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Transport sector electrification in a hydropower resource rich developing country: Energy security, environmental and climate change co-benefits

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A B S T R A C T

This paper analyzes the co-benefits of transport sector electrification in terms of reductions of greenhouse gas and local environmental emissions, improvement in energy security and employment generation during 2015–2050 in the case of Nepal—a developing country with large hydropower potential. A bottom up energy system model of Nepal based on the MARKAL framework was developed to assess the effects of meeting a part of the land transport service demand through electrified mass transport system and electric vehicles. The present study shows that if the share of electricity based transport services is to grow from 10% in 2015 to 35% by 2050, the hydropower generation capacity would have to increase by 495 MW by 2050 as compared to the base case, while the annual electricity generation in 2050 would have to increase by 7.86 TWh. As a result, the cumulative total imported energy would decrease by 14.6% in the 35% transport electrification scenario as compared to the base case during 2015–2050. In addition, the cumulative greenhouse gas emissions would be reduced by 12.9% (74.7 million tons CO_2e) in the same scenario during 2015–2050.

Introduction

The rising prices of fossil fuels, particularly oil and gas, have been a matter of serious international concern, especially for the low income energy importing developing countries. The growing dependence of such countries on imported fuels has increased their economic vulnerability to increases in fossil fuel prices. The case of Nepal can be a good example. The country is one of the low income developing countries and spent 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). Besides, the growing urban air pollution in the country (mainly due to the vehicular emissions) is creating acute environmental and health problems (ADB/ICIMOD, 2006; Shrestha and Rajbhandari, 2010). 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 a greater use of its indigenous resources. The country has a huge hydropower resource with a theoretical potential of 83,000 MW, of which 42,000 MW is reported to be economically feasible (NEA, 2008a; WECS, 2006a). However, less than 2% of the country's economically feasible hydropower potential remains exploited at present. Thus, promotion of a sustainable transport system based on electricity emerges as an important national strategic option. Such a strategy is expected to enhance the national energy security and at the same time reduce the country's macroeconomic vulnerability. It is also expected to generate co-benefits in terms of reduction in emissions of greenhouse gases (GHG) and local air pollutants as well as employment generation (NESS, 2003).

There are only a limited number of studies focused on 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 narrowly at the sectoral level and fail 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 (Subway, LRT, monorail, electric passenger and freight train) 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 mass rapid transit system (MRTS) and railway service for Thailand, while Kim and Moon (2008) studied the effects on energy mix and CO_2 emissions of introducing hydrogen vehicles in Korea. The effect on CO_2 emissions of introducing hybrid and fuel cell vehicles in the passenger transport system in the case of Japan is 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 emissions from the introduction of fuel cell vehicles in the case of United Arab Emirates. However, the study does not consider cost optimization as an objective.

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There exist only a few studies that assess 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 emissions reduction (Shrestha, 2007). To the knowledge of the authors, no study so far has carried out 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.

This paper analyzes the effects of different levels of land transport system electrification over a long term (2005–2050) in Nepal. It assesses the effects of the transport sector electrification on environmental emissions (including GHGs) and energy security under five different levels of electrification of the road transport system in the country (i.e., 10%, 20%, 30% and 35% electrification of road transport services) by 2050. For the purpose of the present study, a bottom up cost minimization national energy system model was developed by taking into account the diverse physiographical and the rural–urban demographic characteristics of the country.

The paper is divided into seven sections. The next section (second section) presents a brief overview of transport and energy policies of Nepal. The third section discusses the national energy system model developed for the study. Descriptions of the scenarios are presented in the fourth section. This is followed by the discussion of the base case and effects of different electrification scenarios. Finally, key findings of the study are summarized along with concluding remarks.

Overview of energy and transport policy in Nepal

Nepal has a population of about 25 million, of which 16% lived in the urban areas in 2005 (CBS, 2007). The urban population of the country is growing at a rate of 6.4%, which is over 3.5 times that of the rural population growth rate during 1991–2001 (CBS, 2003). This has caused a high growth in the stock of transport vehicles operating in the country. The average annual growth rate of passenger transport vehicles in the country is found to be above 13% during 1996–2005, while that of freight transport vehicles is found to be 9% (CBS, 2007).

The Government of Nepal (GoN) has issued the National Transport Policy 2001/02, which emphasized the promotion of electricity based transport system throughout the country with private sector participation. The Eighth, Ninth and Tenth Five-Year Plans of the country (covering the periods of 1992–1997, 1997–2002 and 2002–2007 respectively) gave an emphasis on the expansion of the government owned electric trolley bus service operating inside the Kathmandu valley (see Gyawali et al., 2004; NESS, 2003). However, such an expansion did not materialize and the trolley bus service became dysfunctional by 2004. On the other hand, electric 3-wheelers operated by the private sector is still in operation inside the Kathmandu valley. In the recent three-year interim plan (2007/08 to 2009/10), the GoN has declared a long-term vision to make the transport system safe, affordable, non-polluting, and service-oriented (GoN, 2008). Recently, the GoN has come up with the long-term plan to introduce electric railway system in Nepal (RITES/SILT, 2010).

Similarly, the country's Hydropower Development Plan of 1992 emphasized the use of electricity in the transport sector to reduce fossil fuel consumption and diversify the use of electricity. Furthermore, the GoN has adopted the 25-year National Water Resources Strategy 2002, one of the objectives was to increase the total demand for electricity through diversification of electricity usage and to promote indigenous hydropower development (WECS, 2005a). Recently, the GoN has also developed a medium term plan to develop 10,000 MW hydropower plants by 2020 that would be dedicated to both domestic and export markets (MOWR, 2009). Later, the GoN revised the medium term hydropower development plan mentioning the potential to develop 37,628 MW of hydropower plants for domestic consumption and export by 2030 (MOE, 2010). However, the existing transport and hydropower policy documents of the country fail to systematically analyze the interrelations between the transport sector electrification and hydropower development, which the present study is focused on.

Methodology

A bottom up cost minimization energy system model (based on MARKet ALlocation model (MARKAL) framework) has been developed for the purpose of the study (see ETSAP, 2007). 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. The primary energy supply module represents extraction of primary energy from indigenous energy resources (mainly hydropower and biomass) and import of fossil fuels. The conversion and process technology module consists of secondary energy generation, transmission and distribution to the end use services. The 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, and Non-methane Volatile Organic Compound (NMVOC) and PM_{10}) are dealt within 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 energy consumption patterns due to physiographic variations. The physiographic regions have been further disaggregated into urban and rural sub-regions in order to capture the differences in energy consumption patterns due to variations in the levels of sub-regional development. The Kathmandu valley has been treated as a separate sub-region due to the large concentration of economic activities and urban population in the valley. Detailed physiographic and economic disaggregation adopted in the model is shown in Fig. 1.

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.

In this study, future demands for end use services are projected using econometric methods following Shrestha and Rajbhandari (2010) and are exogenous to the MARKAL model.[1] The end use demands are estimated in terms of services, e.g., passenger-km of passenger transport, ton-km of freight transport rather than the demand for final energy needed for the transport services. In some cases, where data did not permit direct estimation of service demands (e.g., cooking and water heating), demand is expressed in terms of the useful energy needed for such end uses and not in terms of their final energy requirements, which, would vary with energy efficiency of devices.

The end use service demands in the residential sector and land passenger transport subsector are estimated by using the following equation:

$$ESD_{i,t} = (POP_t / POP_0)^{\alpha 1i} \times (GDP_t / GDP_0)^{\alpha 2i} \times ESD_{i,0} \qquad (1)$$

[1] Various energy efficient technology options (e.g., efficient ACs, efficient stoves, etc.) are considered in the MARKAL model for meeting each end use service demand (or for meeting useful energy demand in cases, where service demands could not be directly estimated). The model would determine endogenously the cost effective technology option for each end use.