25)	(47.32)	(11.15)	6.90	2.77	(23.54)
Total commodity export[b]	(2.86)	(31.11)	(8.49)	(0.88)	(3.59)	(24.99)

[a] Figure inside parenthesis indicates % decrease in value compared to the value in CT-HIG.
[b] Total commodity import in monetary term under CT-HIG is 0.22 10^{12} NRs in 2030 and 0.53 10^{12} NRs in 2050.

9.4.3 Effects on the Energy Consumption and Environment

The energy intensity of GDP would decrease increase under CTR25 and CTR50, but decrease under CTR100 scenario in 2030 and 2050 (Table 9.16a, 9.16b). The average energy intensity of GDP during 2005 to 2050 would be 238.2 MJ/$10^3$2005 NRs under the CT-HIG (Figure 9.7). The value of average energy intensity of GDP would be increased by 2.2% under CTR25, where as it would be decreased by 0.1% under CTR50 and 3.5% under CTR100. The average GHG intensity during the study period would be 5.55 kg CO_2e/ $10^3$2005 NRs under CT-HIG (Figure 9.8). The average GHG intensity would be increased by 14.8% under CTR25, grow by 11.0% under CTR50, and increased by 4.7% under CTR100. This indicates that at high level of C-tax recycling scheme it is possible to reduce distortionary effects of C-tax on the economy as well as improve the energy intensity.

Table 9.16a: Effects on estimated energy consumption and energy intensity due to C-Tax Revenue Recycling in Nepal in 2030

Parameter	CT-HIG	CTR25	CTR50	CTR100
Total Final Energy Consumption (TFEC) (PJ)	496.51	517.85	499.40	481.13
Electricity share in TFEC (%)	12.75	10.83	8.58	10.26
Fossil fuel share in TFEC (%)	24.32	29.05	29.17	25.04
Biomass fuel share in TFEC (%)	62.93	60.12	62.24	64.70
Electricity intensity ($MJ/10^3$2005NRs)	17.56	15.56	11.89	13.70
Energy intensity ($MJ/10^3$2005NRs)	137.77	143.69	138.57	133.50

Table 9.16b: Effects on estimated energy consumption and energy intensity due to C-Tax Revenue Recycling in Nepal in 2050

Parameter	CT-HIG	CTR25	CTR50	CTR100
Total Final Energy Consumption (TFEC) (PJ)	563.62	721.45	715.20	543.00
Electricity share in TFEC (%)	13.86	10.80	9.99	12.75
Fossil fuel share in TFEC (%)	30.94	46.05	46.48	29.92
Biomass fuel share in TFEC (%)	55.19	43.15	43.53	57.33
Electricity intensity ($MJ/10^3$2005NRs)	9.16	9.14	8.38	8.12
Energy intensity ($MJ/10^3$2005NRs)	66.10	84.61	83.88	63.68

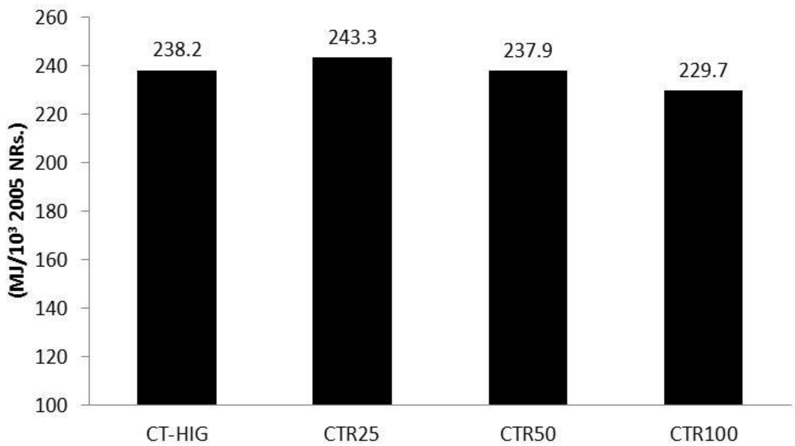


Figure 9.7: Estimated average energy intensity of GDP during 2005-2050

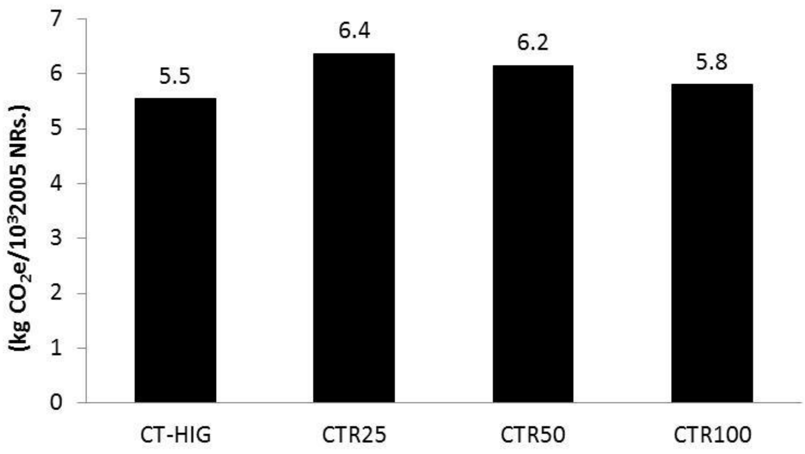


Figure 9.8: Estimated average GHG intensity of GDP during 2005-2050

Table 9.17a: Change in estimated GHG emission due to C-Tax Revenue Recycling in Nepal in 2030

Parameter	CT-HIG	CTR25	CTR50	CTR100
GHG emission (10^3 tons)	11543	14599	14580	14171
CO_2 intensity (kg / $10^3$2005NRs)	2.40	3.26	3.26	3.14
CH_4 intensity (kg / $10^3$2005NRs)	0.027	0.027	0.027	0.027
N_2O intensity (kg / $10^3$2005NRs)	0.0005	0.0004	0.0004	0.0004
GHG intensity (kg/$10^3$2005NRs)	3.20	4.05	4.05	3.93

Table 9.17b: Change in estimated GHG emission due to C-Tax Revenue Recycling in Nepal in 2050

Parameter	CT-HIG	CTR25	CTR50	CTR100
GHG emission (10^3 tons)	15417	30365	30364	15547
CO_2 intensity (kg / $10^3$2005NRs)	1.46	3.21	3.21	1.48
CH_4 intensity (kg / $10^3$2005NRs)	0.011	0.011	0.011	0.011
N_2O intensity (kg / $10^3$2005NRs)	0.0002	0.0002	0.0002	0.0002
GHG intensity (kg/$10^3$2005NRs)	1.81	3.56	3.56	1.82

9.5 Sensitivity Analyses

The introduction of C-tax is expected to result in changes in the composition of intermediate inputs and value additions of production sectors. It results in change in the composition of the energy inputs from carbon intensive to cleaner fuel options. It also results in the substitution of energy factor of production by other factors of production during the general equilibrium process to minimize production cost. Sensitivity analysis was carried out for elasticity of substitution for aggregate energy and capital “σ_{EK}” and elasticity of substitution associated with electricity and non-electricity energy input “σ_E” by varying its value by 10% in both direction (i.e., ±10% from base year value). In case of demand side, this policy is expected to change the composition of the consumption of different types of energy commodities as price of the energy commodity rises under C-tax. Considering this, a sensitivity analysis was done for elasticity of substitution associated with energy commodity consumption “σ_{DHDE}” with variation in the range of 10% deviation from initial value.

Table 9.18: Effects of variation in elasticity of substitution for aggregate energy and capital “σ_{EK}” in the production function in selected years

Deviation from BASE4	2015		2030		2050	
σ_{EK} =0.3	σ_{EK} =0.27	σ_{EK} =0.33	σ_{EK} =0.27	σ_{EK} =0.33	σ_{EK} =0.27	σ_{EK} =0.33
GDP (% change)	3.40	22.66	(3.95)	(3.88)	15.21	15.18
Energy consumption (% change)	(1.29)	(0.16)	(7.39)	(6.19)	(27.12)	(31.52)
GHG emission (% change)	(11.72)	(2.46)	(9.83)	(9.83)	(47.12)	(49.05)
Equivalent variation (welfare) [a]	0.08	0.14	1.06	0.2	2.41	1.43

[a] Measured in terms of equivalent variation (EV) in income as compared to the base year

Table 9.19: Effects of variation in elasticity of substitution for electricity and non-electricity energy input "σ_{Ei}" in the production function in selected years

Deviation from BASE4 σ_{Ei} =0.2 – 0.5	2015		2030		2050	
	σ_{Ei} = 0.18 - 0.45	σ_{Ei} = 0.22 – 0.55	σ_{Ei} = 0.18 - 0.45	σ_{Ei} = 0.22 – 0.55	σ_{Ei} = 0.18 - 0.45	σ_{Ei} = 0.22 – 0.55
GDP (% change)	5.41	(0.82)	(4.44)	(9.06)	15.40	13.34
Energy intensity (% change)	(1.06)	(4.20)	(7.94)	(16.81)	(33.75)	(49.22)
GHG intensity (% change)	(8.30)	(10.96)	(11.93)	(26.95)	(45.44)	(57.58)
Equivalent variation (welfare) [a]	0.11	0.87	0.86	3.5	2.57	17.80

[a] Measured in terms of equivalent variation (EV) in income as compared to the base year

The analysis shows the change in the value of the for elasticity of substitution of aggregate energy and capital "σEK" in the production function would result moderate change in the macroeconomic, welfare parameters, energy and environment parameters in 2015 and 2030 (Table 8.18). Change in the value of parameters has been observed to grow in the later years due to the compounding effects of the change in value in the previous years.

Table 9.20: Effects of variation in elasticity of substitution between energy commodity consumption "σ_{DHDE}" in selected years

Deviation from BASE4 σ_{DHDE} =0.3	2015		2030		2050	
	σ_{DHDE} =0.27	σ_{DHDE} =0.33	σ_{DHDE} =0.27	σ_{DHDE} =0.33	σ_{DHDE} =0.27	σ_{DHDE} =0.33
GDP (% change)	(0.26)	1.63	(4.57)	(6.27)	15.74	14.78
Energy intensity (% change)	(0.38)	0.06	(7.64)	(9.64)	(30.76)	(33.69)
GHG intensity (% change)	(4.35)	0.78	(11.19)	(4.31)	(53.06)	(47.99)
Equivalent variation (welfare) [a]	0.08	0.03	0.42	0.16	32.39	2.72

[a] Measured in terms of equivalent variation (EV) in income as compared to the base year

Similar effects has been observed in case of the sensitivity analysis for the effects of elasticity of substitution for electricity and non-electricity energy input "σEi" in the production function in the selected years (Table 8.19). The change in the value of elasticity of substitution among energy commodities consumed by household "σDHDE" would result moderate change in the macroeconomic, welfare parameters, energy and environment parameters in 2015 and 2030.

Change in these parameters is comparatively larger in 2050 compared the changes in their value in 2015 and 2050 (Table 9.20). This indicates that results given by this study is subjected to change if the value of elasticity is altered mostly in the later years of the study period.

9.6 Conclusion and Policy Implications

The study indicates that if C-tax policy is implemented in Nepal, there would be significant decrease in the energy consumption and GHG emission but at the cost of moderate loss in GDP and household welfare as compared to the base case (BASE4).

Altogether, three C-tax scenarios were considered representing different levels of carbon pricing on the carbon intensive fuels for analyzing the C-tax policy. In the scenario with the lower level of C-tax, the price of GHG emission starts at US$ 3/tCO_2e in 2015 which would gradually increase to US$ 20/tCO_2e by 2050 (CT-LOW). The scenario with the medium level of C-tax comprised of the pricing of GHG emission that starts at US$ 13/tCO_2e in 2015 which would gradually increase to US$ 100/tCO_2e by 2050 (CT-MED). The rate of C-tax starts at US$ 32/tCO_2e in 2015 which would gradually increase to US$ 200/tCO_2e by 2050 (CT-HIG).

The study shows that the national economy shifts toward the energy efficient path under the C-tax policy. The average energy intensity of GDP during 2005 to 2050 would be 244.0 MJ/$10^3$2005 NRs under the BASE4. The value of average energy intensity of GDP would be decreased by 5.0% under CT-LOW, 3.1% under CT-MED and 2.4% under CT-HIG. Similarly, average electricity intensity of GDP would be 18.3 MJ/$10^3$2005 NRs under BASE4. There would be decrease in the value of average electricity intensity by 19.6% under CT-LOW and increase by 1.3% under CT-MED, while there would be increase in the average electricity intensity by 7.3% under CT-HIG. There would be shift from carbon intensive fuel sources to the cleaner and greener energy resource as shown by the decrease in the share of fossil fuels and increase in the share of electricity and biomass in the total energy consumption in the country under C-tax scenarios as compared to the base case.

Under C-tax policy, there would be significant reduction in the GHG emission as compared to the base case thus proving to be an effective policy tool for the country to follow low carbon development path in the long run. This would support the effective implementation of national climate change policy 2010. The average GHG intensity during the study period would be 6424.8 kg CO2e/ $10^3$2005 NRs under BASE4. The average GHG intensity would be decreased by 6.2% under CT-LOW, 9.3% under CT-MED and 13.7% under CT-HIG.

A Distortinary effect of C-tax on the economy of Nepal is expected to be moderate. The cumulative undiscounted real GDP at 2005 price during 2005 to 2050 would be 173.4 trillions in the base case. There would be decrease in the cumulative real GDP by 2.3% under CT-LOW, 4.9% under CT-MED, and 8.1% under CT-HIG. The household welfare would decrease under all the C-tax scenarios as compared to BASE4 in 2030 and 2050. This is evident from a decrease in the value of the cumulative equivalent variation in income during the study period for all the C-tax scenarios as compared to BASE4.

There would be decrease in the import of fossil fuels and electricity under all C-tax scenarios as compared to the base case in 2030. In 2050, there would be decrease in the import of all the commodities except agriculture and forestry and service based commodities under all C-tax scenarios as compared to the BASE4. The import of fossil fuel would decrease most significantly in all C-tax scenarios as compared to BASE4 both in 2030 and 2050 highlighting the effectiveness of C-tax in controlling the use of carbon intensive fossil fuels. Under CT-HIG there would be a significant increase in the electricity consumption.

There would be a major decrease in the export of commodities produced from agriculture and forestry, manufacturing and transport sectors under all the C-tax scenarios in 2030. However, the export of electricity would increase under all C-tax scenarios in 2030. There would be decrease in the export of all the commodities produce in the country under all the C-tax scenarios in 2050.

The analysis shows that if C-tax revenue collected under CT-HIG is recycled back to the national household there would be positive gain in the household welfare as compared to the CT-HIG. This indicates the lump-sum transfer of C-tax revenue to household is an effective policy tool to reduce negative effects of C-tax on the household welfare. Besides, there would be reduction in the GDP loss under C-tax recycling scenarios. Interestingly, if the C-tax revenue is recycled above 50%, there would be an additional benefit related to the reductioin in average energy intensity of GDP as compared to CT-HIG.

Considering the above results, this study comes out with the following recommendations for the national and international policy makers and related stakeholders:

- C-tax policy would be a promising pricing instrument for fulfilling the objectives of the climate change policy by reducing GHG emission intensity of GDP and help energy policies by reducing energy intensity of GDP. The national policy makers should give special emphasis on devising additional mechanism to reduce contraction effects of C-tax policy on GDP and household welfare. There should be active involvement of academia and policy research institutions in analyzing the short, medium, and long term effects of such policy inorder to guide the policy makers and also to reccommend corrective measures before hand to compensate any potential distortionary effects due to the policy under consideration.
- The study indicates that the introduction of C-tax in Nepal would result in significant reduction in GHG emissions and thus help to minimize the adverse effects of the global climate change on the long-run. International communities could work together to adopt policies like adjusting border tax in favor of the commodities produced in the countries adopting such policies.
- Successful implementation of the C-tax and realization of its multi-faceted benefits depends on many factors. This chapter is focused on the economy-wide effects in terms of GDP distribution, consumer welfare, energy and GHG intensities of GDP. The detail analysis interms of energy system development, energy system costs, energy security, GHG and local pollutant emissions was discussed in Chapter 6. Further studies on the C-tax policy can be done on issues not covered in this study, such as, distributional effects of C-tax on different households based on income level, effects of the allocation of C-tax revenue in different economic activities, integrating C-tax with low carbon financing, etc.

Chapter 10

Conclusions and Recommendations

10.1 Conclusions

This study analysed the energy, environmental and economy-wide implications of selected low carbon development strategies in Nepal with huge untapped hydropower potential but still relying heavily on the imported fossil fuels for its commercial energy demand. The study developed and used soft inked integrated energy-environment-economic modeling tools to examine the mid and long term effects of a sectoral low carbon strategy, i.e., transport sector electrification and an economy-wide carbon tax (C-tax) strategy. The bottom-up energy system model (namely Nepal-ESM) was used to study the effects of selected low carbon strategies on the hydropower development, energy supply mix, energy system cost and global and local environmental emissions in the country. Due to the inherited limitations of the bottom up model, the overall macroeconomic and welfare implications of the low carbon strategies are comprehensively studied by the use of the hybrid top-down type model (namely Nepal-CGE) with the provision of backstop technology in the transport and electricity sectors.

The implications of transport sector electrification on hydropower development, energy supply mix, energy system cost, energy security and environmental emissions during 2015-2050 were studied by using Nepal-ESM model. The analysis shows that transport electrification policy would promote the development of indigenous hydropower resource in Nepal highlighting a need for an integrated development strategy for transport sector electrification and hydropower development. The hydropower capacity addition would increase by up to 538 MW under high transport electrification scenario EMT20+EV15 (20% modal shifts to electric mass transport (EMT) and 15% penetration of the electric vehicles (EV) by 2050). Electrification of the transport system would show a noticeable improvement in the energy security of the country with a decline in the cumulative imported energy and improvement in diversification of the primary energy supply system of the country. There would be a decrease in the discounted total energy system cost under transport electrification scenarios as compared to the base case. As a climate related co-benefit, there would be a reduction of as high as 13% of global greenhouse gas (GHG) emissions in cumulative terms under 35% transport sector electrification. In addition, there would be reduction in the emissions of local pollutants consisting of CO, NO_X, SO_2, NMVOC and PM_{10} due to the transport sector electrification. The study also shows that there would be additional employment generation during 2015-2050 associated purely with the additional hydropower development and recharging stations serving electric vehicles required under the transport electrification scenarios.

Nepal-CGE model was used to examine the economy-wide effects of transport sector electrification policy. The main finding of the study indicates that Nepal would benefit economically from the implementation of transport sector electrification in the long run with the increase in GDP and household welfare under all the transport electrification scenarios. Besides, transport electrification would promote energy efficiency improvement and green economy with significant reduction in the energy intensity of GDP and greenhouse gas intensity of GDP. This highlights the importance of the transport sector electrification as one of the desirable options in pursuing the low carbon development path in the country. It also indicates that the transport sector electrification would result appreciation of the national currency triggering reduction in the export of other non-transport and non-electricity related commodities produced in the country in the long run (i.e., the presence of Dutch disease kind of effect). Introducing foreign direct investment would reduce such effects to some level.

The effects of C-tax under different global GHG stabilization targets of 450 ppmv (CT-HIG), 550 ppmv (CT-MED) and 650 ppmv (CT-LOW) on the hydropower development, energy supply mix, energy system cost, energy security and environmental emissions were studied by using Nepal-ESM model. It reveals there would be a need to install additional hydropower capacity of 614 MW in CT-MED to 945 MW in CT-HIG by 2050. It indicates an improvement in the efficiency of the cumulative total final energy consumption in all the C-tax scenarios compared to the base case. The study also shows the co-benefits in terms of employment generation associated with additional hydropower development under the C-tax scenarios and that through the establishment of more electric recharging stations under CT-MED and CT-HIG. It reveals there would be a reduction in the emission of short-lived local pollutants. The adoption of C-tax would decrease the discounted net fuel import cost but increases discounted total energy system cost including C-tax. However, by recycling of 100% of the carbon tax back to the economy, the discounted total energy system cost excluding C-tax is expected to decrease under CT-HIG.

The examination of the economy-wide consequences of C-tax policy was analysed by using Nepal-CGE model. It indicates that if C-tax policy is implemented in Nepal, there would be significant decrease in the energy consumption and GHG emission but at the cost of moderate loss in GDP and household welfare as compared to the base case. Under CT-HIG there would be a significant increase in the electricity consumption. Interestingly, the study shows that if C-tax revenue collected under CT-HIG is recycled back to the national household there would be a partial recovery in GDP loss and a positive gain in the household welfare. This indicates the lump-sum transfer of C-tax revenue to household is effective policy tool to reduce negative effects of C-tax on the GDP and household welfare. Besides, if the C-tax revenue is recycled above 50%, there would be an additional benefit related to the reductioin in average energy intensity of GDP as compared to CT-HIG.

This study also indicates that it is possible to analyze low carbon development strategies from Energy, Environment and Economy-wide (3E) perspective for the developing country under limited availability of database by developing appropriate type of top-down and bottom-up models establishing a soft linkage.

10.2 Key policy implications and reccommendations

This study comes out with several recommendations for the national and international policy makers and stakeholders as follows:

a) Transport electrification policy

- Transport sector electrification program would be a promising option for fulfilling the objectives of the climate change policy, hydropower development policy and national transport policy of Nepal. The national policy makers should give special emphasis on the implementation of transport electrification program due to the multi-faceted benefits of its implementation. There is a need for studying the elaborate inter-relationship among the policies related to energy, climate change and transport so as to develop the effective and sustainable policy in an integrated framework in the long run.

- The government should create an enabling environment by developing and implementing effective policies to attract Foreign Direct Investment (FDI) as it is expected to result the GDP gain, decrease energy and emission intensities and reduce Dutch disease effects observed under transport electrification policy. However, there is also a need for study on the additional mechanism to improve household welfare under increased role of FDI.

- The study indicates that transport sector electrification in the country with substantial affordable renewable energy resources would be a promising option to mitigate global GHG emissions and thus help to minimize the adverse effects of the global climate change in the long run. International communities should support the renewable energy based transport sector electrification program in the developing country through the financial support (with allocation of different GHG mitigation funds under international cooperation) and the proper technology transfer.

b) Carbon tax policy

- This study suggests that the C-tax policy would be a promising pricing instrument for fulfilling the objectives of the climate change policy and energy policies. The national policy makers should give special emphasis on the implementation of C-tax citing the multi-faceted benefits it results in terms of improvement of energy security, indigenous energy resource development, reduction of global and local pollutants.

- The study indicates that introduction of C-tax in Nepal would result in significant reduction in GHG emission and thus help to minimize the adverse effects of the global climate change in the long run. International communities should work together to adopt policies like C-tax and adjust border tax in favor of the commodities produced in the countries adopting such policies.

10.3 Scope for further work

This study is limited to analysing the implications of transport electrification and C-tax policies in terms of the energy system development, energy system costs, energy security, GHG and local pollutant emissions, GDP distribution, consumer welfare, energy and GHG intensities.

Further studies on the transport electrification policy can be done on issues such as, use of different financing mechanisms; effects of the integration of the transport electrification policy with other policies; distributional effects of the policy on the households based on income levels with some modifications in the existing Nepal-ESM and Nepal-CGE models developed in this study. For better understanding the effects of a FDI, it is recommended to develope a global CGE model incorporating the country under study as a sub region.

For the C-tax policy further studies can be done on issues related to the distributional effects of the C-tax revenue recycling on different households based on income level by disaggregating the national household; effects of other C-tax recycling mechanisms other other than lump-sum government transfer to the household; and effects of allocating C-tax revenue in different economic activities like subsidizing in the use of less carbon intensive energy commodity and reducing production tax for less carbon intensive industries by modification in the existing Nepal-CGE model. Futher studies can also be done on the issues related to effects of an integration of the C-tax policy with other policies by modification in the existing Nepal-ESM and Nepal-CGE models.

The existing energy system model and CGE model developed under this study can be used directly or with some modifications for analysing other low carbon development based policies, such as, hydropower development policy by setting targets for different level of hydropower development; clean and green production policy by technology level disaggregation of industrial sectors with provision for cleaner backstop technologies in CGE model; energy tax by introducing additional tax on the energy consumption; emission cap by setting limit to the emissions from particular sector; energy efficiency improvement policy by phasing out of the less energy efficient devices and introduction of energy efficient devices.

References

Abrell, J., 2010. Regulating CO_2 emissions of transportation in Europe: A CGE-analysis using market-based instruments. Transport Research Part D 15, 235-239.

Acharya, S., 2010. Potential impacts of the devaluation of Nepalese currency: A general equilibrium approach. Economic Systems 34, 413-436.

Acharya, S., Cohen, S., 2008. Trade liberalization and household welfare in Nepal. Journal of Policy Modeling 30, 1057-1060.

Ahmed, V., O'Donoghue, C., 2010. External Shocks in a Small Open Economy: A CGE - Microsimulation Analysis. The Lahore Journal of Economics 15 : 1 (Summer 2010), 45-90.

Ale, B.B., Shrestha S.O.Bade, 2009. Introduction of hydrogen vehicles in Kathmandu Valley: A clean and sustainable way of transportation. Renewable Energy 34, 1432-1437.

Alternative Energy Promotion Centre (AEPC), 2009. ESAP II, Lalitpur, Nepal (http://www.aepc.go.np; accessed on 14 March 2009).

Andersson, E., Lukaszewicz, P., 2006. Energy consumption and related air pollution for Scandinavian electric passenger trains. Department of Aeronautical and Vehicle Engineering, Royal Institute of Technology, Stockholm, Sweden (http://www.kth.se/polopoly_fs/1.179879!/Menu/general/column-content/attachment/Energy_060925_full_pdf.pdf; accessed on 11 March 2010).

Andre, M.A., Cardenete, M.A., Velazques, E., 2003. Performing an Environmental Tax Reform in a Regional Economy. A Computable General Equilibrium Approach. Working Paper No. 2003-125. Tilberg University.

Andress, D., Nguyen, T.D., Das, S., 2011. Reducing GHG emissions in the United States' Transportation sector. Energy for Sustainable Develiopment 15(2), 117-136.

Armington, P.S., 1969. A Theory of Demand for Products Distinguished by Place of Production. IMF Staff Papers 16 (March), 159-178.

Asia Pacific Energy Research Centre (APERC), 2007. A Quest for Energy Security in the 21st Century, Resources and Constraints. Tokyo.

Asian Development Bank (ADB), 2002. Hand Book of Integrating Risk Analysis in the Economic Analysis of Projects. Manila.

Asian Development Bank (ADB), 2004. Trolley Bus development in Ring Road of the Kathmandu Valley, Pre-Feasibility Study Report. Prepared by Winrock International Nepal, Kathmandu.

Asian Development Bank (ADB), 2009. Electric Bikes in the People's Republic of China: Impact on the Environment and Prospects for Growth. ADB, Manila.

Asian Development Bank/International Centre for Integrated Mountain Development (ADB/ICIMOD), 2006. Environment Assessment of Nepal, Emerging Issues and Challenges. ICIMOD, Kathmandu.

Babiker, M., Gurgel, A., Paltsev, S., Reilly, J. M., 2008. A Forward Looking Version of the MIT Emissions Prediction and Policy Analysis (EPPA) Model. Report

No.161 (May 2008), MIT Joint Program on the Science and Policy of Global Change.

Bakker, S.J.A., Arvanitakis, A.G., Bole, T., Brug, E., Doets, C.E.M., Gilbert, A., 2007. Carbon credit supply potential beyond 2012. ECN-E-07-090, Eneregy Research Centre of the Neatherlands.(http://www.ecn.nl/docs/library/report/2007/e07090.pdf; accessed on 20 June 2010).

Bardley, R., Yang, M., 2006. Raising the Profile of Energy Efficiency in China - Case study of standby power efficiency. International Energy Agency (IEA), Paris.

Barry, M.P., 2009. Foreign Direct Investments in central Asian Energy: A CGE Model. Eurasian Journal of Business and Economics 2(3), 35-54.

Bataille, C., Jaccard, M., Nyboer, J., Rivers, N., 2006. Towards general equilibrium in a technology-rich model with empirically estimated behavioral parameters. The Energy Journal 27, 93-112 (Special Issue #2: Hybrid modeling of energy-environment policies: Reconciling bottom-up and top-down).

Benjamin, N.C., Devarajan, S., Weiner, R.J., 1989. The Dutch Disease in a Developing Country: Oil Revenues in Cameroon. Journal of Development Economics 30, 71-91.

Bhatta, S.D., Joshi, D.R., 2004. Are electric vehicles viable in Kathmandu? A cost-benefit perspective. Prepared for Kathmandu Electric Vehicle Alliance Secretariat under USAID/Nepal.

Bhattacharyya, S.C., 1996. Applied general equilibrium models for energy studies: a survey. Energy Economics 18, 145–164.

Bhattarai, K.R., 1996. Financial Deepening and Economic Development in Nepal: A Forward Looking CGE Model with Financial Intermediation, Ph.D. Dissertation, The Department of Economics, Northeastern University, Boston, Massachusetts.

Bhattarai, K.R., 2008. On Economic Model for New Nepal. Hull University Business School, Hull, UK. (http://www.accessecon.com/pubs/PET08/PET08-08-00061S.pdf; accessed on 28 June 2008).

Bhattarai, N.P., 2005. Hydropower Development in Nepal - A Study of Demand for Electricity and Financial Requirement up to 2030; Bhattarai, D.K.: Kathmandu, Nepal.

Blanford, G.J., Richels, R.G., Rutherford, T.F., 2009. Feasible climate targets: The roles of economic growth, coalition development and expectations. Energy Economics 31(Supplement 2), S82-S93.

Bohringer, C., 1998. The synthesis of bottom-up and top-down in energy policy modeling. Energy Economics 20 (3): 233-248.

Bohringer, C., Loschel, A., 2006. Promoting renewable energy in Europe: A hybrid computable general equilibrium approach. The Energy Journal 27: 135-150 (Special Issue #2: Hybrid modeling of energy-environment policies: Reconciling bottom-up and topdown).

Bose, R.K., Shukla, M., 1999. Elasticities of Electricity Demand in India. Energy Policy 27 (3), 137–146.

Brenkert, A.L., Sands, R.D., Kim, S.H., Pitcher, H.M., 2004. Model documentation: the second generation model. Pacific Northwest National Laboratory Report 14256. (http://www.globalchange.umd.edu/models/sgm/; accessed on 28 June 2009).

Brinckerhoff, P., 2007. Analysis of Future Issues and Changing Demands on the System: Part M. Significant Systematic Changes to Transportation Infrastructure Capacity, Commission Briefing Paper 4M-02, Comparative Global Performance Trends.(http://transportationfortomorrow.org/final_report/volume_3_html/technical_issues_papers/paper4m_02.aspx; accessed on 21 June 2008).

Brooke, A., D. Kendrick, A. Meeraus, and R. Raman. 1998. GAMS: A user's guide. Washington, D.C.: GAMS Development Corporation.

Buehrer, T., di Mauro, F., 1993, A Computable General Equilibrium Model of Nepal, Report No. 60, Asian Development Bank, Manila.

Burfisher, M.E., 2011. Introduction to Computable General Equilibrium Models. Cambridge University Press, New York.

Central Bureau of Statistics (CBS), 2003a, Population Monograph 2003. National Planning Commission Secretariats, GoN, Kathmandu.

Central Bureau of Statistics (CBS), 2003b. Population Projections for Nepal 2001-2021. National Planning Commission Secretariats, GoN, Kathmandu.

Central Bureau of Statistics (CBS), 2007. Statistical Year Book 2007. National Planning Commission Secretariats, GoN, Kathmandu.

Central Bureau of Statistics (CBS), 2008. Census of Manufacturing Establishments 2006/07, National Level. National Planning Commission Secretariats, GoN, Kathmandu.

Chuanyi, L., 2009. Effects of investment growth in energy sectors of western areas on local economy and emissions: Case of Shaanxi Province of China based on a CGE model. International Journal of Energy Sector Management 3 (1), 29-49.

Chuanyi, L., Xiliang, Z., Jiankun, H., 2010. A CGE analysis to study the impacts of energy investment on economic growth and carbon dioxide emission: A case of Shaanxi Province in western China. Energy 35 (11), 4319-4327.

Dahal, M.K., 2004. Nepalese Economy: Towards Building a Strong Economic Nation-State. Central Department of Economics, Tribhuvan University and New Hira Books Enterprises, Kathmandu.

Dai, H., Masui, T., Matsuoka, Y., Fujimori, S., 2011. Assessment of China's climate commitment and non-fossil energy plan towards 2020 using hybrid AIM/CGE model. Energy Policy 39, 2875-2887.

den Elzen, M.G.J., Höhne, N., 2010. Sharing the reduction effort to limit global warming to 2° C. Climate Policy 10, 247-260.

Devarajan, S., Go, D. S., 1998. The Simplest Dynamic General-Equilibrium Model of an Open Economy. Journal of Policy Modeling 20 (6), 677–714.

Devarajan, S., Go, D., Robinson, S., Thierfelder, K., 2009. Tax Policy to Reduce Carbon Emissions in South Africa. Policy Research Working Paper WPS4933, The World Bank, Africa Region.

Devarajan, S., Lewis, J. D., Robinson, S., 1993. External shocks, purchasing power parity and the equilibrium real exchange rate. World Bank Economic Review 7, 45-63.

Dhakal, S, 2006. Urban transportation and the Environment in Kathmandu Valley, Nepal, first ed. Institute for Global Environmental Strategies (IGES), Hamaya.

Dhungel, H., 1996. Macroeconomic adjustments to large energy investments in a small controlled open economy: A policy analysis of hydropower development in Paraguay. PhD Dissertation, University of Pennsylvania, Pennsylvania.

Drouet, L., Sceia, A., Thalmann, P., Vielle, M., 2006. Evaluation of a Swiss carbon tax with the Computable General Equilibrium Model GEMINI-E3. Research lab on the Economics and Management of the Environment. http://infoscience.epfl.ch/record/117045/files/BAFU_Preliminary_Report_GEMINIE3_REME.pdf.

Dutt, G.S., Ravindranath, N.H., 1993. "Alternative bioenergy strategies for cooking", in Johansson, T.B., Kelly, H., Reddy, A.K.N., and Williams, R.H., (eds.), Renewable Energy: Sources for Fuels and Electricity, Island Press, Washington, DC, pp. 653-697.

Dutt, G.S., 1994. Illumination and sustainable development Part I: technology and economics. Energy for Sustainable Development 1(1), 23–35.

Eaves, S., Eaves, J., 2004. A cost comparison of fuel-cell and battery electric vehicles. Journal of Power Sources 130, 208–212.

Edenhofer, O., Lessmann, K., Bauer, N., 2006. Mitigation strategies and costs of climate protection: Effects of ETC in the hybrid model MIND. The Energy Journal 27: 207-222 (Special Issue #1: Endogenous technological change and the economics of atmospheric stabilisation).

EEA (European Environment Agency), 2009. EMEP/EEA air pollutant emission inventory guidebook — 2009, Technical Report No 6/2009 (Tier 1 default emission factors). Copenhagen, Denmark.

EMEP/CORINAIR, 2007. EMEP/CORINAIR Emission Inventory Guidebook - 2007; European Environment Agency: Copenhagen, Denmark.

Endo, E., 2007. Market penetration analysis of fuel cell vehicles in Japan by using the energy system model MARKAL. Int J Hydro Energy 32,1347–1354.

Energy Information Administration (EIA), 2009a. International Energy Outlook 2009, Washington DC.

Energy Information Administration (EIA), 2009b. Annual Energy Outlook 2009 with Projections to 2030. Washington DC.

Estache, A., Perrault, J., Savard, L., 2008. Impact of Infrastructure Spending in Sub-Saharan Africa CGE Modeling Approach. GREDI Working Paper 08-03, University of Sherbrooke, Quebec.

ETSAP, 2010. Models and Applications: Energy Technology Systems Analysis Programme (ETSAP),USA. (http://www.estap.org; accessed on 12 June 2010).

ESMAP, 2012. Planning for a Low Carbon Future: Lessons Learned from Deven Country Studies. Energy Sector Management Assistance Program, The World

Bank, Washington DC. (https://www.esmap.org/sites/esmap.org/files/ESMAP_LCD-LessonsLearned_2012_0.pdf; accessed on 4 Dec 2010).

European Renewable Energy Council (EREC)/ GREENPEACE, 2008. Energy Revolution: A Sustainable Global Energy Outlook.

Federal Office for Scientific, Technical and Cultural Affairs (FOSTCA), 2001, The Belgian Markal Database. FOSTCA, Brussel, Belgium.

Federation of Nepalese Chambers of Commerce and Industry (FNCCI), 2006. Nepal and the World : A Statistical Profile 2006. Kathmandu.

Gilbert, J., Banik, N., 2010. Socioeconomic impacts of Cross-Border Transport Infrastructure Development in South Asia. ADBI Working paper Series No. 211. Tokyo: Asian Development Bank Institute. (http://www.adbi.org/working-paper/2010/04/14/3655.socioeconomic.transport.infrastructure/; accessed on 20 June 2010).

Grubb, M., Butler, L., Twomey, P., 2006. Diversity and security in UK electricity generation: The influence of low-carbon objectives. Energy Policy 34(18), 4050–4062.

Gyawali, D., Dixit, A., Upadhya, M., 2004. Ropeways in Nepal. Nepal Water Conservation Foundation (NWCS), Kathmandu.

Haddad, E.A., Hewings, G.J.D., 2004. Transportation Costs, Increasing Returns and Regional Growth: An Interregional CGE Analysis. (http://www.iioa.org/pdf/Intermediate-2004/351.pdf; accessed on 12 September 2010).

Holmoy, E., Heide, K.M., 2005. Is Norway immune to Dutch Disease? CGE Estimates of Sustainable Wage Growth and De-industrialization. Discussion Papers No. 413, March 2005, Statistics Norway, Research Department, Kongsvinger.

Hosoe, N., Gasawa, K., Hashimoto, H., 2010. Textbook of Computable General Equilibrium Modeling: Programming and Simulations. Palgrave Macmillan, Hampshire.

Hourcade, J.C., Jaccard, M., Bataille, C., Ghersi, F., 2006. Hybrid modeling: New answers to old challenges – Introduction to the special issue of The Energy Journal. The Energy Journal 27, 1-11 (Special Issue #2: Hybrid modeling of energy-environment policies: Reconciling bottom-up and top-down).

Ichinohe, M., Endo, E., 2006. Analysis of the vehicle mix in the passenger-car sector in Japan for CO2 emissions reduction by a MARKAL model. Applied Energy 83, 1047-1061.

Indian Institute of Management India (IIM), 2009. Low Carbon Society Vision 2050. India.

Institute for Energy and Environmental Research Heidelberg (IFEU), 2010. Ecological Transport Information Tool for Worldwide Transports: Methodology and Data. pp. 41-44. (http://www.ecotransit.org/download/ecotransit_background_report.pdf; accessed on 21 December 2010).

Institute for Policy Research and Development (IRPAD), 2007. GTAP Compatible Input Output (I/O) Table and Social Accounting Matrix (SAM) for Nepal, Final Report. Submitted to Enhancing Nepal's Trade-Related Capacity/UNDP, Kathmandu.

Intergovernmental Panel on Climate Change (IPCC), 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Institute for Global Environmental Strategies, Japan.

Intergovernmental Panel on Climate Change (IPCC), 2007a. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (eds.), Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC), 2007b. Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (2007). Metz B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A. (eds), Cambridge University Press.

International Energy Agency (IEA), 2005. Energy Technology Analysis: Prospects for Hydrogen and Fuel Cells. Paris.

International Energy Agency (IEA), 2008. Energy Technology Perspectives 2008: Scenarios and Strategies to 2050. Paris.

Jaccard, M., Nyboer, J., Bataille, C., Sadownik, B., 2003. Modeling the cost of climate policy: Distinguishing between alternative cost definitions and long-run cost dynamics. The Energy Journal 24 (1): 49-73.

Jacoby, H.D., Reilly, J.M., McFarland, J.R., Paltsev, S., 2006. Technology and technical change in the MIT EPPA model. Energy Economics 28: 610-631 (Special Issue: Technological change in climate policy analysis).

Japan Bank for International Cooperation (JBIC), 2004. Sector Study for Power Sector in the Kingdom of Nepal, Final Report. Tokyo.

Japan International Corporation Agency (JICA), 1992. The Study on Kathmandu Valley Urban Road Development Interim Report, Volume 1. Department of Road, Ministry of Works and transportation, GoN, Kathmandu, Nepal.

Jegarl, S., Baek, J., Jang, D., Ryu, C., 2009. Impact assessment of CO2 mitigation options in Korea using energy system analysis model, Energy Procedia 1 (2009) 3747–3754.

Jha, D.K., Yorino N., Zoka, Y., 2007. A Modified DEA Model for Benchmarking of Hydropower Plants. Power Tech 2007 IEEE Lausanne, 1374-1379, doi 10.1109/PCT.2007.4538516.

Kainuma, M., Shukla, P.R., Jiang, K., 2012. Framing and Modeling of a Low Carbon Society: An Overview, Energy Economics (2012), doi: 10.1016/j.eneco.2012.07.015.

Karki, S., Mann, M.D., Salehfar, H., 2007. Substitution and Price Effects of carbon Tax on CO2 Emissions Reduction from Distributed Energy Sources. Presented at Power Systems Conference: Advanced Metering, Protection, Control, Communication, and Distributed Resources, 14-17 March 2006, 236-243. (http://ieeexplore.ieee.org/stamp/ stamp.jsp?tp=&arnumber=4064674; accessed on 8 Dec 2010)

Karplus, V.J., Paltsev, S., Reilly, J. M., 2009. Prospects for Plug-in Hybrid Electric Vehicles in the United States and Japan: A General Equilibrium Analysis. Report

No.172 (April 2009), MIT Joint Program on the Science and Policy of Global Change.

Kazim, A., 2003. Introduction of PEM fuel-cell vehicles in the transportation sector of the United Arab Emirates. Applied Energy 74, 125–133.

Kenworthy, J.R., Laube, F.B., 1999. An International Source Book of Automobile Dependence in Cities 1960-1990. University Press of Colorado, Colorado.

Kim, E., Hewings G.J.D., 2003. An Application of Integrated Transport Network-Multiregional CGE Model II: Calibration of Network Effects of Highway. Paper presented at the 42nd Southern Regional Science Association in Louisville, KY, April 10-12, 2003. (http://www.real.illinois.edu/d-paper/03/03-t-24.pdf; accessed on 28 June 2009).

Kim, J., Moon, I., 2008. The role of hydrogen in the road transportation sector for a sustainable energy system: A case study of Korea. International Journal of Hydrogen Energy 33, 7326 – 7337.

Kim, K.S., 2004. A Study on the Economic Implications of Domestic Greenhouse Gas Emission Trading: A Computable General Equilibrium Model for Korea. PhD Dissertation (ET-04-1), Asian Institute of Technology, Thailand.

Kojo, N.C., 2005. Bhutan: Power Exports and Dutch Disease. Centre for Bhutan Studies: Monographs. (http://www.asia-studies.com/2bhutanmono.html; accessed on 28 June 2010).

Kruyt, B., van Vuuren, D.P., de Vries, H.J.M., Groenenberg, H., 2009. Indicators for energy security. Energy Policy 37, 2166–2181.

Kyophilavong, P., Toyoda, T., 2008. Foreign capital inflows in the natural resource sectors: Impacts on the Lao economy. Paper presented at The Future of Economic Integration in Asia Conference, 20-21 Nov 2008, Bangkok, Thailand.

Kypreos, S., Regemorter, D.V., Guel, T., 2006. Key Drivers for Energy Trends in EU; Specification of the Baseline and Policy Scenarios. Working paper RS2, WP2.3, New Energy Externalities Developments for Sustainability (NEEDS) Integrated Project.

Levin, T., Thomas, V.M., Lee, A.J., 2011. State-scale evaluation of renewable electricity policy: The role of renewable electricity credits and carbon taxes. Energy Policy 39, 950-960.

Levy, S., 2007. Public Investment to Reverse Dutch Disease: the Case of Chad. Journal of African Economics 16(3), 439-484.

Limmeechokchai, B., Hieu, N.D., 2003. Integrated Resource Planning with Carbon Tax: Effects on Power Generation Expansion Planning in Vietnam. Thammasat International Journal of Science and Technology 8(2), 55-64.

Loschel, A., 2004. Technologies, energy consumption and environmental policy in energy–economy models. International Journal of Energy Technology and Policy 2 (3), 250– 261.

Loulou, R., Goldstein, G., Noble, K., 2004. Documentation for the MARKAL Family of Models. Energy Technology Systems Analysis Programme. (http://www.etsap.org/MrklDoc-I_StdMARKAL.pdf; accessed on 4 June 2008).

Loulou, R., Lavigne, D., 1996. MARKAL model with elastic demands: Application to GHG emission control. In: Operations Research and Environmental Engineering, edited by C. Carraro and A. Haurie, 201-20. Boston: Kluwer Academic Publishers.

Maplecroft, 2011. Climate Change Vulnerability Map 2011. (http://www.maplecroft.com; accessed on 4 June 2011).

Manne, A.S., Richels, R.G., Mendelsohn, R., 1995. MERGE: A model for evaluating regional and global effects of GHG reduction policies. Energy Policy 23: 17-34.

Manne, A.S., Wene. C.O., 1992. MARKAL-MACRO: A linked model for energy-economy analysis. Brookhaven National Laboratory.

Martinsen, D., Linssen, J., Markewitz, P., Vogele, S., 2007. CCS: A future CO2 mitigation option for Germany?-A bottom-up approach. Energy Policy 35, 2110–2120.

Mathur, J., Bansal, N.K., Wagner, H.J., 2003. Investigation of greenhouse gas reduction potential and change in technological selection in Indian power sector. Energy Policy 31, 1235–1244.

McFarland, J.R., Reilly, J.M., Herzog, H.J., 2004. Representing energy technologies in top-down economic models using bottom-up information. Energy Economics 26(4), 685-707.

Ministry of Energy (MOE), 2010. Twenty-Year Hydropower Development Plan 2010-2030, Twenty-Year Hydropower Development Plan Implementation Task Force, GoN, Kathmandu.

Ministry of Environment (MOEV), 2010. Climate Change Policy 2010. GoN, Kathmandu.

Ministry of Finance (MOF), 2007. Economic Survey Fiscal Year 2006/07. GoN, Kathmandu.

Ministry of Finance (MOF), 2009. Economic Survey Fiscal Year 2008/09. GoN, Kathmandu.

Ministry of Industry (MOI), 2010. Industrial Policy 2010 (2067). GoN, Kathmandu.

Ministry of Physical Planning and Works (MOPPW), 2007. Vision paper -2007, New Physical Infrastructure – Foundation of the New Nepal. GoN, Kathmandu.

Ministry of Population and Environment (MOPE), 2004, Nepal Initial National Communication to the Conference of the Parties of the United Nations Framework Convention on Climate Change, MoPE, GoN, Kathmandu.

Ministry of Water Resource (MOWR), 2009. Ten Ten-Year Hydropower Development Plan 2010-2020, Part 1: Main Report. Ten Year Hydropower Development Plan Implementation Task Force, GoN, Kathmandu.

Morrow, K., Karner, D., Francfort, J., 2008. Plug-in Hybrid Electric Vehicle Charging Infrastructure Review, Final Report. Battelle Energy Alliance Contract No. 58517, Prepared for the U.S. Department of Energy Assistant Secretary for Energy Efficiency and Renewable Energy.

Nakata, T., 2003. Energy modeling on cleaner vehicles for reducing CO_2 emissions in Japan. Journal of Cleaner Production 11, 389–396.

Nakata, T., Lamont, A., 2001. Analysis of the impacts of carbon taxes on energy systems in Japan. Energy Policy 29,159–166.

Nakata, T., Silva, D., Rodionov, M., 2011. Application of energy system models for designing a low-carbon society. Progress in Energy and Combustion Science 37(2011), 462-502.

National Environmental and Scientific Services (NESS), 2003. Analysis of HMG Policies and Regulations affecting Electric Vehicles, Final report. Kathmandu.

National Institute for Environmental Studies (NIES), 2007, Aligning Climate Change and Sustainability – Scenarios, Modeling and Policy Analysis. Asia Pacific Integrated Modeling Team, Center for Global Environment Research, NIES, Tokyo.

Nepal Electricity Authority (NEA), 2005. Corporate Development Plan FY2004/05-2008/09, Kathmandu.

Nepal Electricity Authority (NEA), 2006, Nepal Electricity Authority Fiscal Year 2005/06-AYear in Review. Kathmandu.

Nepal Electricity Authority (NEA), 2008a, Nepal Electricity Authority Fiscal Year 2007/08-AYear in Review. Kathmandu.

Nepal Electricity Authority (NEA), 2008b. Nepal Electricity Authority Generation 6th Issue. Kathmandu.

Nepal Rastra Bank (NRB), 2006. Report on Household Budget Survey Nepal (Mid-Nov 2005 - Mid-Nov 2006). Kathmandu.

Nepal Rastra Bank (NRB), 2007. Economic Report 2006/07. Kathmandu.

Nexant SARI/Energy, 2002. Regional Hydro-power Resources: Status of Development and Barriers, Prepared for USAID-SARI/Energy Program.

Nguyen, Q.K., 2005. Long term optimization of energy supply and demand in Vietnam with special reference to the potential of renewable energy, Ph. D. Dissertation, University of Oldenburg, Germany.

Osmani, S.R., Bajracharya, B.B., Tenzing, S., Wangyal, T., 2007. Annex 5, Hydropower and Dutch Diesease. In Macroeconomics of Poverty Reduction: The case study of Bhutan. 2nd Edition, A report prepared for UNDP under its regional project on the 'Macroeconomics of Poverty Reduction'. UNDP Regional Centre in Colombo. (http://www.undp.org.bt/assets/files/publication/Macroeco_cs_for_Bhutan.pdf; accessed on 20 Nov 2010).

Palatnik, R.R., Shechter, M., 2010. Assessing the Economic Impacts of Climate Change Using a CGE Model with Decentralized Market Instruments. Journal of Siberian Federal University. Humanities & Social Sciences 6 (2010-3), 912-923.

Paltsev, S., Reilly, J. M., Jacoby, H.D., Eckaus, R.S., McFarland, J., Sarofim, M., Asadoorian, M., Babiker, M., 2005. The MIT Emissions Prediction and Policy Analysis (EPPA) Model: version 4. Report No.125 (August 2005), MIT Joint Program on the Science and Policy of Global Change.

Paltsev, S., Viguir, L., Babiker, M., Reilly, J., Tay, K.H., 2004. Disaggregating Household Transport in the MIT-EPPA Model. Techinical Note No.5 (July 2004), MIT Joint Program on the Science and Policy of Global Change.

Pradhan, S., Ale, B.B., Amatya, V.B., 2006. Mitigation Potential of Greenhouse Gas Emission and Implications on Fuel Consumption due to Clean Energy Vehicles as Public Passenger Transport in Kathmandu Valley of Nepal: A Case Study of Trolley Buses in Ring Road, Energy 31, 1748-1760.

Promotion of Renewable Energy, Energy Efficiency and GHG Abatement Nepal (PREGA), 2006a. Development of an East-West Electric Railway in Nepal, Pre-Feasibility Study Report. Winrock International Nepal, Kathmandu.

Promotion of Renewable Energy, Energy Efficiency and GHG Abatement Nepal (PREGA), 2006b. Sisdol Landfill Gas to Energy Project- A CDM Project Design Document. Winrock International Nepal, Kathmandu.

Proost, S., van Regemorter, D., 2000. How to achieve the Kyoto target in Belgium – modelling methodology and some results. Working paper series no 2000-09. Katholieke Universiteit Leuven.

Quasem, A.A., Abdul Hamid, Jaafar, A.H., Siwar, C., 2008. Macroeconomic effects of carbon dioxide emission reduction: a computable general equilibrium analysis for Malaysia. MPRA Paper No. 8667. (http://mpra.ub.uni-muenchen.de/8667/; accessed on 20 May 2009).

Rai, S., Koirala, D., 2006. Prospects of Jatropa Biodiesel in Nepal. In: Proceedings of the First National Conference on Renewable Energy Technology for Rural Development (RETRUD-06), 12-14 October 2006, Centre for Energy Study, Kathmandu, p.153-157.

Rao, S., Kepp. I., Riahi, K., 2006. Importance of technological change and spillovers in longterm climate policy. The Energy Journal 27: 123-139 (Special Issue #1: Endogenous technological change and the economics of atmospheric stabilisation).

Reddy, M.S., Venkataraman, C., 2002a. Inventory of aerosol and sulphur dioxide emissions from India: I – Fossil fuel combustion. Atmospheric Environment 36, 677-697.

Reddy, M.S., Venkataraman, C., 2002b. Inventory of aerosol and sulphur dioxide emissions from India: II – Biomass combustion. Atmospheric Environment 36, 699-712.

RITES Ltd. and SILT Consultants (RITES/SILT), 2010. Feasibility Study of Mechi-Mahakali and Pokhara-Kathmandu Electric Railway. Submitted to Ministry of Physical Planning and Works (MOPPW), GoN, Kathmandu.

Rosenthal, R.E., 2011. GAMS - A User's Guide. Washington, D.C.: GAMS Development Corporation.

Ruehle, B., 2005. Global Long-Term Demand for Transportation: Interim Report. International Institute for Applied Systems Analysis, Luxemburg, Austria.

Sadeghi, M., Hosseini, H.M., 2008. Integrated energy planning for transportation sector—A case study for Iran with techno-economic approach. Energy Policy 36, 850–866.

Sands, R., 2004. Dynamics of carbon abatement in the Second Generation Model. Energy Economics 26(4), 721-738.

Sands, R., Fawcett, A., 2005. The Second Generation Model: Data, Parameters, and Implementation. Prepared for the United States Environmental Protection Agency.

Santisirisomboon, J., Limmeechokchai, B., Chungpaibulpatana, S., 2001. Impacts of biomass power generation and CO_2 taxation on electricity generation expansion planning and environmental emissions. Energy Policy 29(12), 975-985.

Sapkota, P.P., Cockburn, J., 2008. Trade Liberalization and Poverty in Nepal: An Applied General Equilibrium Analysis. Poverty and Economic Policy Network, MPIA Working Paper 2008-13.

Sapkota. P.R., Sharma, R. K., 1998. A Computable General Equilibrium Model of the Nepalese Economy. Paper presented at the Micro Impacts of Macroeconomic and Adjustment Policies (MIMAP), Third Annual Meeting, 2-6 Nov 1998, Kathmandu. (http://www.idrc.ca/uploads/user-S/10282122230mimap56.pdf; accessed on 8 June 2008).

Scaramucci, J.A., Perin, C., Pulino, P., Bordoni, Orlando F.J.G., da Cunha, Marcelo P., Cortez, Luis, A.B., 2006. Energy from sugarcane bagasse under electricity rationing in Brazil: A computable general equilibrium model, Energy Policy 34, 986–992.

Schafer, A., Jacoby, H.D., 2005. Technology detail in a multisector CGE model: transport under climate policy. Energy Economics 27, 1-24.

Schafer, A., Jacoby, H.D., 2006a. Vehicle technology under CO2 constraint: a general equilibrium analysis. Energy Policy 34, 975-985.

Schafer, A., Jacoby, H.D., 2006b. Experiments with a hybrid CGE-MARKAL Model. The Energy Journal 27: 171-177 (Special Issue #2: Hybrid modeling of energy-environment policies: Reconciling bottom-up and top-down).

Schmidt, J., Leduc, S., Dotzauer, E., Schmid, E., 2011. Cost-effective policy instruments for greenhouse gas emission reduction and fossil fuel substitution through bioenergy production in Austria. Energy Policy (2011), doi:10.1016/j.enpol.2011.03.018.

Schumacher, K., 2007. Innovative Energy Technologies in Energy Economy Models: Assessing economic, energy and environmental impacts of climate policy and technological change in Germany. PhD. Dissertation, Humboldt University of Berlin, Germany.

Schumacher, K., Sands, D.R., 2006. Innovative energy technologies and climate policy in Germany. Energy Policy 34(18), 3929-3941.

Shakya, S.R., Kumar, S., Shrestha, R.M., 2012. Co-benefits of a carbon tax in Nepal. Mitig. Adapt. Strateg. Glob. Change 17 (1), 77–101.

Shakya, S.R., Shrestha, R.M., 2011. Transport sector electrification in a hydropower resource rich developing country: energy security, environmental and climate change co-benefits. Energy Sustainable Dev. 15, 147–159.

Shiwakoti, R.G., 2006. Pricing of Electricity for Generation in Nepal. Master Thesis, Tribhuvan University, Kathmandu.

Shoven, J.B. and Whalley, J., 1992. Using applied general equilibrium models, chapter five in Applying General Equilibrium, Cambridge surveys of economic literature, Cambridge.

Shrestha R.M., Pradhan, S., Liyanage, M.R., 2008. Effects of Carbon Tax on Greenhouse Gas Mitigation in Thailand. Climate Policy 8 Supplement 1(2008), 140–155.

Shrestha R.M., Shrestha, R., Bhattacharya, S.C., 1998. Environmental and electricity planning implications of carbon tax and technological constraints in a developing country. Energy Policy 26(7), 527-533.

Shrestha, R.M., Marpaung, C.O.P., 1999. Supply-and demand-side effects of carbon tax in the Indonesian power sector: an integrated resources planning analysis. Energy Policy 27(4), 185-194.

Shrestha, R.M., Rajbhandari, S., 2010. Energy and environmental implications of carbon emission reduction targets: Case of Kathmandu Valley, Nepal. Energy Policy 38(9), 4818-27.

Shrestha, R.M., Shakya, S.R., 2012. Benefits of low carbon development in a developing country: Case of Nepal, Energy Economics (2012), doi:10.1016/j.eneco. 2012.03.014.

Shrestha, S.L., 2007. Long Term Energy System Planning of Nepal: An Assessment of Linkage between Electrified transport sector and Hydropower Development. M.Sc. Thesis, Asian Institute of Technology, Thailand.

Shukla, P.R., Dhar, S., Mahapatra, D., 2008. Low-caron society scenarios for India. Climate Policy 8 Supplement 1 (2008), 156–176.

Siddiqui, R., 2007. Quantifying the impacts of Development of Transport sector in Pakistan. The Pakistan development Review 46(4), 779-802.

Siriwardana, M., Meng, S., McNeill, J., 2011. The Impact of a Carbon Tax on the Australian Economy: Results from a CGE Model. Business, Economics and Public Policy Working Papers, Number: 2011 – 2. University of New England's School of Business Economics and Public Policy, Armidale, Australia.

Smith, K.R., Uma, R., Kishore,V.V.N., Lata, K., Joshi, V., Zhang, J., Rasmussen, R.A., Khalil, M.A.K., 2000. Greenhouse Gases from Small-Scale Combustion Devices in Developing Countries: Phase IIa Household Stoves in India. Prepared for USEPA, Washington, DC.

Sue Wing, I., 2003. Computable General Equilibrium Models and Their Use in Economy-Wide Policy Analysis: Everything You Ever Wanted to Know (But Were Afraid to Ask).

Sue Wing, I., 2006a. The Synthesis of Bottom-up and Top-down Approaches to Climate Policy Modeling: Electric Power Technologies and the Cost of Limiting US CO_2 Emissions. Energy Economics 34, 3847–3869.

Sue Wing, I., 2006b. Representing Induced Technological Change in Models for Climate Policy Analysis. Energy Economics 28, 539–562.

Sue Wing, I., 2008. The Synthesis of Bottom-up and Top-down Approaches to Climate Policy Modeling: Electric Power Technology Detail in a Social Accounting Framework. Energy Economics 30, 547–573.

Sue Wing, I., 2009. Computable General Equilibrium Models for the Analysis of Energy and Climate Policies. In J. Evans and L.C. Hunt (eds.), International Handbook on the Economics of Energy, Cheltenham: Edward Elgar, 332-366.

The Energy and Resources Institute (TERI), 2006. National Energy Map for India: Technology Vision 2030. TERI Press, Delhi.

Timilsina, G.R., 2001. A General Equilibrium Analysis of Greenhouse Gases Mitigation Policy Options in Thailand, Ph.D. Dissertation, Asian Institute of Technology, Thailand.

Timilsina, G.R., Shrestha, R.M., 2002. A general equilibrium analysis of economic and environmental effects of carbon tax in a developing country: case of Thailand. Environmental Economics and Policy Studies 5, 179–211.

Timilsina, G.R. and Shrestha, R.M.,2007. Alternative Tax Instruments for CO2 Emission Reduction and Effects of Revenue Recycling Schemes. Energy Studies Review 15 (1), 19-48.

United States Environmental Protection Agency (USEPA), 2006, MARKAL Scenario Analyses of Technology Options for the Electric Sector: The Impact on Air Quality, EPA, Washington DC.

United States Environmental Protection Agency (USEPA), 2010. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008, EPA 430-R-10-006, Annex 3.2, April 2010. (http://www.unep.org/publications/ebooks/emissionsgapreport; accessed 29 May 2010).

United Nations (UN), 1974. Manual VIII Methods for Projections of Urban and Rural Population. UN, New York.

United Nations (UN), 2008. World Population Prospects: The 2008 Revision. Department of Economic and Social Affairs, Population Division, New York.

United Nations Development Programme (UNDP), 2004. Nepal Human Development Report 2004. UNDP, Kathmandu, Nepal.

United Nations Environment Program, Regional Resource Centre for Asia / Centre for Energy Studies (UNEP/CES), 2005. A Study on Hydrogen Gas Production From Surplus Hydropower and Its Utilization in Vehicles in Nepal, Thailand.

United Nations Environment Programme (UNEP), 2010. The Emissions Gap Report: Are the Copenhagen Accord Pledges Sufficient to Limit Global Warming to 2ºC or 1.5ºC ?, A preliminary assessment. Full Report. Kenya, (http://epa.gov/climatechange/ emissions/ downloads10/US-GHG-Inventory-2010_Report.pdf; accessed 29 December 2010).

United Nations Population Division (UNPD), 2009. World Population Prospects: The 2008 Revision. Department of Economic and Social Affairs, New York.

Van Heerden, J., Gerlagh, R., Blignaut, J., Horridge, M., Hess, S., Mabugu, R., Mabugu, M., 2006. Searching for triple dividends in South Africa: Fighting CO2 pollution and poverty while promoting growth. The Energy Journal 27 (2), 113-141.

van Vuuren, D.P., Hoogwijk, M., Barker, T., Riahi, K., Boeters, S., Chateau, J., Scrieciu, S., Vliet, J., Masui, T., Blok, K., Blomen, E., Kram, T., 2009. Comparison of top-down and bottom-up estimates of sectoral and regional greenhouse gas emission reduction potentials. Energy Policy 37 (2009), 5125–5139.

Varian, H.R., 1992. Microeconomic Analysis, Third Edition, W.W. Norton & Company, New York.

Warr, P., 2006. The Gregory Thesis Visits the Tropics. The Economic Record 82 (257), 177-194.

Watcharejyothin, M., 2010. Analysis of Economic and Environmental Implications for Thailand of Integrated Energy Resource Development in Selected Greater Mekong Subregion Countries. PhD Dissertation, Asian Institute of Technology, Thailand.

Water and Energy Commission Secretariat (WECS), 1995. Energy Resources Base of Nepal, Perspective Energy Plan Supporting Document No.2. GoN, Kathmandu.

Water and Energy Commission Secretariat (WECS), 1999. Detailed Energy Consumption Survey in The Commercial Sector of Nepal. GoN, Kathmandu.

Water and Energy Commission Secretariat (WECS), 2000. Detailed Energy Consumption Survey in Transport Sector of Nepal, Volume 2 (Annexes). GoN, Kathmandu.

Water and Energy Commission Secretariat (WECS), 2001. Agriculture Sector Energy Consumption in Nepal. GoN, Kathmandu.

Water and Energy Commission Secretariat (WECS), 2005a, National Water Plan 2005. Ministry of Water Resources, GoN, Kathmandu.

Water and Energy Commission Secretariat (WECS), 2005b. Detailed Energy Consumption Survey in Urban Residential Sector of Nepal. GoN, Kathmandu.

Water and Energy Commission Secretariat (WECS), 2006a. Energy Synopsis Report 2006. Ministry of Water Resources, GoN, Kathmandu.

Water and Energy Commission Secretariat (WECS), 2006b, Energy Usage Pattern in the Industrial Sector of Central Development Region, GoN, Kathmandu.

Webster, M., Paltsev, S., Reilly, J., 2008. Autonomous efficiency improvement or income elasticity of energy demand: Does it matter? Energy Economics 30 (2008), 2785–2798.

Welsch, H., 1998. Coal subsidization and nuclear phase-out in a general equilibrium model for Germany. Energy Economics 20 (2), 203-222.

Winkler, H., Marquard, A., 2009. Analysis of the economic implications of a carbon tax. The economics of climate change mitigation, Energy Research Centre, University of Cape Town. (http://www.erc.uct.ac.za/Research/publications/09Winkler-Marquard-carbon_tax.pdf; accessed 29 December 2011).

Wissema, W, Dellink, R., 2007. AGE analysis of the impact of a carbon energy tax on the Irish economy. Ecological Economics 61(4), 671–683.

World Bank, 2003. Project Appraisal Document for a Nepal Power Development Project, April, 2003. Washington DC.

Xu, Y., 2010. Carbon tax or cap-and-trade: a computable general equilibrium analysis of Chinese economy. The James Hutton Institute. (http://www.econmodels.com/upload7282/27172cc93d8292880bf6d7eb8103cfd9.pdf; accessed 29 December 2011).

Yusuf, A.A., Resosudarmo, B.P., 2007. On the Distributional Effect of Carbon Tax in Developing Countries: The Case of Indonesia. Australian National University, Economics and Environment Network Working Paper, EEN0706.

Yusuf, S., Nabeshima, K., 2006. Postindustrial East Asian cities: innovation for growth. International Bank for Reconstruction and development/ the World Bank, Wasington DC.

Zhang, J., Smith, K.R. , Ma, Y., Ye, S., Jiang, F., Qi, W., Liu, P., Khalil, M.A.K., Rasmussen, R.A., Throneloe, S.A., 2000. Greenhouse gases and other airborne pollutants from household stoves in China: a database for emission factors. Atmospheric Environment 34, 4537-4549.

Zhong, X.Z., 1998. Macroeconomic Effects of CO_2 Emission Limits: A Computable General Equilibrium Analysis for China. Journal of Policy Modeling 20(2), 213-250.

Zhou, S., Shi, M., Li, N., Yuan, Y., 2011. Impacts of Carbon Tax Policy on CO2 Mitigation and Economic Growth in China. Advances in Climate Change Research 2(3), 124-133.

Publications from this study

Shakya, S.R., Kumar, S., Shrestha, R.M., 2012. Co-benefits of a carbon tax in Nepal. Mitigation and Adaptation Strategies for Global Change 17 (1), 77–101.

Shakya, S.R., Shrestha, R.M., 2011. Transport sector electrification in a hydropower resource rich developing country: energy security, environmental and climate change co-benefits. Energy for Sustainable Development 15, 147–159.

Shrestha, R.M., Shakya, S.R., 2012. Benefits of low carbon development in a developing country: Case of Nepal, Energy Economics (2012), In Press, Corrected Proof, Available online 27 March 2012.

Shrestha, R.M., Shakya, S.R., 2010. Nepal-MARKAL: Carbon Tax Effects. Presented in the second Asia Modeling Exercise Meeting held on March 23-25, 2010, at Wenjin Hotel, Beijing, China.

Shrestha, R.M., Shakya, S.R., 2010. Nepal-MARKAL: Effects of Some Low Carbon Strategies in Transport and Power Sectors of Nepal. Presented in the third Asia Modeling Exercise Meeting held on Sept 13-15, 2010, at Grand Hilton Seoul Hotel, Seoul, Korea.

APPENDICES

Appendix A

This appendix contains level of disaggregation of the service demands and associated fuel considered in the Nepal-ESM model.

Detail disaggregation of service demands

Sector	Subsector	Service demand	Fuel
Agriculture	Irrigation	Irrigation pumping	Diesel, Electricity
	land tilling	Land tilling	Diesel
Commercial	Education, Hotel and restaurant, Health, Other services	Air conditioning, Cooking, Lighting, Space heating, Water boiling, Other electrical appliances	Electricity, Biomass, Kerosene, LPG, Solar
Industrial	Cement Iron and rod Brick Sugar Pulp and paper Other industries	Mechanical processing Thermal processing Lighting	Bagasse, Diesel, Electricity, Fuelwood, Kerosene
Residential	Kathmandu valley Mid hills rural Mid hills urban Mountain rural Mountain urban Terai rural Terai urban	Agro-processing and animal feed preparation, Cooking, Lighting, Space cooling, Space heating, Water boiling, Computer, Refrigerator, TV	Biomass, Electricity, Kerosene, LPG, Solar
Transportation	Air freight	Freight-Air plane (Domestic and International)	ATF
	Rope way freight	Fright-Rope way	Electricity
	Land freight	Pick up, Tractor, Truck	Biodiesel, Diesel, Electricity
	Air passenger	Passenger-Air plane (Domestic and International)	ATF
	Cable car passenger	Passenger-Cable Car	Electricity
	Land passenger	Bus, Micro bus, Cars , Taxi, 3-wheelers, 2-wheelers	Biodiesel, Diesel, Electricity, Ethanol, Gasoline, Hydrogen, LPG

Appendix B

This appendix contains the detail of the techno-economic characteristics of technologies considered in the demand side and supply side of Nepal-ESM model.

Appendix B.1: Techno-economic characteristics of the transportation technologies considered in the model

Transport technology	Fuel used	Life time (years)[a]	Energy intensity (GJ/1000pkm, GJ/1000tkm)[a]	Investment cost (2005 US$/vehicle)[a]	Annual service delivered (1000pkm/vehicle/year, 1000tkm/vehicle/year)[b,c]	
					Kathmandu	RoN
Bus	D/BD	14	0.16	53,333	1980	2507.9
Bus (electrical)	E	12	0.05	104,748	1980	2507.9
Bus (diesel hybrid)[d]	D+E	14	0.11	82,380	1980	2507.9
Bus (fuel cell)	H	14	0.07	136,250	1980	2507.9
Trolley bus	E	14	0.10	115,044	1980	
Mini bus	D/BD	12	0.23	26,000	1113.8	1335.6
Car (diesel)	D/BD	8	0.91	8,344	47.2	72.2
Car (gasoline)	G/GH	8	0.87	8,323	44.3	57.4
Car (electrical)	E	8	0.25	17,365	44.3	57.4
Car (diesel hybrid) [d]	D+E	8	0.57	13,146	47.2	72.2
Car (gasoline hybrid) [d]	G+E	8	0.55	13,124	44.3	57.4
Car (fuel cell)	H	8	0.37	21,845	44.3	57.4
Taxi	G+GH	8	0.87	8,323	96.5	95
Taxi (electrical)	E	8	0.25	19,704	96.5	95
Taxi (gasoline hybrid) [d]	G+E	8	0.55	14,723	96.5	95
Taxi (fuel cell)	H	8	0.37	21,845	96.5	95
3-wheelers	D/BD	7	0.30	4,696	323.4	371.2
3-wheelers (LPG)	L	7	0.20	3,569	323.4	346.2
3-wheelers (electrical)	E	7	0.08	6,384	323.4	346.2
Micro-bus	D/BD	12	0.14	11,164	445.5	445.5
Micro-bus (LPG)	LPG	12	0.14	10,967	445.5	445.5
Micro-bus (Electrical)	E	12	0.07	25,945	445.5	445.5
2-wheelers	G+GH	7	0.30	935	17.5	18.3
2-wheelers (Electrical)	E	7	0.17	1,269	17.5	18.3
Truck	D/BD	12	1.26	32,038	213.7	267.1
Truck (diesel hybrid) [d]	D+E	12	1.01	57,288	213.7	267.1
Pick-up	D/BD	10	2.23	19,223	71.2	89
Pick-up (diesel hybrid) [d]	D+E	10	1.38	31,343	71.2	89
Tractor	D/BD	10	2.68	6,408	29.3	36.6
Electric Mass Transport technology	**Fuel used**	**Life time (years)**	**Energy intensity (GJ/1000pkm, GJ/1000tkm)**	**Investment cost (US$/1000pkm-yr, US$/1000tkm-yr)**	**Infrastructure Investment cost (US$/1000pkm-yr, US$/1000tkm-yr)**	
Passenger Train [e,f,g]	E	15	0.07	9.31	356.56	
Freight Train [e,f,g]	E	15	0.10	9.00	179.51	
MRT (surface rail) [e,f,g]	E	15	0.17	13.99	356.56	
Freight Train (Kathmandu) [e,f,g]	E	15	0.23	12.72	179.51	
Passenger ropeway [h]	E	15	0.45	445		
Freight ropeway [h]	E	15	5.44	5336		

Note: D≡Diesel, BD≡10% blend Bio-diesel, G≡Gasoline, GH≡10% blend Gasohol, E≡Electricity, H≡Hydrogen, L≡LPG

a. Cost, efficiency and life time of transport technologies are based on several national and international resources. Major data are taken from ADB (2009); Bhatta and Joshi (2004), Dhakal (2006), IEA (2008), NIES (2007), TERI (2006), Eaves and Eaves (2004).
b. Occupancy rate are considered as 10 persons for 3-wheelers, 1.6 person for 2-wheelers, 50 persons for bus, 30 persons for mini-bus, 2.6 persons for car and taxi, 12 persons for micro-bus, 6 tons for truck, 2 tons for pick up and tractor (Dhakal, 2006; WECS, 2000).
c. Annual distance travel by different mode of transport are taken from Dhakal (2006) and WECS (2000).
d. Hybrid passenger and freight vehicles are assumed to provide 50% of service demand by electricity and remaining 50% by conventional fuels for all mode of transport.
e. Passenger train is assumed to contain 10 coaches in each locomotive, 74 passengers per coach, operating at an average speed of 68 km/hr. Similarly, freight train is assumed to contain 10 wagons in each locomotive, 60 ton per wagon, operating at an average speed of 45km/hr (pay loads are weighted average estimated from RITES/SILT (2010)). Similarly, freight train for Kathmandu is assumed to contain 3 cars in each locomotive operating at an average speed of 45km/hr. MRT for Kathmandu is assumed to have occupancy of 296 passengers per trip, operating at average speed of 68 km/hr. Cost for locomotive, cars and MRT are taken from RITES/SILT (2010) and Baumgartner (2001).
f. Energy intensities of passenger and freight electric trains are estimated by using the method as mentioned by IFEU (2010). The estimated values are comparable with for similar railway transport system as mentioned in IFEU (2010), Baumgartner (2001) and Andersson and Lukaszewicz (2006).
g. Per unit infrastructure cost of railway is based on RITES/SILT (2010).
h. Cost and efficiency of passenger ropeway is estimated based on the performance of an existing Manakamana Cable Car operating in the aerial distance of 3 km in Nepal (Gyawali et al., 2004). It was assumed that, ropeway would operate for 16 hr per day, with 34 passenger car each containing 6 seat capacity, 10 min travel time with continuous power supply of 420 kW.
i. In case of existing freight ropeway in Nepal, most of them were built temporarily at the construction sites of hydropower plants and some for mining purpose. As they are not built for commercial purposes, estimation of freight ropeway is done by assuming the payload of each car mentioned in 'h' as 500 kg per wagon and rest remaining the same.

Data for battery recharging system is used from Morrow et al. (2008) and data for hydrogen refueling system is taken from IEA (2005). Future energy efficiency improvement and cost projections are taken from IEA (2008).

Appendix B.2: Manufacturing Process Technologies

Industrial Product	Technology Type	Fuel Type	Unit	Investment Cost (Million US$/unit)	Efficiency (unit/PJ)
Brick Industry	Clamped Chimney (Thado Vhatta)*	Fuel wood + Lignite	million pcs	0.01	177.35
	Fixed Chimney	Coal + Lignite	million pcs	0.004	253.38
	Moving Chimney	Coal + Lignite	million pcs	0.01	202.87
	Hoffman Kilns	Coal + Lignite	million pcs	0.01	332.53
	VSBK	Coal + Lignite	million pcs	0.01	415.64
Cement Industry	Tube Mill*	Diesel + Electricity	millin tons	20	4.34
	Vertical Mill	Diesel + Electricity	millin tons	20	5.31
	Conventional Kiln Burner*	Coal	millin tons	10	50.00
	Energy Efficient Kiln Burner	Coal	millin tons	12	
	Conventional Kiln Cooler*	Coal + Diesel + Electricity	millin tons	10	0.30
	Energy Efficient Kiln Cooler	Coal + Diesel + Electricity	millin tons	10	0.34
	Clinker Grinder	Electricity	millin tons	20	31.45
	Ball Mill for Final Product*	Electricity + Diesel	millin tons	18	3.74
	Vertical Mill for Final Product	Diesel + Electricity	millin tons	20	4.93
Paper Industry	Pulp Preparation (Kraft)*	Electricity + Steam	millin tons	169.5	0.34
	Pulp Preparation (Soda)	Electricity + Steam	millin tons	113	0.34
	Bleach Pulp	Electricity + Steam	millin tons	169.5	0.57
	Stock Preparation	Electricity + Steam	millin tons	113	0.43
	Convert to Paper*	Electricity + Steam	millin tons	339	0.15
	Convert to Paper (Improved)	Electricity + Steam	millin tons	350	0.19
	paper thermal (Fuel wood)	Wood	PJ	0.03	0.40
	paper thermal (Diesel)	Diesel	PJ	0.5971	0.70
	paper thermal (Fuel oil)	Fuel Oil	PJ	0.8312	0.70
Iron and Steel Industry	Heart Furnace*	Electricity	millin tons	24,160.00	
	Heart Furnace (Improved)	Electricity	millin tons	30,200.00	
	Final Product Processing*	Electricity	millin tons	50,642.00	1722.85
	Final Product Processing(Improved)	Electricity	millin tons	50,642.00	2210.45
	Sugar Cogeneration (Bagassee)	Bagassee	PJ	6.4872446	0.86
	Sugar Cogeneration (Fuel wood)	wood	PJ	3.35	0.83
	Bagassee Boiler	Bagassee	PJ	0.03	0.40
	Diesel Steam Gnerator	Diesel	PJ	0.5971	0.70
Sugar Industry	Juice Extraction*	Electricity + Steam	millin tons	40	1.45
	Energy Efficient Juice Extraction	Electricity + Steam	millin tons	45	1.59
	Sugar Evaporation*	Electricity + Steam	millin tons	40	1.09
	Energy Efficient Sugar Evaporation	Electricity + Steam	millin tons	45	1.33
	Sugar Crystallization*	Electricity + Steam	millin tons	40	0.71
	Energy Efficient Sugar Crystallization	Electricity + Steam	millin tons	45	0.81

Source: IEA (2008), NIES (2007), TERI (2006), USEPA (2006)

Appendix B.3: Technology details for agriculture, residential, commercial and industrial sectors

End Use	Technology Type	Fuel Type	Unit	Life	Investment Cost (Million US$/unit)	Efficiency (unit/PJ)	FOM
Land Tilling	Tractor*	Diesel	PJ	10	11.17	0.33	0.559
	Tractor (New)	Diesel	PJ	10	11.17	0.40	0.559
Irrigation Water Pumping	Water Pump*	Diesel	PJ	10	14.90	0.31	0.745
	Energy Efficient Water Pump	Diesel	PJ	10	14.90	0.37	0.745
	Electric Pump*	Electricity	PJ	10	11.47	0.33	0.574
	Energy Efficient Electric Pump (Efficient)	Electricity	PJ	10	11.47	0.40	0.574
Air Conditioning	Air-conditioner*	Electricity	Thousand pcs	10	1.41	144.68	0.071
	Energy Efficient Air-conditioner	Electricity	Thousand pcs	10	1.69	222.58	0.085
Lighting**	Incandescent lamp*	Electricity	billion lumen hour	1	0.0002	3777.78	
	Fluorescent tube lamp	Electricity	billion lumen hour	2	0.0007	12626.26	
	Compact fluorescent lamp	Electricity	billion lumen hour	4	0.0046	19097.22	
	LED lamp	Electricity	billion lumen hour	9	0.0368	18888.89	
	LED lamp for Solar Tuki	Electricity	billion lumen hour	9	0.0365	13888.89	
	Kerosene lamp*	Kerosene	billion lumen hour	3	0.0331	34.47	
Cooking	Electric Hot Plate Cooker	Electricity	PJ	15	7.01	0.80	0.350
	LPG Cooker*	LPG	PJ	15	4.20	0.60	0.210
	Kerosene Cooker*	Kerosene	PJ	5	0.88	0.45	0.044
	Biomass Cooker - Fuel wood*	Fuel wood	PJ	5	0.22	0.11	0.011
	Improved Cook Stove	Fuel wood	PJ	5	0.77	0.20	0.038
	Biomass Cooker - Animal Dung*	Animal Dung	PJ	5	0.22	0.07	0.011
	Biomass Cooker - Agriculture Residue*	Agriculture Residue	PJ	5	0.22	0.10	0.011
	Biogas Cooker	Biogas	PJ	5	2.80	0.55	0.140
Space Heating	Electric Heater	Electricity	PJ	8	7.15	1.00	0.357
	LPG Heater	LPG	PJ	8	6.68	0.65	0.334
	Kerosene Heater*	Kerosene	PJ	8	3.04	0.80	0.152
	Fuel wood Heater*	Fuel wood	PJ	5	0.22	1.00	0.011
	Agriculture Residue Heater*	Agriculture Residue	PJ	5	0.22	1.00	0.011

Appendix B.3: Technology details for agriculture, residential, commercial and industrial sectors (contd.)

End Use	Technology Type	Fuel Type	Unit	Life	Investment Cost (Million US$/unit)	Efficiency (unit/PJ)	FOM
Water Boiling	Electric Water Heater	Electricity	PJ	15	7.01	0.80	0.350
	Electric geiser	Electricity	PJ	15	10.21	0.91	0.511
	Kerosene Water Heater*	Kerosene	PJ	5	0.88	0.45	0.044
	Fuel wood Water Heater*	Fuel wood	PJ	5	0.22	0.11	0.011
	LPG Water Heater	LPG	PJ	15	4.20	0.60	0.210
	LPG Geyser	LPG	PJ	15	4.53	0.75	0.227
	Agriculture Residue Water heater*	Agriculture Residue	PJ	5	0.22	0.10	0.011
	Solar Water Heater*	Solar	PJ	15	140.16	0.60	7.008
Refrigeration	Refrigerator*	Electricity	Thousand pcs	7	0.17	484.74	
	Energy Efficient Refrigerator	Electricity	Thousand pcs	7	0.32	682.54	
Television	Conventional Television*	Electricity	Thousand pcs	7	0.55	1025.01	
	LCD-display Telivision	Electricity	Thousand pcs	7	1.0719	1454.33	
	Plasma-display Television	Electricity	Thousand pcs	7	1.23	609.16	
	LED-display Television	Electricity	Thousand pcs	7	1.65	1772.12	
Computer	Desk top Computer CRT	Electricity	Thousand pcs	7	0.43	1902.59	
	Desk top Computer LCD	Electricity	Thousand pcs	7	1.66	2209.10	
	Lap top Computer	Electricity	Thousand pcs	7	1.82	4424.62	
Space Cooling Fan	Electric Fan*	Electricity	PJ	5	186.96	0.31	
	Energy Efficient Tower Fan	Electricity	PJ	5	243.04	0.34	
Process Heat***	Standard Diesel Boiler*	Diesel	PJ	20	0.83	0.65	0.042
	Energy Efficient Diesel Boiler	Diesel	PJ	20	1.08	0.70	0.054
	Standard Coal Boiler*	Coal	PJ	20	0.57	0.45	0.029
	Energy Efficient Coal Boiler	Coal	PJ	20	1.08	0.50	0.054
	Fuel Oil Boiler Boiler	Fuel oil	PJ	20	0.83	0.65	0.042
	Fuel wood Boiler*	Fuel wood	PJ	20	0.03	0.40	0.002
	Agri Residue Boiler	Agri Residue	PJ	20	0.03	0.40	0.002
	Bagassee Boiler	Bagassee	PJ	20	0.03	0.40	0.002
Motive Power***	Diesel Motor*	Diesel	PJ	20	0.76	0.32	0.038
	Standard Electric Motor*	Electricity	PJ	20	0.65	0.65	0.032
	Energy Efficient Motor	Electricity	PJ	20	0.85	0.70	0.043

Source: IEA (2008), NIES (2007), TERI (2006), USEPA (2006)

Appendix B.4: Characteristics of generation technology

Technology Type	Fuel Type	Unit	Life	Investment Cost (Million US$/unit)	Efficiency (PJ/PJ)	FOM (million$/GW)	VOM (million $/PJ)	Availability factor
Micro-hydro Power Plant*	Hydropower	GW	30	3,000.00		30		SV
Solar Home System	Solar	GW	20	6,600.00	0.11	660		SV
Small Solar Home System (Solar Tuki)	Solar	GW	10	18,000.00	0.11	2000		SV
Biomass Power Plant (BIGCC)	Wood fuel	GW	30	2,192.82	0.38	52.79	0.13	0.80
Cogeneration Plant - Bagasse	Bagasse	GW	30	587.06	0.17	11.66	0.0035	1.00
Urban Land Fill Gas based Power Plant	Organic solid waste	GW	30	1828.83	0.25	112.36	0.0004	0.80
Thermal Power Plant - Diesel fired (existing)	Diesel	GW	20	601.07	0.35	18.03	0.88	0.68
Thermal Power Plant CC - Diesel	Diesel	GW	20	680.46	0.4	20.41	0.88	0.68

Note: SV stands for seasonal variation

Source: IEA (2008), NIES (2007), TERI (2006), USEPA (2006)

Appendix C

This appendix contains the detail of the technology specific emission factors of the transportation technologies considered in Nepal-ESM and Nepal-CGE model (thousand ton/bpkm, thousand ton/btkm).

Transport Technology	CH_4[a,d]	CO[b]	HC[b]	N_2O[a,d]	NVOC[c]	NO_X[b]	PM_{10}[b]
Bus (D)	0.0006	0.1037	0.0479	0.0006	0.0057	0.1538	0.0505
Bus (BD)	0.0006	0.0933	0.0432	0.0006	0.0051	0.1384	0.0455
Mini bus (D)	0.0009	0.1531	0.0642	0.0009	0.0082	0.0691	0.05
Car (D)	0.0035	0.5937	0.249	0.0035	0.0218	0.2681	0.1724
Car (BD)	0.0032	0.5343	0.2241	0.0032	0.0196	0.2413	0.1551
Car (G)	0.0287	6.7993	2.2838	0.0028	0.2575	0.4441	0.0589
Car (GH)	0.0273	6.4885	3.328	0.0043	0.3412	0.1663	0.053
Car hybrid (D+E)	0.0018	0.2968	0.1245	0.0018	0.0109	0.1341	0.0862
Car hybrid (G+E)	0.0143	3.3996	1.1419	0.0014	0.0101	0.2221	0.0295
Taxi (G)	0.0287	6.7993	2.2838	0.0028	0.2575	0.4441	0.0589
Taxi (GH)	0.0273	6.4885	3.328	0.0043	0.3412	0.1663	0.053
Taxi hybrid(G+E)	0.0143	3.3996	1.1419	0.0014	0.0101	0.2221	0.0295
3-wheelers (D)	0.0012	0.225	0.126	0.0012	0.0116	1.3	0.168
3-wheelers (BD)	0.0011	0.2025	0.1134	0.0011	0.0104	1.17	0.1512
3-wheelers (L)	0.0127	0.248	0.1084	4E-05	0.0416	0.065	0
Micro-bus (D)	0.0005	0.0912	0.0382	0.0005	0.0053	0.0412	0.0265
Micro-bus (BD)	0.0005	0.0821	0.0344	0.0005	0.0048	0.0371	0.0238
Micro-bus (L)	0.009	0.1751	0.0765	3E-05	0.0293	0.0459	0
2-wheelers (G)	0.0255	6.4848	0.6245	0.0019	0.7211	0.1009	0.0384
2-wheelers (GH)	0.0301	6.1884	0.91	0.0104	0.9556	0.0378	0.0346
Truck (D)	0.0049	0.2204	0.37	0.0049	0.0441	1.0194	0.0331
Truck (BD)	0.0044	0.1984	0.333	0.0044	0.0397	0.9175	0.0298
Truck hyb (D+E)	0.0025	0.1102	0.185	0.0025	0.022	0.5097	0.0165
Pick-up (D)	0.0087	0.5348	0.6118	0.0087	0.0851	0.7293	0.1361
Pick-up (BD)	0.0078	0.4813	0.5506	0.0078	0.0766	0.6564	0.1225
Pick-up hyb (D+E)	0.0044	0.2674	0.3059	0.0044	0.0425	0.3647	0.0681
Tractor (D)	0.0104	0.6418	0.7341	0.0104	0.1021	0.8752	0.1634
Tractor (BD)	0.0094	0.5776	0.6607	0.0094	0.0919	0.7876	0.147

Note: D≡Diesel, BD≡10% blend Bio-diesel, G≡Gasoline, GH≡10% blend Gasohol, E≡Electricity, H≡Hydrogen, L≡LPG

Source: [a] IPCC (2006); [b] Dhakal (2006); [c] EMEP/EEA (2009); [d]USEPA (2010)

These data are for the base year.

Appendix D

This appendix contains the elasticities for service demand drivers used for enduse service demand projections in Nepal-ESM model.

Sector/End use service	population elasticity, α_1	GDP elasticity, α_2	sectoral value added elasticity, α_3
Agriculture			
Irrigation, Land tilling			1.75
Commercial			
Education, Hotel and restaurant, Health, Other services			1.03
Industrial			
Brick			1.86-0.8[c]
Cement			2.72-0.8[c]
Iron and rod			2.34-0.8[c]
Pulp and paper			1.70-0.8[c]
Sugar			0.88
Other industries			0.78
Residential			
Agro-processing and animal feed preparation	0.98	0.03	
Cooking	0.98	0.03	
Lighting	3.75-0.9[c,e]	0.28	
Space cooling	3.75-0.9 [c,e]	0.28-0.07	
Space heating	0.98	0.03	
Water boiling	0.98	0.03	
Electric appliances	3.75-0.25[c,e]	0.28	
Transport			
Road: Kathmandu			
Passenger	0.44-0.18[c]	1.01-0.4[c]	
Freight		0.99-0.33[c]	
Road: RoN			
Passenger	1.25-0.5[c]	1.34-0.49[c]	
Freight		1.52-0.3[c]	
Air: Passenger(Domestic)		2.42-0.6 [c,d]	
Passenger(International)		2.72-0.6 [c,d]	
Air: Freight(Domestic)		1.15-0.4 [c]	
Freight(International)		1.83-0.4 [c]	

Note:

a. The values of elasticities have been obtained from regression analysis using log linear demand model (as mentioned in Shrestha and Rajbhandari (2009)) with time series data of industrial production, passenger demand, freight demand, sectoral energy consumption, residential electricity consumption as dependent variable, and sectoral value addition of GDP, aggregate GDP and population as independent variables using available time series data between 1986 to 2005. Number of annual data used for calculation of elasticities for different sector varies between ten years to nineteen years as per availability of data. Sectoral energy consumption has been used as dependent variable during elasticity calculation of end-use demand for residential and commercial sectors in the absence of time series data for end-use demand for the country.

b. Different studies done by Shrestha and Rajbhandari (2010), Kypreos et al. (2006), Nguyen (2005), and FOSTCA (2001) have been found to use demand elasticities value ranging from 0.5 to 4.71 for residential sector, 0.5 to 1.8 for agriculture sector, 0.5 to 1 for commercial sector, 0.7 to 1 for industrial sector, and 0.6 to 2 for transport sector.
c. Range of values showing gradual decrease in the elasticity.
d. GDP per capita was used as independent variable.
e. Residential electricity demand elasticities are found to be as high as 4.71 for developing country in the literature (Bose and Shukla, 1999).

Appendix E

This appendix contains the candidate hydropower plants and supply side characteristics used in Nepal-ESM model.

Plant	Capacity (MW)	Plant	Capacity (MW)	Plant	Capacity (MW)
Andhi Khola	180	Lower Modi	19	Tama Koshi-5	102
Arun-III	800	Madi Ishaneswor	86	Tama Koshi-6	113
Bagmati	140	Mai Loop	60	Tamur Storage	380
Bheri Babai	286	Marsyangdi-III	42	Tamur	83
Bheri Babai Diversion	48	Middle Bhote Koshi	96	Tila-2	185
Bhote Koshi-Trisuli	100	Mewa	18	Tila-3	116
Budhi Gandaki Storage	600	Mugu Karnali-1	90	Trisuli-1	200
Budhi Ganga	20	Mugu Karnali-3	124	Upper Marsyangdi-2	600
Chameliya	30	Nalsyaugad	400	Upper Marsyangdi-3	121
Dudh Koshi Storage	300	Naumure	245	Upper Arun	335
Dudh Koshi-4	49	Rahughat Khola	27	Upper Karnali	900
Humla Karnali-1	178	Sanjen	35	Upper Marsyangdi-A	50
Humla Karnali-4	111	Saptagandaki	225	Upper Modi-A	43
Hewa Khola	10	Sarada Babai Storage	93	Upper Sanjen	11
Indrawati-2	33	Seti Trisuli	170	Upper Seti	128
Kabeli-A	30	Seti-3	107	Upper Tamakoshi	456
Khimti-2	27	Simbua	53	Upper Tamakoshi-A	45
Kali Gandaki-2	660	Sun Koshi Storage	1700	Upper Trishuli-3A	61
Kankai Storage	90	Sun Koshi Diversion	61	Upper Trisuli - 3B	37
Langtang Khola Storage	175	Tama Koshi-A	100	Upper Trisuli-2	300
Likhu-4	51	Tama Koshi Storage-3	287	Devighat	14
Lower Arun	400	Tama Koshi-2	600	West Seti	750
Lower Bhote Koshi	96	Tama Koshi-3	880		
Lower Madi	17	Tama Koshi-4	126		

Source: NEA (2008a, 2008b, 2005), MOE (2010), MOWR (2009), Shiwakoti (2006), Nexant SARI/Energy (2002)

Transmission and distribution loss is assumed to decrease gradually from present 24.83% in 2005 to 17% by 2050 during the study period. NEA (2005) considered minimum loss of 17% in its generation planning. The reserve margin is assumed to reach 10% by 2030 and remains constant thereafter.

Appendix F

This appendix contains the rate of carbon tax used for national environment policy analysis in Asia.

Author	Country	Model / coverage	Carbon tax (US \$/ton CO_2e)		
			2015	2030	2050
IIM (2009)	India	AIMCGE-MARKAL/ National	3 32	8 87	20 200
Shukla et al. (2008)	India	AIMCGE-MARKAL/ National	3 13	8 14	20 100
Shrestha et al. (2008)	Thailand	AIM-Enduse / National	10 75 100	24 75 100	100 75 100
Karki et al. (2007)	India	Hybrid Optimization Model for Electric Renewables (HOMER)/ Power sector	50 100 150 190 200	50 100 150 190 200	50 100 150 190 200
Shrestha and Marpaung (1999)	Indonesia	Integrated Resource Planning model/ Power sector	5 50 100 200	5 50 100 200	5 50 100 200
Jegarl et al. (2009)	Korea	MARKet ALlocation (MARKAL)/ Power sector	13 25 50 75	13 25 50 75	13 25 50 75
Limmeechokchai and Hieu (2003)	Vietnam	Wien Automatic System Planning (WASP) IV/ Power sector	5 10 20 30 50 100	5 10 20 30 50 100	5 10 20 30 50 100
Santisirisomboon et al. (2001)	Thailand	Wien Automatic System Planning (WASP) IV/ Power sector	5 7.5 10	5 7.5 10	5 7.5 10
Shrestha et al. (1998)	Pakistan	Wien Automatic System Planning (WASP) III/ Power sector	10 50 100 150 200	10 50 100 150 200	10 50 100 150 200

Appendix G

Social Accounting Matrix of Nepal for the Year 2005 (NRs. In Million)

			Production Activity										Commodity														Non-compititive import	Factor of Production		Indirect Tax				Direct Tax	Consumption		Investment (S-I)	Rest of World	
			1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	11	12	13	14													
S. NO			Agriculture and Fishing	Manufacturing	Motor vehicles	Commercial	Government Services	Air Transport	Land Transport	Electricity	Coal (Lignite)	Fuel wood	Agriculture and Fishing	Manufacturing	Motor vehicles	Commercial	Government Services	Air Transport	Land Transport	Electricity	Coal (Lignite)	Fuel wood	Petrol	Diesel	Kerosene	LPG	Non-compititive import	Labor	Capital	Import Tariff	Export Tax	Sales Tax	Production Tax	Income Tax	Household	Government	Total	Total	Output
	Activity	Agriculture and Fishing											253,029																										253,029
		Manufacturing												242,145																									242,145
		Motor vehicles													856																								856
		Commercial														271,748																							271,748
		Government Services															63,681																						63,681
		Air Transport																13,251																					13,251
		Land Transport																	35,174																				35,174
		Electricity																		19,205																			19,205
		Coal(Lignite)																			7																		7
		Fuel wood																				14,992																	14,992
1	Commodity	Agriculture and Fishing	17,468	24,683	-	12	297	-	-	-	-	-																							198,679		8,151	6,994	256,283
2		Manufacturing	19,610	60,068	736	6,931	8,996	318	845	1,797	0	37																							79,478		102,655	51,657	333,127
3		Motor vehicles	-	472	1	-	-	-	23	-	-	-																							6,811		371	-	7,678
4		Commercial	4,633	27,788	65	52,509	1,080	3,722	1,981	2,234	0	145																							122,857		42,848	23,104	282,965
5		Government	-	-	-	30	575	-	-	-	-	-																								52,453	12,091	-	65,149
6		Air Transport	1	20	-	445	15	169	9	139	-	2																							1,446		10,499	1,159	13,904
7		Land Transport	3,657	530	-	3,666	137	1,522	174	1,254	0	8																							13,498		10,274	1,739	36,458
8		Electricity	281	6,373	-	973	12	54	41	7	0	1																							4,737		7,389	593	20,462
9		Coal(Lignite)	-	7	-	-	-	-	-	-	-	-																							-			-	7
10		Fuel wood	-	1,483	-	-	-	-	-	-	-	-																							13,509			-	14,992
11		Petrol	-	-	-	-	-	-	-	-	-	-																							4,140				4,140
12		Diesel	-	-	-	-	-	-	-	-	-	-																							571				571
13		Kerosene	-	-	-	-	-	-	-	-	-	-																							8,416				8,416
14		LPG	-	-	-	-	-	-	-	-	-	-																							4,865				4,865
1	Non-compititive imported intermediate input	Coal	-	1,775	-	-	-	-	-	-	-	-																											1,775
10		Petrol	-	-	-	-	-	-	370	-	-	-																											370
11		Diesel	3,028	703	2	-	-	-	7,724	510	-	-																											11,967
12		Kerosene	-	-	-	351	109	-	-	-	-	-																											460
13		ATF	-	-	-	-	-	2,311	-	-	-	-																											2,311
14		LPG	-	-	-	378	117	-	59	-	-	-																											554
		Non-fuel imported intermediate input	17,562	26,517	23	6,919	3,792	342	2,715	1,488	-	-																											59,357
	Factor of Production	Labor	112,903	59,043	18	62,796	46,207	2,590	8,462	2,048	1	5,313																											299,383
		Capital	73,591	26,552	8	136,291	2,325	1,498	11,511	9,687	5	8,833																											270,302
	Import Tariff	Import Tariff	-	1,681	2	87	11	192	235	0.25	-	-	197	5,798	1,365	-	-	29	85	-	-	-	1,389	29	115	164													11,379
	Import Tariff for Petroleum Fuel	Coal	-	70	-	-	-	-	-	-	-	-																											70
		Petrol	-	-	-	-	-	-	31	-	-	-																											31
		Diesel	186	43	0.1	-	-	-	474	31	-	-																											735
		Kerosene	-	-	-	5	2	-	-	-	-	-																											6
		ATF	-	-	-	-	-	35	-	-	-	-																											35
		LPG	-	-	-	15	5	-	2	-	-	-																											22
	Export Tax	Agriculture and Fishing																																				13	13
		Manufacturing																																				724	724
	VAT	VAT											403	11,875	398	4,748	-	264	121	-	-	0.2170	476	66	-	560													18,911
	Production Tax	Production Tax	109	4,340	-	340	-	499	517	9	-	654																											6,467
	Income Tax	Income Tax																																10,466					10,466
		Household																										299,383	270,302							2,823		51,477	623,984
		Government																												12,278	736	18,911	6,467		10,466			29,584	78,441.95
		Saving-Investment																																	150,907	17,213		26,158	194,279
		Rest of World (ROW)											2,654	73,309	5,058	6,469	1,469	361	1,078	1,257	-	-	2,274	476	8,300	4,142	76,794								3,606	5,953			193,200
		Output	253,029	242,145	856	271,748	63,681	13,251	35,174	19,205	7	14,992	256,283	333,127	7,678	282,965	65,149	13,904	36,458	20,462	7	14,992	4,140	571	8,416	4,865	76,794	299,383	270,302	12,278	736	18,911	6,467	10,466	623,984	78,442	194,279	193,200	

Appendix H

This appendix contains the value of parameters related to the Armington elasticity of substitution, elasticity of substitution in the production and household sectors, annual energy efficiency improvement, labor factor productivity, depreciation rate, emission factors used in Nepal-CGE model.

Appendix H.1: Value of of substitution parameters used in the study

	AGRIC	MANUF	MOVEH	COMMR	PSERV	ATRAN	OTVEH	TRNFR	TRNPG	ELECT	LIGNIT	FWOOD
σ_{XXcm}	-1.8000	-1.6000	-0.7000	-0.7000	-0.7000	-0.7000	-0.7000	-0.7000	-0.7000	-1.2000	-0.7000	-0.7000
σ_{Xcm}	2.0000	2.0000	2.0000	0.7000	0.7000	0.7000	0.7000	0.7000	0.7000	1.8000	0.7000	0.7000

Note:

σ_{Xcm} = Armington elasticity of substitution between consumption of commodity cm imported from RoW and domestic production.

σ_{XXcm} = Armington elasticity of substitution between production of commodity cm exported to RoW and supply to domestic market.

Appendix H.2: Value of elasticity of substitution parameters in the production sector used in the study

	AGRIC	MANUF	MOVEH	COMMR	PSERV	ATRAN	OTVEH	TRNFR	TRNPG	ELECT	LIGNIT	FWOOD
σ_{Zi}	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
σ_{EKLi}	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
σ_{XMi}	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
σ_{EKi}	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
σ_{XEMi}	0.500	0.500	0.500	0.500	0.500	0.200	0.200	0.500	0.500	0.500	0.200	0.200
σ_{FSi}	0.500	0.500	0.500	0.500	0.500	0.200	0.200	0.500	0.500	0.500	0.200	0.200
σ_{DMi}	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250

Note:

σ_{Zi} = elasticity of substitution between energy-capital-labor composite and aggregate non-energy intermediate inputs.

σ_{EKLi} = elasticity of substitution between energy-capital composite and labor inputs.

σ_{XMi} = elasticity of substitution between associated with domestic intermediate input composite and imported intermediate input composite

σ_{EKi} = elasticity of substitution between energy composite and capital factor of sector i.

σ_{XEMi} = elasticity of substitution between associated with electricity and non-electricity energy input.

σ_{FSi} = elasticity of substitution for non-electricity energy input.

σ_{DMi} = elasticity of substitution for domestic intermediate input.

Appendix H.3: Value of annual energy efficiency improvement (AEEI) used in the study

	AGRIC	MANUF	MOVEH	COMMR	PSERV	ATRAN	OTVEH	LIGNIT	FWOOD	HXD
1	0	0	0	0	0	0	0	0	0	0
2	0.00576	0.00672	0.00672	0.00672	0.00672	0.00672	0.00672	0.0048	0.0048	0.00672
3	0.00624	0.00728	0.00728	0.00728	0.00728	0.00728	0.00728	0.0052	0.0052	0.00728
4	0.00624	0.00728	0.00728	0.00728	0.00728	0.00728	0.00728	0.0052	0.0052	0.00728
5	0.00648	0.00756	0.00756	0.00756	0.00648	0.00648	0.00648	0.0054	0.0054	0.00756
6	0.00588	0.00686	0.00686	0.00686	0.00588	0.00588	0.00588	0.0049	0.0049	0.00686
7	0.00504	0.00588	0.00588	0.00588	0.00504	0.00504	0.00504	0.0042	0.0042	0.00588
8	0.0042	0.0049	0.0049	0.0049	0.0042	0.0042	0.0042	0.0035	0.0035	0.0049
9	0.0042	0.0049	0.0049	0.0049	0.0042	0.0042	0.0042	0.0035	0.0035	0.0049

Appendix H.4: Value of labor factor productivity used in the study

	AGRIC	MANUF	MOVEH	COMMR	PSERV	ATRAN	OTVEH	LIGNIT	FWOOD
1	0	0	0	0	0	0	0	0	0
2	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
3	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075
4	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
6	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
7	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
8	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075
9	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075
10	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075

Appendix H.5: Depreciation rate used in Nepal-CGE model

	AGRIC	MANUF	MOVEH	COMMR	PSERV	ATRAN	OTVEH	TRNFR	TRNPG	ELECT	LIGNIT	FWOOD
ρ	0.032	0.029	0.029	0.029	0.029	0.028	0.04	0.04	0.04	0.04	0.025	0.025

Appendix H.6: Value of elasticity of substitution parameters in the household consumption

	σ_{HD}	σ_{HDNT}	σ_{HDTR}	σ_{DHDE}	σ_{DHDNE}	σ_{TRPU}
elasticity of substitution	0.03	0.03	0.03	0.03	0.03	0.03

Note:

σ_{HD} = elasticity of substitution between transport composite and non-transport composite household consumptions

σ_{HDNT} = elasticity of substitution between energy composite and non-energy composite commodities consumptions

σ_{HDTR} = elasticity of substitution between private and purchased transport consumptions.

σ_{DHDE} = elasticity of substitution associated with energy commodity consumption.

σ_{DHDNE} = elasticity of substitution associated with non-energy commodity consumption.

σ_{TRPU} = elasticity of substitution associated with household purchased transport service.

Appendix H.7: Energy and CO_2 emission factors used in Nepal-CGE model

Fuel commodity	Energy factor (MNRs/PJ)	CO_2 emission factor (1000 ton/PJ)
Lignit	71.4	101.0
Fuel wood	52.5	0.0
Coal	276.8	94.6
Gasoline	1400.2	69.3
Diesel	917.9	74.1
Kerosene	1002.6	71.9
ATF	992.1	71.5
LPG	1165.1	63.1
Electricity	2130.2	0.0

Appendix H.8: CH_4 emission factors used in Nepal-CGE model (1000 ton/PJ)

	AGRIC	MANUF	MOVEH	COMMR	PSERV	OTVEH	ATRAN	HXD
COAL		0.0107						
GASOL								
DISEL	0.0065	0.0256	0.0256			0.0039		
KERSN				0.0100	0.0100			0.0101
ATF							0.0030	
LPG				0.0050	0.0050			0.0049
FWOOD		0.0373						0.3000
LIGNIT		0.0005						

Appendix H.9: N_2O emission factors used in Nepal-CGE model (1000 ton/PJ)

	AGRIC	MANUF	MOVEH	COMMR	PSERV	OTVEH	ATRAN	HXD
COAL		0.0016						
GASOL								
DISEL	0.0177	0.0051	0.0051			0.0039		
KERSN				0.0005	0.0005			0.0005
ATF							0.0005	
LPG				0.0001	0.0001			0.0001
FWOOD		0.0050						0.0040
LIGNIT		0.0001						

Appendix I

Description of Nepal-CGE Model

Nepal-CGE model is a multi-sector, single region recursive dynamic computable general equilibrium model designed for an assessment of macroeconomic effects consisting of sectoral distribution of the economy, consumer welfare, energy intensity and GHG emission intensity due to the transport electrification policy and carbon tax policy in the country during 2000-2050. It contains 5 non-energy commodity production sectors (agriculture and forestry, manufacturing, motor vehicles, commercial and other public services), 3 energy commodity production sectors (electricity, lignite and fuelwood) and 4 transport service sectors (land freight, land passenger, air transport sectors and other transport). The land freight and land passenger transport service sectors are further sub divided into different mode and technology disaggregation to facilitate selection of technology based on least cost per physical unit (PJ, billion passenger- km, billion ton-km). The household consumption is disaggregated into transport and non-transport categories with further disaggregation into the technology level sub-categories in the private owned transport service (car and 2-wheelers). The model considers capital (K) and labor (L) as two primary factors, imported energy inputs, non-competitive imported intermediate input and domestically produced intermediate inputs; one representative household group (h); the government institution; and the rest of the world (ROW).

Sets:

i, j production sectors
c,d commodities
e electricity commodity
f fossil fuel commodity
tf land freight transport
tp land passenger transport
mf = mode of freight transport
mp = mode of passenger public transport
fi = technology level subsector for freight transport
pi = technology level subsector for passenger public transport
ei = technology level subsector for electricity generation
t = time period

<u>Equations:</u>

(1) Production module:

<u>Commodity and Intermediate inputs</u>

$$XD_c = Z_i . FCF_{c,i} \quad (1)$$

$$EKL_i = \delta_{Zi}\left(\frac{PZ_i}{PEKL_i}\right)^{\sigma_{Zi}} Z_i \quad (2)$$

$$XM_i = \left(1-\delta_{Zi}\right)\left(\frac{PZ_i}{PXM_i}\right)^{\sigma_{Zi}} Z_i$$
(3)

$$EK_i = \delta_{EKLi}\left(\frac{PEKL_i}{PEK}\right)^{\sigma_{EKLi}} EKL_i \quad (4)$$

$$L_i = \left\{\alpha_{Li}\,.\left(1-\delta_{EKLi}\right)\right\}\left(\frac{PEKL_i}{W}\right)^{\sigma_{EKLi}} EKL_i \quad (5)$$

$$DM_i = \delta_{XM\,i}\left(\frac{PXM_i}{PDM_i.}\right)^{\sigma_{XMi}} XM_i \quad (6)$$

$$MM_i = \left(1-\delta_{XM\,i}\right)\left(\frac{PXM_i}{PMM_i\,\left(1+trfip_i\right)}\right)^{\sigma_{XMi}} XM_i \quad (7)$$

$$E_i = \delta_{EK\,i}\left(\frac{PEK_i}{PE_i}\right)^{\sigma_{EKi}} EK_i \quad (8)$$

$$K_i = \left(1-\delta_{EK\,i}\right)\left(\frac{PEK_i}{PK}\right)^{\sigma_{XEMi}} EK_i \quad (9)$$

$$EL_i = \alpha_{AEEI\,i}^{\;\sigma_{Ei}-1}\;\delta_{E\,i}\left(\frac{PE_i}{PX_{el}}\right)^{\sigma_{Ei}} E_i \quad (10)$$

$$FS_i = \alpha_{AEEI\,i}^{\;\sigma_{Ei}-1}\;\left(1-\delta_{E\,i}\right)\left(\frac{PE_i}{PFS_i}\right)^{\sigma_{Ei}} E_i \quad (11)$$

$$M_{i,c} = \delta_{DM\,i}\left(\frac{PDM_i}{PX_c.}\right)^{\sigma_{XMi}} DM_i$$
(12)

$$FU_{i,f} = \delta_{FS\,i}\left(\frac{PFS_i}{PX_f.\;\left(1+\left(\frac{EMM_f}{FF_f.PX_f}\right).\,ctax_f\right)}\right)^{\sigma_{FSi}} FS_i$$
(13)

$$Z_{tf} = \sum_{mf}\sum_{fi} z_{mf,fi} \quad (14)$$

$$Z_{tp} = \sum_{mp}\sum_{pi} z_{mp,pi} \quad (15)$$

Note: For carbon tax scenario analysis, mode based aggregate freight (i.e., truck, tracor, pickup, railway, ropeway) and aggregate passenger (i.e., bus, microbus, 3-wheelers and taxi) transport service production and category wise household and government owned transport service (car and 2-wheelers) consists of CES function of an individual technology level service production subsectors and technology level private mode of transport, as such their formulation is similar to the electricity generation sector given below.

$$Z_{ei} = \delta_{Z\,ei}\left(\frac{PZ_e}{PZ_{ei}}\right)^{\sigma_{Ze}} Z_e \tag{16}$$

For backstop or new technology which is not available in the base year, its share would be included only if its price per unit physical unit is below the price of related reference technology. Here price of hydropower is considered as the reference technology. The syntax for above mentioned endogenous relational operation functions is developed by using Relaxed Mixed Integer Nonlinear Programming (RMINLP) of GAMS/PATHNLP. The penetration of the new technology is controlled by using the initial rate of penetration and rate of increment of the penetration as presented below.

$$EGEN_{new} = \delta_{Z\,new,e}\left(\frac{PZ_e}{PEGEN_{new}}\right)^{\sigma_{Ze}} Z_e \qquad \text{for, } PEGEN_{new,t} \le PEGEN_{ref,t}$$

$$= 0 \qquad \text{for, } PEGEN_{new,t} > PEGEN_{ref,t} \tag{16a}$$

Where,

$$\delta_{new,t+1} = \delta_{new,t}\ .\left(1 + shgw_{new,t}\right) \quad \text{for, } \delta_{new,t} > 0;\ PX_{new,t} \le PX_{ref,t}$$

$$= \delta_{new,t} \qquad \text{for, } \delta_{new,t} = 0;\ PX_{new,t} \le PX_{ref,t}$$

$PEGEN_{new,t}$ = Cost per physical unit of electricity for new technology (10^{12} NRs/PJ) in period n

$PEGEN_{ref,t}$ = Cost per physical unit of electricity for reference technology (10^{12} NRs/PJ) in period n

$\delta_{new,t}$ = initial share parameter of new technology for the period t.
$shgw_{new,t}$ = increment rate of the share composition of new technology for the period t.

Zero profit condition

$$Z_i\,.PZ_i = EL_i.PX_e + \sum_f FU_{f,i}.PX_f \,.\left(1 + \left(\frac{EMM_f}{FF_f\,.\,PX_f}\right).\,ctax_f\right) + PMM_i\left(1 + trfip_i\right)$$
$$+ \sum_k M_{k,i}.PX_k + L_i.W + K_i.PK \tag{17a}$$

$$Z_e\,.PZ_e = \sum_j EGEN_j\,.PEGEN_j \tag{17b}$$

$$PXD_{cm}\,.\,XD_{cm} = PZ_i\,.(1 + prtax_i)\,.\left(FCF_i\,.\,Z_i\right) \tag{18}$$

(2) Price module:

$$PIMP_c = pwimp_c.(1+timp_c).ER \tag{19}$$
$$PMM_i = pwmm_i.(1+trfip_i).ER \tag{20}$$
$$PMM_e = pwmm_e.(1+trfip_e).ER \tag{21}$$
$$PMM_{tf} = pwmm_{tf}.(1+trfip_{tf}).ER \tag{22}$$
$$PMM_{tp} = pwmm_{tp}.(1+trfip_{tp}).ER \tag{23}$$
$$PEXP_c = \frac{pw\exp_c}{(1+t\exp_c)}.ER \tag{24}$$
$$PZ_i = \left[\delta_{Zi}.PEKL_i^{1-\sigma_{Zi}} + \left(1-\delta_{Zi}\right).PXM_i^{1-\sigma_{Zi}}\right]^{\frac{1}{1-\sigma_{Zi}}} \tag{25}$$
$$PEKL_i = \left[\delta_{EKLi}.\left(PEK\right)^{1-\sigma_{EKLi}} + \left\{\alpha_{Li}.\left(1-\delta_{EKLi}\right)\right\}.\left(W\right)^{1-\sigma_{EKLi}}\right]^{\frac{1}{1-\sigma_{EKLi}}} \tag{26}$$
$$PXM_i = \left[\delta_{XMi}.\left(PDM_i\right)^{1-\sigma_{XMEi}} + \left(1-\delta_{XMi}\right).\left(PMM_i.\left(1+trfip_i\right)\right)^{1-\sigma_{XMi}}\right]^{\frac{1}{1-\sigma_{XMi}}} \tag{27}$$
$$PEK_i = \left[\delta_{EKi}.PE_i^{1-\sigma_{EKi}} + \left(1-\delta_{EKi}\right).PK_i^{1-\sigma_{EKi}}\right]^{\frac{1}{1-\sigma_{EKi}}} \tag{28}$$
$$PE_i = \frac{1}{\alpha_{AEEI\,i}}\left[\delta_{Ei}.\left(PEL_i\right)^{1-\sigma_{Ei}} + \left(1-\delta_{Ei}\right).\left(PFS_i\right)^{1-\sigma_{Ei}}\right]^{\frac{1}{1-\sigma_{Ei}}} \tag{29}$$
$$PDM_i = \left[\sum_k \delta_{DMk,i}.\left(PX_{k,i}\right)^{1-\sigma_{DMi}}\right]^{\frac{1}{1-\sigma_{DMi}}} \tag{30}$$
$$PFS_i = \left[\sum_i \delta_{FSk,i}.\left(PX_{f,i}.\left(1+\left(\frac{EMM_f}{FF_f.PX_{f,i}}\right).ctax_f\right)\right)^{1-\sigma_{FSi}}\right]^{\frac{1}{1-\sigma_{FSi}}} \tag{31}$$
$$PZ_e = \left[\sum_j \delta_{Zj,e}.PEGEN_{j,e}^{1-\sigma_{Ze}}\right]^{\frac{1}{1-\sigma_{Ze}}} \tag{32}$$
$$PZ_{tf} = \frac{\sum_{mf}\sum_{fi} PZ_{mf,fi}.z_{mf,fi}}{Z_{tf}} \tag{33}$$
$$PZ_{tp} = \frac{\sum_{mp}\sum_{pi} PZ_{mp,pi}.z_{mp,pi}}{Z_{tp}} \tag{34}$$
$$PZ_{ei} = \sum_c M_{c,ei}.PX_c + \sum_f FSS_{0,f,ei}.PX_f.\left(1+\left(\frac{EMM_f}{FF_f.PX_f}\right).ctax_f\right) + EL_{0,ei}.PX_e$$
$$+ MM_{0,ei}.PMM_{ei} + L_{0,ei}.W + K_{0,ei}.PC$$

(35)

$$PZ_{mf,fi} = \sum_c M_{c,mf,fi} \,.\, PX_c + \sum_f FSS_{0,f,mf,fi} \,.\, PX_f \,.\left(1+\left(\frac{EMM_f}{FF_f \,.\, PX_f}\right).\, ctax_f\right)$$
$$+ EL_{0,mf,fi} \,.\, PX_e \quad + MM_{0,mf,fi} \,.\, PMM_{mf,fi} + L_{0,mf,fi} \,.\, W + K_{0,mf,fi} \,.\, PC$$

(36)

$$PZ_{mp,pi} = \sum_c M_{c,mp,pi} \,.\, PX_c + \sum_f FSS_{0,f,mp,pi} \,.\, PX_f \,.\left(1+\left(\frac{EMM_f}{FF_f \,.\, PX_f}\right).\, ctax_f\right)$$
$$+ EL_{0,mp,pi} \,.\, PX_e + MM_{0,mp,pi} \,.\, PMM_{mp,pi} + L_{0,mp,pi} \,.\, W + K_{0,mp,pi} \,.\, PC$$

(37)

(3) Income module:

$$TTAX = hhtx.\left(W.\,\overline{LTOT} + PC.\,\overline{CTOT}\right) + \sum_c \left(HXD_c + GXD_c + INV_c\right).\, PX_c .\, tvat_c$$
$$+ \sum_f \left(HXD_f + GXD_f + INV_f + \sum_i M_{f,i}\right).\ \left(\left(\frac{EMM_f}{FF_f}\right).\, ctax_f\right)$$
$$+ \sum_f \left(\sum_{tw}\left(HXDT_{f,tw} + GXDT_{f,tw}\right) + \sum_{cr}\left(HXDT_{f,cr} + GXDT_{f,cr}\right)\right).\, PX_f \,.\, tvat_f$$
$$+ \sum_f \left(\sum_{tw}\left(HXDT_{f,tw} + GXDT_{f,tw}\right) + \sum_{cr}\left(HXDT_{f,cr} + GXDT_{f,cr}\right)\right).\left(\left(\frac{EMM_f}{FF_f}\right).\, ctax_f\right)$$
$$+ \left(\sum_i M_{c,i} + \sum_{ei} M_{0,ei} \,.\, Z_{ei} + \sum_{mf}\sum_{fi} M_{0,mf,fi} \,.\, z_{mf,fi} + \sum_{mp}\sum_{pi} M_{0,mp,pi} \,.\, z_{mp,pi}\right).\left(\left(\frac{EMM_f}{FF_f}\right).\, ctax_f\right)$$
$$+ Z_i .\, PZ_i \,.\, prtax_i + \sum_c \left(p\exp_c .\, EXP_c .\, t\exp_c\right) + \sum_c \left(pwmp_c .\, IMP_c .\, timp_c \,.\, ER\right)$$
$$+ \sum_i \left(pwmm_i .\, MM_i .\, trfip_i \,.\, ER\right) + \sum_{ei} \left(pwmm_e .\, MM_{ei} .\, Z_{ei} .trfip_e \,.\, ER\right)$$
$$+ \sum_{mf}\sum_{fi} \left(pwmm_{tf} .\, MM_{mf,fi} .\, Z_{mf,fi} .trfip_{tf} \,.\, ER\right) + \sum_{mf}\sum_{pi} \left(pwmm_{tp} .\, MM_{mf,pi} .\, Z_{mf,pi} .trfip_{tp} \,.\, ER\right)$$
$$+ prtax_i .\, PZ_i .\, Z_i .\, FCF_{c,i}$$

(38)

$$YG = TTAX + \left(trgrw - trhhgr\right) \tag{39}$$

$$YH = \left(W.\,\overline{LTOT} + PC.\,\overline{CTOT}\right).\left(1 - hhtx\right) + trhhgr + trhhw \tag{40}$$

(4) Expenditure module:

$$GCONST = rg \,.\, GDPREAL \tag{41}$$

$$GSAV = YG - GCONST \tag{42}$$

$$HSAV = mps \,.\, YH \tag{43}$$

$$HCONST = YH - HSAV \tag{44}$$

$$HCONST = PHDTR \,.\, HDTR + PHDNT \,.\, HDNT \tag{45}$$

$$HDTR = \frac{\delta_{HD} \,.\, HCONST}{PHDTR^{\sigma_{HD}} \,.\, \left[\delta_{HD} \,.\, PHDTR^{(1-\sigma_{HD})} + \left(1-\delta_{HD}\right) . PHDTN^{(1-\sigma_{HD})}\right]} \tag{46}$$

$$HDTN = \frac{\left(1-\delta_{HD}\right) . \, HCONST}{PHDTN^{\sigma_{HD}} \,.\, \left[\delta_{HD} \,.\, PHDTR^{(1-\sigma_{HD})} + \left(1-\delta_{HD}\right) . PHDTN^{(1-\sigma_{HD})}\right]} \tag{47}$$

$$PHDNT \,.\, HDNT = PHDE \,.\, HDE + PHDNE \,.\, HDNE \tag{48}$$

$$HDE = \frac{\left\{\alpha_{HHEEI} \,.\, \delta_{HDNT}\right\} . \, PHDNT \,.\, HDNT}{PHDE^{\sigma_{HDNT}} \,.\, \left[\left\{\alpha_{HHEEI} \,.\, \delta_{HDNT}\right\} . PHDE^{(1-\sigma_{HDNT})} + \left(1-\delta_{HDNT}\right) . PHDNE^{(1-\sigma_{HDNT})}\right]} \tag{49}$$

$$HDNE = \frac{\left(1-\delta_{HDNT}\right) . \, PHDNT \,.\, HDNT}{PHDNE^{\sigma_{HDNT}} \,.\, \left[\left\{\alpha_{HHEEI} \,.\, \delta_{HDNT}\right\} . PHDE^{(1-\sigma_{HDNT})} + \left(1-\delta_{HDNT}\right) . PHDNE^{(1-\sigma_{HDNT})}\right]} \tag{50}$$

$$PHDTR \,.\, HDTR = PTRPR \,.\, TRPR + PTRPU \,.\, TRPU \tag{51}$$

$$PTRPU \,.\, TRPU = \sum_{TPUB} PX_{TPUB} \,.\, (1 + tvat_{TPUB}) \,.\, HXD_{TPUB} \tag{52}$$

$$PHDE \,.\, HDE = PX_{e} \,.\, HXD_{e} + PX_{f} \,.\, \left(1 + tvat_{f} + \left(\frac{EMM_{f}}{FF_{f} \,.\, PX_{f}}\right) . \, ctax_{f}\right) . \, HXD_{f} \tag{53}$$

$$HXD_{c} = \frac{\delta_{DHDE} \,.\, PHDE \,.\, HDE}{\left[PX_{DHDE} \,.\, \left(1 + tvat_{DHDE}\right)\right]^{\sigma_{DHDE}} \,.\, \sum_{DHDE} \delta_{DHDE} \,.\, \left[PX_{DHDE} \,.\, \begin{pmatrix} 1 + tvat_{DHDE} \\ + \left(\dfrac{EMM_{DHDE}}{FF_{DHDE} \,.\, PX_{DHDE}}\right) \\ .\, ctax_{DHDE} \end{pmatrix}\right]^{(1-\sigma_{DHDE})}}$$

for all energy commodity consumption

$$= \frac{\delta_{DHDNE} \,.\, PHDNE \,.\, HDNE}{\left[PX_{DHDNE} \,.\, \left(1 + tvat_{DHDNE}\right)\right]^{\sigma_{DHDNE}} \,.\, \sum_{DHDNE} \delta_{DHDNE} \,.\, \left[PX_{DHDNE} \,.\, \left(1 + tvat_{DHDNE}\right)\right]^{(1-\sigma_{DHDNE})}}$$

for all non-energy commodity consumption

$$= \frac{\delta_{TRPU} \,.\, PTRPU \,.\, TRPU}{\left[PX_{TRPU} \,.\, \left(1 + tvat_{TRPU}\right)\right]^{\sigma_{TRPU}} \,.\, \sum_{TRPU} \delta_{TRPU} \,.\, \left[PX_{TRPU} \,.\, \left(1 + tvat_{TRPU}\right)\right]^{(1-\sigma_{TRPU})}}$$

for all public transport service use

(54)

$$PTRPR\,.\,TRPR = PTRTW.\,TRTW + PTRCR\,.\,TRCR \quad (55)$$

$$TRPR = PTRTW_0.\,TRTW + PTRCR_0\,.\,TRCR \quad (56)$$

$$TRTW = \sum_{tw} hqdtw_{tw} \quad (57)$$

$$TRCR = \sum_{cr} hqdcr_{cr} \quad (58)$$

$$PTRTW\,.\,TRTW = \sum_{tw} PTTW_{tw}.\,hqdtw_{tw} \quad (59)$$

$$PTRCR\,.\,TRCR = \sum_{cr} PTCR_{cr}.\,hqdcr_{cr} \quad (60)$$

$$HXDT_{tinp,tw} = hqd_{tw}.\,dtrmov_{tinp,tw}.\,PTTW_{0,tw} \quad (61)$$

$$HXDT_{tinp,cr} = hqd_{cr}.\,dtrmov_{tinp,cr}.\,PTCR_{0,cr} \quad (62)$$

$$GDTR = PGRTW_0.\,GRTW + PGRCR_0\,.\,GRCR \quad (63)$$

$$GXD_{PS}.\,PX_{PS} = GCONST - PGDTR.\,GDTR \quad (64)$$

$$PGDTR.\,GDTR = PGRTW.\,GRTW + PGRCR\,.\,GRCR \quad (65)$$

$$GRTW = \sum_{tw} gqdtw_{tw} \quad (66)$$

$$GRCR = \sum_{cr} gqdcr_{cr} \quad (67)$$

$$PGRTW\,.\,GRTW = \sum_{tw} PTTW_{tw}.\,gqdtw_{tw} \quad (68)$$

$$PGRCR\,.\,GRCR = \sum_{cr} PTCR_{cr}.\,gqdcr_{cr} \quad (69)$$

$$GXDT_{tinp,tw} = gqd_{tw}.\,dtrmov_{tinp,tw}.\,PTTW_{0,tw} \quad (70)$$

$$GXDT_{tinp,cr} = gqd_{cr}.\,dtrmov_{tinp,cr}.\,PTCR_{0,cr} \quad (71)$$

$$PTTW_{tw}.\left(hqdtw_{tw}+gqdtw_{tw}\right)=\sum_{tinp}\left(HXDT_{tinp,tw}+GXDT_{tinp,tw}\right)$$

$$.\,PX_{tinp}\,.\left(1+tvat_{tinp}+\left(\frac{EMM_{tinp}}{FF_{tinp}.\,PX_{tinp}}\right).\,ctax_{tinp}\right) \qquad (72)$$

$$PTCR_{cr}.\left(hqdtw_{cr}+gqdtw_{cr}\right)=\sum_{tinp}\left(HXDT_{tinp,cr}+GXDT_{tinp,cr}\right)$$

$$.\,PX_{tinp}\,.\left(1+tvat_{tinp}+\left(\frac{EMM_{tinp}}{FF_{tinp}.\,PX_{tinp}}\right).\,ctax_{tinp}\right) \qquad (73)$$

$$fsav=\sum_{c}pwimp_{c}\,.\,IMP_{c}+\sum_{i}pwmm_{i}\,.\,MM_{i}+\sum_{e}pwmm_{e}\,.\,MM_{e}+\sum_{tf}pwmm_{tf}\,.\,MM_{tf}$$

$$+\sum_{tp}pwmm_{tp}\,.\,MM_{tp}-\sum_{c}pw\exp_{c}\,.\,EXP_{c}-\frac{\left[trgrw+trhhw\right]}{ER} \qquad (74)$$

(5) Investment module:

$$INVTOT=HSAV+GSAV+fsav.\,ER \qquad (75)$$

$$IT=\frac{INVTOT}{PI} \qquad (75)$$

$$INV_{c}=dinvt_{c}.\,IT \qquad (76)$$

$$PI=\sum_{c}dinvt_{c}.\,(1+tvat_{c})\,.\,PX_{c} \qquad (76)$$

(6) Trade module:

$$X_{c}=\left[\delta_{Xc}{}^{\frac{1}{\sigma_{Xc}}}.\,IMP_{c}{}^{\frac{\sigma_{Xc}-1}{\sigma_{Xc}}}+\left(1-\delta_{Xc}\right)^{\frac{1}{\sigma_{Xc}}}.\,XDD_{c}{}^{\frac{\sigma_{Xc}-1}{\sigma_{Xc}}}\right]^{\frac{\sigma_{Xc}}{\sigma_{Xc}-1}} \qquad (77)$$

$$XD_{c}=\left[\delta_{XXc}{}^{\frac{1}{\sigma_{XXc}}}.\,EXP_{c}{}^{\frac{\sigma_{XXc}-1}{\sigma_{XXc}}}+\left(1-\delta_{XXc}\right)^{\frac{1}{\sigma_{XXc}}}\,.\,XDD_{c}{}^{\frac{\sigma_{XXc}-1}{\sigma_{XXc}}}\right]^{\frac{\sigma_{XXc}}{\sigma_{XXc}-1}} \qquad (78)$$

$$PX_{c}\,.\,X_{c}=PIMP_{c}\,.\left(1+timp_{c}\right).\,IMP_{c}+PXDD_{c}\,.\,XDD_{c} \qquad (79)$$

$$PXD_{c}\,.\,XD_{c}=PXP_{c}\,.\,EXP_{c}.(1+t\exp_{c})+PXDD_{c}\,.\,XDD_{c} \qquad (80)$$

$$IMP_c = \delta_{Xc}\left(\frac{PX_c}{PMP_c\left(1+timp_c\right)}\right)^{\sigma_{Xc}} X_c \tag{81}$$

$$EXP_c = \delta_{XD\,c}\cdot\left(\frac{PXD_c}{PXP_c.(1+t\exp_c)}\right)^{\sigma_{XDc}} XD_c \tag{82}$$

(7) Market Equilibrium module:

$$\begin{aligned}
X_c &= HXD_c + GXD_c + INV_c + \sum_i M_{c,i} \\
&\quad + \sum_{ei} M_{0,c,ei}\,.\,Z_{ei} + \sum_{mf}\sum_{fi} M_{0,c,mf,fi}\,.\,z_{mf,fi} + \sum_{mp}\sum_{pi} M_{0,c,mp,pi}\,.\,z_{mp,pi} \\
&\quad + \sum_c\left(\sum_{tw}\left(HXDT_{c,tw} + GXDT_{c,tw}\right) + \sum_{cr}\left(HXDT_{c,cr} + GXDT_{c,cr}\right)\right)
\end{aligned}$$

for non-energy commodities

$$\begin{aligned}
&= HXD_c + GXD_c + INV_c + \sum_i EL_i + \sum_{ei} EL_{0,c,ei}\,.\,Z_{ei} \\
&\quad + \sum_{mf}\sum_{fi} EL_{0,c,mf,fi}\,.\,z_{mf,fi} + \sum_{mp}\sum_{pi} EL_{0,c,mp,pi}\,.\,z_{mp,pi} \\
&\quad + \sum_{tw}\left(HXDT_{e,tw} + GXDT_{e,tw}\right) + \sum_{cr}\left(HXDT_{e,cr} + GXDT_{e,cr}\right)
\end{aligned}$$

for electricity

$$\begin{aligned}
&= HXD_c + GXD_c + INV_c + \sum_i FS_{c,i} + \sum_{ei} FS_{0,c,ei}\,.\,Z_{ei} \\
&\quad + \sum_{mf}\sum_{fi} FS_{0,c,mf,fi}\,.\,z_{mf,fi} + \sum_{mp}\sum_{pi} FS_{0,c,mp,pi}\,.\,z_{mp,pi} \\
&\quad + \sum_f\left(\sum_{tw}\left(HXDT_{f,tw} + GXDT_{f,tw}\right) + \sum_{cr}\left(HXDT_{f,cr} + GXDT_{f,cr}\right)\right)
\end{aligned}$$

for non-electric fuel

(83)

$$\overline{CTOT} = \sum_i K_i + \sum_{ei} K_{0,ei}\,.\,Z_{ei} + \sum_{mf}\sum_{fi} K_{0,mf,fi}\,.\,z_{mf,fi} + \sum_{mp}\sum_{pi} K_{0,mp,pi}\,.\,z_{mp,pi} \tag{84}$$

$$\overline{LTOT} = \sum_i L_i + \sum_{ei} L_{0,ei}\,.\,Z_{ei} + \sum_{mf}\sum_{fi} L_{0,mf,fi}\,.\,z_{mf,fi} + \sum_{mp}\sum_{pi} L_{0,mp,pi}\,.\,z_{mp,pi} \tag{85}$$

(8) Other Macroeconomic Parameters

$$\begin{aligned}
GDPNOMINL &= HCONST + GCONST + INVTOT \\
&\quad + \sum_i pwxp_i\,.\,XP_i\,.\,ER - \sum_i pwmp_i\,.\,MP_i\,.\left(1+timp_i\right).\,ER
\end{aligned} \tag{86a}$$

$$GDPREAL = \left(HCONST + GCONST + INVTOT\right) \Big/ CPI + \sum_i pwxp_{0i} \,.\, XP_i \,.\, ER_0 - \sum_i pwmp_{0i} \,.\, MP_i \,.\, \left(1 + timp_i\right) . \, ER_0 \tag{86b}$$

$$GDPINCO = LTOT . W + CTOT . PK + TTAX \tag{87}$$

$$CPI = \frac{\dfrac{\sum_i \left[\begin{array}{l} \left(HXD_i + GXD_i + INV_i + + \sum_{tw} \left(HXDT_{i,tw} + GXDT_{i,tw} \right) + \sum_{cr} \left(HXDT_{i,cr} + GXDT_{i,cr} \right) \right) \\ . \, PX_i . \left(1 + tvat_i + \left(\dfrac{EMM_f}{FF_f . \, PX_f} \right) . \, ctax_f \right) \end{array} \right]}{\sum_i \left(HXD_i + GXD_i + INV_i \right)}}{\dfrac{\sum_i \left[\begin{array}{l} \left(HXD_{0i} + GXD_{0i} + INV_{0i} + + \sum_{tw} \left(HXDT_{0i,tw} + GXDT_{0i,tw} \right) + \sum_{cr} \left(HXDT_{0i,cr} + GXDT_{0i,cr} \right) \right) \\ . \, PX_{0i} . \left(1 + tvat_i + \left(\dfrac{EMM_f}{FF_f . \, PX_f} \right) . \, ctax_f \right) \end{array} \right]}{\sum_i \left(HXD_{0i} + GXD_{0i} + INV_{0i} \right)}} \tag{88}$$

$$EV = \left[\frac{\delta_{HD} . PHDTR_{cf}^{\,1-\sigma_{HD}} + \left(1 - \delta_{HD}\right) . PHDNT_{cf}^{\,1-\sigma_{HD}}}{\delta_{HD} . PHDTR_0^{\,1-\sigma_{HD}} + \left(1 - \delta_{HD}\right) . PHDNT_0^{\,1-\sigma_{HD}}} \right] HCONST_{cf} - HCONST_0 \tag{89}$$

(9) Dynamic module:

$$CTOT_{i,t+1} = \sum_i K_{i,t} . \, (1 - \rho_i) + \sum_{ei} K_{ei,0} . \, Z_{ei,t} \; . \, (1 - \rho_e) + \sum_{mf} \sum_{fi} K_{mf,fi,0} . \, z_{mf,fi,t} \; . \, (1 - \rho_{tf}) + \sum_{mp} \sum_{pi} K_{mp,pi,0} . \, z_{mp,pi,t} \; . \, (1 - \rho_{tp}) + kratio \, . \, INVTOT_t \tag{90}$$

$$LTOT_{t+1} = LTOT_t \, . \left(1 + \beta_t\right) \tag{91}$$

$$\alpha_{L\,i,t+1} = \alpha_{L\,i,t} \; . \left(1 + rtpg_t\right) \tag{92}$$

$$\alpha_{FS\,i,t+1} = \alpha_{FS\,i,t} \; . \left(1 + rfs_t\right) \tag{93}$$

$$\alpha_{HHEEI\;t+1} = \alpha_{HHEEI\;t} \; . \left(1 + rhe_t\right) \tag{94}$$

(10) Energy and Emission module:

$$ENFU_{f,i} = \frac{FU_{f,i}}{FF_f} \tag{95}$$

$$ENEL_i = \frac{EL_i}{FF_e} \tag{96}$$

$$ENFU_{f,it} = \frac{FUS_{0,f,it} \, . \, Z_{it}}{FF_f} \tag{97}$$

$$ENEL_{it} = \frac{EL_{0,it} \, . \, Z_{it}}{FF_e} \tag{98}$$

$$\begin{aligned} ENTOT = & \sum_f \left(\sum_i ENFU_{f,i} + \sum_{ei} ENFU_{f,ei} + \sum_{mf} \sum_{fi} ENFU_{f,mf,fi} + \sum_{mp} \sum_{pi} ENFU_{f,mp,pi} \right) \\ & + \sum_f \left(\frac{\left(HXD_f + GXD_f + INV_f + \sum_{tw} \left(HXDT_{f,tw} + GXDT_{f,tw} \right) + \sum_{cr} \left(HXDT_{f,cr} + GXDT_{f,cr} \right) \right)}{FF_f \, . \, (1 + tvat)} \right) \\ & + \frac{\left(HXD_e + GXD_e + INV_e + \sum_{tw} \left(HXDT_{e,tw} + GXDT_{e,tw} \right) + \sum_{cr} \left(HXDT_{e,cr} + GXDT_{e,cr} \right) \right)}{FF_e \, . \, (1 + tvat)} \\ & + \sum_i ENEL_i + \sum_{ei} ENEL_{ei} + \sum_{mf} \sum_{fi} ENEL_{mf,fi} + \sum_{mp} \sum_{pi} ENEL_{mp,pi} \end{aligned} \tag{99}$$

$$EMMSFU_{f,i} = \frac{FU_{f,i}}{FF_f} \, . \, EMM_{f,i} \tag{100}$$

$$EMMSFU_{f,it} = \frac{FUS_{0,f,it} \, . \, Z_{it}}{FF_f} \, . \, EMM_{f,it} \tag{101}$$

$$\begin{aligned} EMMSTOT = & \sum_f \left(\sum_i ENFU_{f,i} + \sum_{ei} ENFU_{f,ei} + \sum_{mf} \sum_{fi} ENFU_{f,mf,fi} + \sum_{mp} \sum_{pi} ENFU_{f,mp,pi} \right) \\ & + \sum_f \left(\frac{\left(\begin{array}{l} HXD_f + GXD_f + INV_f + \sum_{tw} \left(HXDT_{f,tw} + GXDT_{f,tw} \right) \\ + \sum_{cr} \left(HXDT_{f,cr} + GXDT_{f,cr} \right) \end{array} \right)}{FF_f \, . \, (1 + tvat)} \right) . \, EMM_{f,i} \end{aligned} \tag{102}$$

Endogenous Variables:

CPI = consumer price index.
DM_i = domestic intermediate input composite used by sector i
$EGEN_j$ = electricity produced from 'j' electricity generation technology
E_i = energy composite used by sector i
EK_i = energy-capital composite used by sector i
EKL_i = energy-capital-labor composite used by sector i.
EL_i = electricity used by sector i
EMMSFUf,i = GHG emission due to consumption of "f" fuel as intermediate input for "i" production sector
EMMSFUf,it = GHG emission due to consumption of "f" fuel as intermediate input for "it" production technology wise sub-sector
EMMSTOTge = Total emission of "ge" GHG emission
ENELi = Consumption of electricity as intermediate input for "i" production sector
ENELit = Consumption of electricity as intermediate input for "i" production technology wise sub-sector
ENFUf,i = Consumption of "f" fuel as intermediate input for "i" production sector
ENFUf,it = Consumption of "f" fuel as intermediate input for "it" production technology wise sub-sector
ENTOT = Total consumption of fuel in PJ
ER = exchange rate.
EV = household welfare changed between the counter factual case and base case is measured by using equivalent variation in income.
EXP_c = export of commodity c.
FS_i = non-electricity energy inputs
$FU_{f,i}$ = non-electricity energy input used by sector i
GCONST = government consumption.
GDPINCO = income based nominal GDP.
GDPNOMINL = consumption based nominal GDP.
GDPREAL = consumption based real GDP.
GSAV = government saving.
GXD_c = government consumption of commodity c.
GXD_{PS} = government consumption demand for public service.
$GXDT_{tinp,tw}$, $GXDT_{tinp,cr}$ = commercial, motor vehicle, gasoline, diesel and electricity commodities consumed by individual private transport technology used by the government.
HCONCT = household consumption.
HDE = household consumption of energy composite
HDNE = household consumption of non-energy composite
HDNT = household consumption of non-transport composite.
HDTR = household consumption of transport composite.
HSAV = household saving.
HXD_c = household consumption of commodity c.
$HXDT_{tinp,tw}$, $HXDT_{tinp,cr}$ = commercial, motor vehicle, gasoline, diesel and electricity commodities consumed by individual private transport technology used by the government.
IMP_c = import of commodity c.
INV_c = investment consumption of commodity c.
INV_c = investment consumption of commodity c.
INVTOT = total investment.

IT = real investment
K_{ei} = capital factor input used by electricity sub-sector ei.
K_i = capital factor input used by sector i
$K_{mf,fi}$ = capital factor input used by land freight transport with mode mf and sub-sector fi.
$K_{mp,pi}$ = capital factor input used by land passenger transport with mode mp and sub-sector pi.
L_{ei} = labor factor input used by electricity sub-sector ei.
L_i = labor factor used by sector i
$L_{mf,fi}$ = labor factor input used by land freight transport with mode mf and sub-sector fi.
$L_{mp,pi}$ = labor factor input used by land passenger transport with mode mp and sub-sector pi.
$M_{k,i}$ = domestic intermediate input used by sector i
MM_{ei} = import of non-competitive intermediate input in electricity sub-sector ei.
MM_i = imported intermediate input composite used by sector i
$MM_{mf,fi}$ = import of non-competitive intermediate input in land freight transport with mode mf and sub-sector fi.
$MM_{mp,pi}$ = import of non-competitive intermediate input in land passenger transport with mode mp and sub-sector pi.
PDM_i = price of domestic non-energy intermediate input composite.
$PEGEN_j$ = price of electricity generation from 'j' electricity generation technology.
PEi = price of energy composite.
PEK_i = price of energy-capital composite.
$PEKL_i$ = price of energy-capital-labor composite.
PEL_i = price of electricity.
$PEXP_c$ = export price of commodity c in domestic currency.
PFS_i = price of non-electricity energy inputs.
PFS_i = price of non-electricity energy inputs.
PHDE = price of the energy composite
PHDNE = price of the non-energy composite
PHDNT = price of non-transport composite demand
PHDTR = price of transport composite demand
PI = capital good price
$PIMP_c$ = import price of commodity c in domestic currency.
PK = price of capital factor input.
PMM_e = import price of non-competitive intermediate input in electricity sector in domestic currency.
PMM_i = import price of non-competitive intermediate input in sector i in domestic currency.
PMM_i = price of imported non-energy intermediate input composite.
PMM_{tf} = import price of non-competitive intermediate input in land freight transport sectior in domestic currency.
PMM_{tp} = import price of non-competitive intermediate input in land passenger transport sector in domestic currency.
$PTRCR_0$, $PGRCR_0$, $PTRCR_t$, $PGRCR_t$ = price of household and government demand for aggregate private car transport.
PTRPR = price of the private transport composite
PTRPU = price of the purchased transport composite
$PTRTW_0$, $PGRTW_0$, $PTRTW_t$, $PGRTW_t$ = price of household and government demand for aggregate private two-wheeler transport.

PX_{nt} = price of commodity produced or service provided by new technology not present in the base year.
$PXDD_c$ = price of household consumption of commodity cm from domestic production.
PX_{el} = price of electricity.
PX_f = price of non-electricity fuel.
PX_k = price of intermediate material input.
PXM_i = price of aggregate non-energy intermediate inputs.
PX_{PS} = price of government consumption demand for public service.
PZ_e = price of gross domestic output excluding production tax of electricity sector.
PZ_{ei} = price of gross domestic output excluding production tax of electricity sub-sector ei.
PZ_i = price of gross domestic output excluding production tax of sector i.
$PZ_{mf,fi}$ = price of gross domestic output excluding production tax of land freight transport with mode mf and sub-sector fi.
$PZ_{mp,pi}$ = price of gross domestic output excluding production tax of land passenger transport with mode mp and sub-sector pi.
PZ_{tf} = price of gross domestic output excluding production tax of land freight transport sector.
PZ_{tp} = price of gross domestic output excluding production tax of public land passenger transport sector.
$TRCR_0$, $GRCR_0$, TRCR, GRCR = household and government demand for aggregate private car transport.
TRPR = household consumption of private transport
TRPU = household consumption of purchased transport service
$TRTW_0$, $GRTW_0$, TRTW, GRTW = household and government demand for aggregate private two-wheeler transport.
U = household utility CES function.
W = national average wage rate (price of labor) fixed as numeraire.
Xc = total household consumption of commodity c.
XD_c = commodity c produced from sector i.
XD_c = composite of domestic consumption.
XDDc= household consumption of commodity c from domestic production.
XEM_i = aggregate intermediate inputs of energy and non-energy commodities used by sector i.
YG = government income.
YH = household income.
Z_{ei} = gross domestic output excluding production tax of electricity sub-sector ei.
Z_i = gross domestic output excluding production tax of sector i.

Exogenous Variables:

$\overline{CTOT}$ = total capital supply
$\overline{LTOT}$ = total labor supply
ρ = deprecation rate.
δ_{nt} = CES function share parameter for new technology not present in the base year.
σ_{Ze} = elasticity of substitution for electricity generation technologies.
σ_{Ze} = elasticity of substitution for electricity generation technologies.

δ_{Zei} = CES function share parameter associated with individual electricity generation technology.

$\delta_{Zj,e}$= CES function share parameter associated with individual electricity generation technology.

α_{AEEIi} = annual energy efficiency improvement (AEEI) factor associated with energy input of sector i

δ_{DHDE} = CES share parameter associated with household energy commodity consumption.

σ_{DHDE} = elasticity of substitution associated with energy commodity consumption.

δ_{DHDNE} = CES share parameter associated with household non-energy commodity consumption.

σ_{DHDNE} = elasticity of substitution associated with non-energy commodity consumption.

δ_{DMi} = CES function share parameter associated with domestic intermediate input.

σ_{DMi} = elasticity of substitution for domestic intermediate input.

δ_{EKi} = CES function share parameter associated with energy composite and capital factor of sector i.

σ_{EKi} = elasticity of substitution between energy composite and capital factor of sector i.

δ_{EKLi} = CES function share parameter associated with energy-capital composite and labor inputs.

σ_{EKLi} = elasticity of substitution between energy-capital composite and labor inputs.

$\delta_{FSf,i}$ = CES function share parameter associated with non-electricity energy input.

σ_{FSi} = elasticity of substitution for non-electricity energy input.

δ_{HD} = CES function share parameter associated with household consumption of transport composite and non-transport composite

σ_{HD} = elasticity of substitution between transport composite and non-transport composite household consumptions

δ_{HDNT} = CES function share parameter associated with energy composite and non-energy composite commodities consumptions

σ_{HDNT} = elasticity of substitution between energy composite and non-energy composite commodities consumptions

δ_{HDTR} = CES function share parameter associated with private and purchased transport

σ_{HDTR} = elasticity of substitution between private and purchased transport consumptions.

α_{HHEEI} = energy efficiency improvement (EEI) factor for household energy consuming devices

α_{Li} = Productivity of labor input of sector i and its value is 1 in the base year

δ_{TRPU} = CES share parameter associated with household purchased transport service.

σ_{TRPU} = elasticity of substitution associated with household purchased transport service.

σ_{Xcm} = Armington elasticity of substitution between consumption of commodity cm imported from RoW and domestic production.

δ_{Xcm} = CES function share parameter associated with consumption of commodity cm imported from RoW and domestic production.

δ_{XEMi} = CES function share parameter associated with electricity and non-electricity energy input.

σ_{XEMi} = elasticity of substitution between associated with electricity and non-electricity energy input.

δ_{XMi} = CES function share parameter associated with domestic intermediate input composite and imported intermediate input composite.

σ_{XMi} = elasticity of substitution between associated with domestic intermediate input composite and imported intermediate input composite

σ_{XXcm} = Armington elasticity of substitution between production of commodity cm exported to RoW and supply to domestic market.

δ_{XXcm} = CET function share parameter associated with production of commodity cm exported to RoW and supply to domestic market.

δ_{Zi} = CES function share parameter associated with energy-capital-labor composite and aggregate non-energy intermediate inputs of sector i

σ_{Zi} = elasticity of substitution between energy-capital-labor composite and aggregate non-energy intermediate inputs.

ctx_f = carbon tax on consumption of fossil fuel.

$dinvt_c$ = investment consumption share in total investment.

$dtrmov_{tinp,cr}$ = share for commercial, motor vehicle, gasoline, diesel and electricity commodities consumed by individual private transport technology.

$EMM_{f,i}$ = Emission factor for GHG emission (10^3 ton/PJ) where common emission factor for fuel is used for CO_2 emission and sector or technology specific emission factors are used for CH_4 and N_2O emissions.

$FCF_{c,i}$ = fixed conversion factor for changing from engineering unit to monetary unit for land transport sectors and electricity sector. For other sectors, its value is one as they do not have to change from engineering unit to monetary unit.

FF_f = Energy conversion factor for converting monetary unit into physical unit (10^{12}NRs/PJ)

fsav = saving by foreign institution

hhtx = household income tax.

hqd_{tw},hqd_{cr}, gqd_{tw},gqd_{cr} = household and government demand for individual technology based private transport.

kratio = capital adjustment ratio.

mps = fixed marginal propensity to saving for household.

$prtax_i$ = production tax in sector i.

$pwexp_c$ = export price of commodity c in foreign currency.

$pwimp_c$ = import price of commodity c in foreign currency.

$pwmm_{el}$ = import price of non-competitive intermediate input in electricity sector in foreign currency.

$pwmm_i$ = import price of non-competitive intermediate input in sector i in foreign currency.

$pwmm_{tf}$ = import price of non-competitive intermediate input in land freight transport sectior in foreign currency.

$pwmm_{tp}$ = import price of non-competitive intermediate input in land passenger transport sector in foreign currency.

PXD_i = producer price of commodity produced by sector i

rfs = autonomous energy efficiency improvement.

rfst = change in energy efficiency improvement factor in energy input of sector i in time t

rg = share representing government consumption as percentage of real GDP.

rhet = change in energy efficiency improvement factor for household energy consuming devices in time t

rtpg = technological progress rate.

rtpgt = technology progress rate due to change in labor productivity in time t

$shgw_{nt}$ = increase in the share of new technology not present in the base year.

$texp_c$ = export tax on commodity c.

$timp_c$ = import tax on commodity c.

$trfip_e$ = import tax on non-competitive imported intermediate input for electricity sub-sector.
$trfip_i$ = import tax on non-competitive imported intermediate input for sector i.
$trfip_{tf}$ = import tax on non-competitive imported intermediate input for land freight ub-sector.
$trfip_{tp}$ = import tax on non-competitive imported intermediate input for land passenger sub-sector.
trgrw = net foreign transfer to government from RoW.
trhhgr = domestic transfer to household from government.
trhhw = net foreign transfer to household from RoW.
$tvat_c$ = value added tax on commodity c.
$z_{mf,fi}$ = gross domestic output in physical unit (million ton km) of land freight transport with mode mf and sub-sector fi.
$z_{mp,pi}$ = gross domestic output in physical unit (million passenger km) of land passenger transport with mode mp and sub-sector pi.
β_t = labor factor growth rate.