Energy Policy 38 (2010) 4818–4827

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

# Energy and environmental implications of carbon emission reduction targets: Case of Kathmandu Valley, Nepal

Ram M. Shrestha*, Salony Rajbhandari

*School of Environment, Resources and Development, Asian Institute of Technology, Thailand*

ARTICLE INFO

*Article history:*
Received 26 September 2009
Accepted 24 November 2009
Available online 4 January 2010

*Keywords:*
Urban energy use
$CO_2$ emission targets
Kathmandu Valley energy system model

ABSTRACT

This paper analyzes the sectoral energy consumption pattern and emissions of $CO_2$ and local air pollutants in the Kathmandu Valley, Nepal. It also discusses the evolution of energy service demands, structure of energy supply system and emissions from various sectors under the base case scenario during 2005–2050. A long term energy system planning model of the Kathmandu Valley based on the MARKet ALlocation (MARKAL) framework is used for the analyses. Furthermore, the paper analyzes the least cost options to achieve $CO_2$ emission reduction targets of 10%, 20% and 30% below the cumulative emission level in the base case and also discusses their implications for total cost, technology-mix, energy-mix and local pollutant emissions. The paper shows that a major switch in energy use pattern from oil and gas to electricity would be needed in the Valley to achieve the cumulative $CO_2$ emission reduction target of 30% (ER30). Further, the share of electricity in the cumulative energy consumption of the transport sector would increase from 12% in the base case to 24% in the ER30 case.



## 1. Introduction

The Kathmandu Valley is the largest urban area of Nepal, where the capital city of the country is located. With rapid population growth and increasing economic activities, the demand for energy (especially fossil fuels) has been growing faster in the Valley than in the rest of the country. In the recent years air pollution has been emerging as a major environmental concern in the Kathmandu Valley. As reported by the permanent air quality monitoring stations in the Valley, the concentrations of the particulate matters in the Valley are found to exceed the National Ambient Air Quality Standards (NAAQS). Even though the concentrations of $SO_2$, $NO_X$, CO and HC in the Valley are presently well below the NAAQS values, they are found to have been increasing over the recent years (Gautam, 2006; Dhakal, 2006).

In the face of the ongoing international concern for climate change, developing country cities are attracting an increasing attention due to their rapidly growing energy consumption and greenhouse gases (GHGs) emissions. However, there are not many studies that analyze the city level GHG emissions and strategies to reduce GHG emissions over a longer term in future. Thus studies on long term benefits and costs of strategies that help to reduce the emissions of GHGs and local pollutants from developing country cities would be of significant interest to the national and international climate policy makers and other stakeholders.

There exist a number of studies that focus on emission of local pollutants and air quality in the Kathmandu Valley (e.g., Giri et al., 2006; Gautam, 2006; ENPHO, 2001; Sharma, 1997). There also exist several studies that analyze energy use and associated emissions from the transport sector of the Kathmandu Valley (Devkota, 1992; Pradhan, 1994; Adhikari, 1997; Dhakal, 2003, 2006; Pradhan et al., 2006; Anandarajah, 2000).

Pradhan et al. (2006) analyze the potential effects of extending the electric trolley bus system in the Kathmandu Valley on fuel consumption and greenhouse gas emissions till 2025 using the Long-range Energy Alternatives Planning (LEAP) System software. The study shows a three-fold increase in the passenger travel demand during 2003–2025, while fuel consumption and GHG emissions would increase by 2.4 and over 3 times respectively during the same period.

To the knowledge of the authors, Shrestha and Malla (1996) is the only study that examined sectoral energy-use patterns and estimated the associated emissions of local pollutants in the Valley in 1993. That study also made projections of pollutant emissions up to 2013. However, the main focus of the study was on estimation of pollutant emissions and not on the analysis of environmental/climate policies. Furthermore, the study did not use a comprehensive energy system optimization model to estimate the future energy consumption and structure of energy use in the Valley. To the knowledge of the authors, no study so far has carried out a comprehensive analysis of energy use and emissions of greenhouse gases (GHGs) and local pollutants from

* Corresponding author.
*E-mail address:* ram.m.shrestha@gmail.com (R.M. Shrestha).

0301-4215/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enpol.2009.11.088

all sectors of the Kathmandu Valley from a sufficiently long term perspective.

A distinctive feature of the present study is that we analyze the potential implications of adopting a policy of $CO_2$ emission reduction from the Kathmandu Valley for energy use, energy-mix, technology mix and discounted energy system cost as well as co-benefits in terms of local pollutant emission reductions over a long term covering the period of 2005–2050. We use a bottom up energy system optimization model based on the MARKAL framework for this purpose.

The plan of the paper is as follows: Section 2 presents an overview of energy situation of the Kathmandu Valley, while the next section describes the modeling approach used and data sources. Scenarios descriptions are presented in Section 4 followed by the discussion of results in Sections 5 and 6. The last section presents a summary of the key findings and final remarks.

## 2. Energy situation of the Kathmandu Valley

In 2005, fossil fuels (coal, lignite and petroleum products) accounted for about 53% of the total energy consumption in the Kathmandu Valley, whereas the share of biomass and electricity were 38% and 9%, respectively (see Appendix B). According to the electricity sales data, around 28% of electricity produced in Nepal in the year 2005, is consumed in the Kathmandu Valley alone (based on data collected from NEA).

The electricity generation in Nepal is almost entirely hydro-based. Nepal's hydropower potential has been estimated to be 83,000 MW purely on a technical basis i.e., based on average river flow (WECS, 2006a). The present exploitation of hydropower in Nepal is only a little over 1% of the economically feasible potential of 42,000 MW. According to the 10-year hydropower development plan of Nepal, the installed hydropower capacity would be increased to around 10,000 MW by 2020 (MoWR, 2009).

In 1993, almost half of the country's fossil fuel imports were consumed in the Kathmandu Valley (Shrestha and Malla, 1996), while in 2005, about 32% of the country's fossil fuel imports were consumed in the Valley.[1] Among the economic sectors, the share of residential sector in the total energy consumption was the highest (53%), followed by the transport (21%), industry (17%), commercial (9%) and agricultural (0.1%) sectors, respectively. The residential sector accounts for more than four-fifths of the total biomass fuels used. Biomass, kerosene, LPG and electricity are the main fuels used in the residential sector. On per capita basis, urban households are found to use less traditional energy and more modern energy than rural households, mainly due to the heavy dependence on biomass fuels and inefficient appliances in rural areas (Shrestha and Malla, 1996). The industrial and transport sectors account for almost two-thirds of total fossil fuel consumption.

Based on the sales data of Nepal Oil Corporation (NOC), the total gasoline import in the Valley in 2005 was 32 million liters; it is assumed that 95% of this figure (i.e., 30 million liters) was used in the transport sector of the Valley and the rest 5% was exported to districts outside the Valley. Similarly, total diesel import in the Valley in 2005 is reported to be 49 million liters. In this study, 80% of the total diesel import into the Valley (amounting to 38.86 million liters) is assumed to be used in the transport and industry sectors of the Valley (i.e., 78% in the transport sector and 2% in the industrial sector). It should be noted here that our estimate of gasoline consumption in the Valley is substantially lower than that of Dhakal (2006), who estimated gasoline consumption in transport sector of the Kathmandu Valley in 2004 to be over 100 million liters.[2]

[1] This was computed using data from various sources listed in Appendix B.

The Kathmandu Valley has a highest share of industries in the Central Development Region (CDR) of Nepal. The Valley constitutes around 56% of modern industries and 57% of small cottage industries present in the CDR. The total energy consumption by the industries in Bagmati zone[3] is around 3.25 PJ among which the share of the Kathmandu Valley is estimated to be around 93% (WECS, 2006b). The brick making is the most energy intensive industries making this sector the largest consumer of coal in the Valley. It consumes around 65,000 t of coal and several thousand tons of biomass every year to produce around 1.14 billion bricks per year (SDC, 2007). The other major users of coal in the Valley are the paper industry followed by the textile, food and the glass industries.

The Kathmandu Valley has a natural gas reserve of around 300 million $m^3$ among which 47.6 million $m^3$ is proven and the rest 270 million $m^3$ is possible reserve. If this gas is utilized in the form of compressed natural gas, it can be used as a useful source for fueling vehicles and thus reduce dependence on imported fossils to some extent. Several deposits of lignite are found in the Valley and the annual production varies from 1500 to 5400 mt (metric tons). Studies tell that the deposits of lignite in the Valley can be mined for more than 20 years at the present rate of production. Generally, lignite is used in the brick industry by mixing with the imported coal, most often in the ratio of 1:3 (lignite:coal) (WECS, 1995).

## 3. Methodological approach

### 3.1. Description of the modeling approach

A long term energy system model of the Kathmandu Valley has been developed for this study using the MARKet ALlocation (MARKAL) framework. Five different economic sectors, i.e., agriculture, residential, commercial, industrial and transport are considered in the model. The industrial sector comprises of the following sub-sectors: food and beverages, brick, textiles and other industries. Except for the brick industry, other industrial end uses of energy have been classified into: process heating, boilers, motive power and lighting. Residential sector demand projection are mainly classified into cooking, lighting, space heating/cooling, water heating, agro processing, refrigeration, television and other appliances. This sector has been divided into urban and peri-urban categories.

The commercial sector is further classified into hotels, restaurants, academic institutions, health, essentials and non-essentials, institutions and others. The hotel group includes both the starred and non-starred hotels. "Essentials" includes shops such as medicine, cloths, grocery while non-essentials include shops such as cosmetics, bookshops, hardware, fancy shops etc. Institutions include government, semi-government offices, banks, etc. "Others" include cinema hall, water supply, public lighting, military/police barrack, air port, bus terminal and religious places. The transport sector is classified into road, railway (i.e., mass

[2] According to NOC (2004), the total import of gasoline in the country in 2004 was 67.96 million liters. Noting that all petroleum products used in Nepal are imported, the value of the transport sector gasoline consumption in the Kathmandu Valley in 2004 as estimated by Dhakal (2006) and presented in Fig. 6.3 of his book seems to be highly overestimated since his estimated value of gasoline use in the Kathmandu Valley in 2004 is 1.5 times higher than the total national consumption of the fuel in that year.

[3] Nepal is divided into 14 zones and 75 districts. The Kathmandu Valley is a part of the Bagmati Zone.

rapid transit (MRT)) and air transports. It is further subdivided into passenger and freight transportation.

The types of service demand considered in each sector are listed in Appendix A. Both conventional and new efficient technologies are considered for each type of end use considered in the model. New technologies include efficient electric and diesel pumps in the agricultural sector, efficient air conditioner, compact fluorescent lamps and efficient cooking technologies such as electric and LPG cooking in the commercial and residential sectors. For brick industry, altogether seven existing and new technology options are considered. The new technology options considered are the efficient Hoffmann and vertical shaft brick kilns. For the road transport, altogether nine fuel options are considered, namely, gasohol, compressed natural gas (CNG), liquefied petroleum gas (LPG), fuel cell, electric, hybrid, biodiesel, gasoline and diesel. The data on emerging technologies (e.g., fuel cell, hybrid cars) are the same as are used in AIM/Enduse Model of Japan, while the data on energy efficient devices in the residential and commercial sectors are assumed to be the same as that used in AIM/Enduse Model of India (NIES, 2006) due to the similarities in the technologies used in India and Nepal. Emission factors considered in this study are based on Economopoulos (1993), IPCC (1996), NIES (2006), Sothea (2007) and USEPA (2009). The fuel price projections considered in this study are based on EIA (2009).

### 3.2. Service demand projections

Estimation of future levels of service demand in the present study is based on three approaches: (i) using population and GDP of the Kathmandu Valley for estimation of service demands in the residential and road passenger transport sectors, (ii) using GDP only for estimation of service demands in the air passenger-, air freight- and road freight- transport sub-sectors and (iii) using sectoral GDP for estimation of service demands in the agricultural, commercial and industrial sectors.

The estimation of service demands in the residential and road passenger transport sectors are based on the following relationship:

$$SD_{i,t} = SD_{i,0} \times \left(\frac{POP_t}{POP_0}\right)^{\alpha_i} \times \left(\frac{GDP_t}{GDP_0}\right)^{\beta_i} \quad (1)$$

where $SD_{i,t}$ and $SD_{i,0}$=service demand of sub sector $i$ in year $t$ and the base year respectively, $POP_t$ and $POP_0$=population of the Valley in year $t$ and the base year, respectively, $GDP_t$ and $GDP_0$=GDP of the Valley in year $t$ and the base year, respectively, $\alpha_i$ and $\beta_i$=population and GDP elasticities of service demand of sub sector $i$, respectively.

The estimation of service demands in air passenger, air freight, road freight, agricultural, commercial and industrial sectors are based on the following relationship:

$$SD_{i,t} = SD_{i,0} \times \left(\frac{Y_t}{Y_0}\right)^{\beta_i} \quad (2)$$

where $SD_{i,t}$ and $SD_{i,0}$=Service demand of sub sector $i$ in year $t$ and the base year, respectively, $Y_t$ and $Y_0$=sectoral value added in the Valley in year $t$ and the base year, respectively, (except in the case of air transport and freight transport (road based) service demands, for which $Y$ represents total GDP); $\beta_i$=GDP (sectoral) elasticity of service demand of sub sector $i$.

Point elasticities of service demands in the residential and industrial sectors are estimated based on the regression analysis using a log linear demand model with the GDP and population as independent variables and energy consumption/service demand as dependent variables. Due to lack of adequate data, arc-elasticities of service demands were estimated in the cases of agriculture, commercial and transport sectors using the relevant data of 1991 and 2001. The estimated elasticity values are shown in Table 1.

**Table 1**
Population and GDP elasticities considered in the analysis.

| Sector/service demand | Population elasticity,$\alpha$ | GDP elasticity,$\beta$ |
|---|---|---|
| **Agricultural** | | |
| Irrigation | – | 1.71 |
| **Commercial** | | |
| Cooking | – | 0.58 |
| Lighting | – | 0.66[a], 0.6[b], 0.58[c,d,e,f,g] |
| Space heating/cooling | – | 0.58 |
| Water boiling | – | 0.58[a,b,e,g], 0.47[c], 0.54[f] |
| Other electric appliances | | 0.58 |
| **Industrial** | | |
| Brick | – | 0.74 |
| Food & beverages, textiles and others | – | 1.64 |
| **Transportation** | | |
| Air passenger | – | 1.93 |
| Air freight | – | 1.15 |
| Road passenger[h] | 1.44 | 0.41 |
| Road freight | – | 0.6 |
| **Residential**[i] | | |
| Lighting, cooking, water heating, agro-processing, space heating/cooling | 1.04 | 0.02 |
| Electric appliances | 3.56[j] | 0.18 |

[a] Restaurants.
[b] Hotels.
[c] Academic Institutions.
[d] Essentials and non-essentials.
[e] Hospital.
[f] Institutions.
[g] Others.
[h] *In 2005, the passenger-km per capita in the Kathmandu Valley is 2009 while it increases to 9020 in 2050, which is quite comparable with South Asian passenger km per capita value of 9018 as cited in* (Ruehle, 2004).
[i] In case of residential sector, the values of elasticities have been obtained using the data for Nepal due to lack of continuous GDP data for Kathmandu Valley. Multiple regression analysis using log linear demand model has been used for this purpose with 21 years data (i.e., 1981–2001) considering residential electricity (and non-electric energy) consumption as a dependent variable and population and GDP as an independent variable.
[j] Residential electricity demand elasticities value ranging from 1.21 to 4.71 has been found to be used (Bose and Shukla, 1999).

The estimation of the service demand in the agricultural sector is mainly related to irrigation and comprises of estimation of stock of diesel and electric pumps.

For the purpose of road transport demand projection, all the vehicles registered in the Bagmati zone are considered to be operating in the Kathmandu Valley. This is considered to be a reasonable assumption because other districts in this zone are hilly areas and are highly un-motorable. So most of the vehicles registered in this zone are found to be plying in the roads of the Valley. The annual average growth rate of vehicles in the Valley during 1991–2004 is found to be over 13% (Dhakal, 2006; ICIMOD, 2007 and data collected from Department of Transport Management (DoTM)).

## 4. Scenarios description

In this study four scenarios are considered: the base case and three alternative scenarios. The base case is defined as the “business as usual” (BAU) scenario.

**Table 2**
Population growth rates in the Kathmandu Valley, %.
*Source*: CBS, 2003; UN, 2008

| Region | 2005–2010 | 2010–2015 | 2015–2020 | 2020–2025 | 2025–2030 | 2030–2035 | 2035–2040 | 2040–2045 | 2045–2050 |
|---|---|---|---|---|---|---|---|---|---|
| **Kathmandu Valley** | 3.05 | 2.65 | 2.35 | 2.10 | 1.69 | 1.36 | 1.09 | 0.88 | 0.70 |

The population of the Kathmandu Valley mainly includes population of the three districts namely, Kathmandu, Bhaktapur and Lalitpur. Among the three districts, the population density in Kathmandu is the highest with 4.7% annual growth during the period from 1981 to 2001. The population of the Kathmandu Valley is estimated to increase to 2.71 million by 2021 (CBS, 2003) and 3.92 million by 2050 (UN, 2008). About 64% of the Valley's population is urban and the urban population growth rate was projected to be around 4.09% during 2001–2006 while the average annual population growth rate during 2001–2006 was estimated to be around 3.05% (CBS, 2003). The population projection considered in this study is based on the projections made by CBS (2003) and UN (2008). The growth rates considered for this analysis are presented in Table 2.

The share of the Kathmandu Valley in the total national GDP was estimated to be around 13.13% in 1991 (JICA, 1993) and around 15.9% in 2001 (UNDP, 2004). Based on the percentage contributions of the Valley in total national GDP in the year 1991 and 2001 the total GDP of the Valley for the year 2005 is estimated to be 84,545 million Nepalese Rupees (NRs.) at constant price 2000/01. Based on these estimates, the compounded annual GDP growth rate for the Valley during 1991–2001 is obtained to be 7.73%. In this study the GDP of the Kathmandu Valley is assumed to grow at the rates of 7.08%, 6.72%, 6.36% and 6% per annum during 2005–2010, 2010–2015, 2015–2020 and 2020–2050, respectively.

Only a small share of fuelwood is met from the domestic supply in the Valley and the rest is met by importing from other parts of the country in 2005. The maximum domestic availability of fuelwood in the Valley in 2005 is estimated to be 0.75 PJ. Similarly, animal dung and agricultural residue availability in the Valley in 2005 is estimated to be 0.07 and 2 PJ, respectively (WECS, 1994b, 2006b). It is assumed that the biomass is produced on sustainable basis and therefore there would be no net $CO_2$ emission involved. The maximum availability of lignite and natural gas is estimated to be 7.54 and 11.11 PJ, respectively (WECS, 1995). The electricity mentioned in the analysis refers to the hydrological electricity, since Nepal's power generation system is solely hydro-based. The emerging technologies like CNG, hybrid, biodiesel and gasohol vehicles are considered to be available from 2015 onwards; electric and LPG light duty vehicles (e.g. car/jeep/van) are considered to be available from 2015 onwards; mass rapid transit (MRT) and fuel cell vehicle options are considered to be available from 2020 to 2025 onwards, respectively. Efficient light duty vehicles (such as car, jeep, van, three-wheelers, taxi, microbus and pick-ups) are considered in the model; the technical characteristics of these vehicles (especially in the future years) are based on IEA (2006). It is assumed in the present that there will be a minimum share of each type of vehicle: That is, buses and 2-wheelers will each supply a minimum of 10% of passenger-km demand, whereas car/jeep/vans (as one category) and 3-wheelers will each supply a minimum of 5% of the passenger-km demand.[4] Micro-buses will supply a minimum of 6% and mini-buses will provide at least 10% of the total demand. No minimum share is assumed in the case of MRTs. An autonomous energy efficiency improvement of 0.25% per year is considered for the electrical appliances (such as electric pumps, television, refrigerator, air conditioner, fan and electric cooker) used in the agricultural, commercial and residential sectors (Webster et al., 2008). No $CO_2$ emission mitigation policy intervention is considered in the base case. The time span for the study is considered to be 2005–2050 with 2005 as the reference year. The discount rate used in this study is 10%. All costs considered in the model are expressed at the constant prices of year 2005.

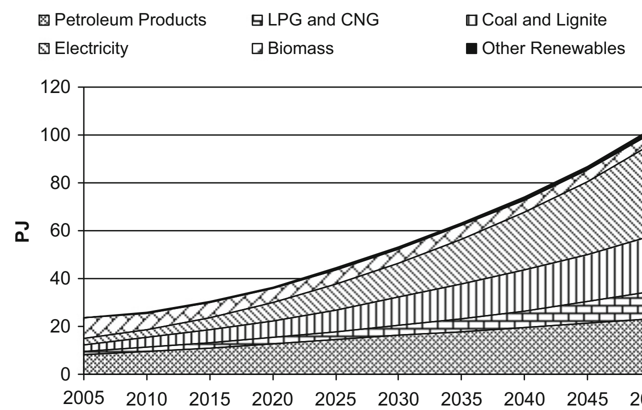


**Fig. 1.** Total energy consumption during 2005–2050, PJ.

Besides the base case, the following three $CO_2$ emission reduction target (ERT) scenarios are considered in this study[5]:

(i) Cumulative $CO_2$ emission reduction target of 10% during 2005–2050 as compared to the cumulative emission in the base case, all other things remaining the same as in the base case (hereafter known as "ER10" case).
(ii) Similarly, cumulative $CO_2$ emission reduction target of 20%, (hereafter known as "ER20" case), and
(iii) Cumulative $CO_2$ emission reduction target of 30%, (hereafter known as "ER30" case).

## 5. Base case analysis

### *5.1. Total energy mix and sectoral energy consumption*

The total energy consumption (TEC) is estimated to rise at an average annual growth rate (AAGR) of 3.2% during 2005–2050. As a result, TEC is found to increase from 24 PJ in 2005, 53 PJ in 2030 and 102 PJ in 2050 (see Fig. 1). Petroleum products[6] including LPG

[4] Note that in 2005, the shares of different types of vehicles in total passenger-km demand were as follows: buses—32%, car/jeep/van—14%, 3-wheelers—10%, 2-wheelers—22%, micro-bus—6% and mini-bus—20%.

[5] A constraint on cumulative $CO_2$ emission during the study period (i.e. 2005–2050) is included in the energy system cost minimization model in order to analyze the effects of ERTs. Thus, for example, in the case of ER10, this constraint would require total emission from all sectors to be equal to 90% of the cumulative emission in the base case.

[6] Petroleum products excluding LPG and CNG.

**Table 3**
Share of sectoral energy consumption during 2005–2050 under the base case, %.

| Sector | 2005 | 2010 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| Agricultural | 0.08 | 0.08 | 0.06 | 0.04 | 0.04 | 0.03 |
| Commercial | 8.0 | 9.3 | 10.2 | 11.5 | 14.9 | 21.8 |
| Industrial | 19.0 | 21.4 | 21.6 | 24.4 | 25.7 | 25.1 |
| Residential | 51.4 | 43.3 | 36.5 | 30.9 | 27.0 | 23.1 |
| Transport | 21.6 | 25.9 | 31.7 | 33.2 | 32.3 | 30.0 |
| **Total in PJ** | **24** | **26** | **36** | **53** | **73** | **100** |

provide the largest share (40%) in TEC in 2005, however, their share is found to be decreasing during the time span of 2005–2050. This is because of the increasing share of electricity, coal, LPG and CNG fuel. CNG is estimated to contribute around 0.07 PJ starting from the year 2015 and remains fairly constant over the whole period, thus providing around 0.07% contribution in the year 2050. This value is constant mainly because of the resource availability limit provided to the model. Renewable energy including biomass, biogas, charcoal and solar energy contributed to almost 37% of TEC in 2005. Among the biomass resources, fuelwood use would decrease from 6.92 PJ in the base year to 4.49 PJ in 2050. In 2005, the combined share of agricultural residue and animal waste[7] in TEC is estimated to be 8% whereas it is estimated to decrease over the time span. Other renewables[8] account for 0.13% in the base year and their share is found to increase to 1.6% by 2050.

Coal and lignite have the third largest share in TEC (around 13%) in the base year, and the share was found to increase to 23% at the end of the time span of 2005–2050. Coal is mostly used in the industrial sector, especially in brick manufacturing industries. Some coal is also found to be used in the residential sector for cooking in the peri urban areas of Kathmandu Valley. The use of lignite would decrease from 0.6 PJ in 2005 to 0.2 PJ in 2015. Lignite deposit is estimated to be exhausted by 2020. Electricity accounts for around 10% of TEC in the Valley in 2005 and the share is estimated to grow to about 38% by 2050. Electricity is estimated to take a larger share in the future representing the higher rate of urbanization.

The residential sector has a dominant share (51.4%) in the TEC in the base year (see Table 3). However, its share is estimated to decline to 23.1% by 2050. The decreasing share of this sector is mainly because of the increasing use of electricity and cleaner (efficient) fuels such as LPG and decreasing use of biomass (mainly agricultural residues and animal waste). Transport and industrial sectors together accounted for 41% of TEC in 2005 and their share would grow to 55% by 2050. The TEC of transport and industrial sectors are estimated to increase at an average growth rates of 4.2% and 3.7%, respectively, during 2005–2050.

The study shows that the commercial sector experiences a higher energy consumption growth rate of 5.54% during 2005–2050. As a result, the sector's energy consumption in 2050 is estimated to be higher by more than 11 times than that in 2005. The sector's share in TEC in 2050 would be 21.8% as compared to 8% in 2005. Kerosene has the highest share in TEC of commercial sector, followed by electricity, LPG and solar. Solar use is not very significant in the base year but its share is found to be considerably increasing towards the end of the time span making contribution of around 2.3% in the TEC of the sector. The solar energy is mostly found in meeting the water heating demand.

The total energy demand of agricultural sector in 2005 is 0.02 PJ contributing around 0.08% in TEC, making this as one of the least energy consuming sector in the TEC. This sector experiences an average growth rate of 0.9% during 2005–2050. Diesel and electricity are the two major fuels used in this sector mainly for irrigation purposes. Generally, the human labor and animal energy are the main energy sources used in this sector. However, the substitution of animate energy with mechanization (and associated commercial energy) is not considered in the present analysis.

### 5.2. *Emissions*

#### 5.2.1. *Carbon dioxide ($CO_2$) emissions*

Total $CO_2$ emission is found to grow nearly by 5 folds by the year 2050. The total emission was estimated to be 962 kton (kt) in 2005, 2520 kt in 2030 and 4561 kt in 2050 (see Fig. 2). The total cumulative $CO_2$ emission during the time span of 2005–2050 is estimated to be 124,322 kt$CO_2$.

Transport sector accounts for the highest share (34%) in the total $CO_2$ emissions in 2005 followed by industrial sector (33%), residential sector (23%) and commercial sector (10%). The combined share of the transport and industrial sectors in the total $CO_2$ emissions is estimated to increase from 67% in 2005 to 88% by 2050, when the share of industrial sector would attain about 50%. This is mainly because of the increasing coal and diesel consumption in the industry sector.

The share of the residential sector in total $CO_2$ emission would be decreasing over time to about 4% in 2050 mainly because of usage of LPG for cooking and electricity for space heating, cooling and cooking purposes and both electricity and solar energy for water heating. The share of commercial sector is found to decrease to around 8% in 2050. This is mainly because of the increasing share of electricity. The agricultural sector contributes the least (0.1% in 2005) in the overall $CO_2$ emissions.

#### 5.2.2. *Emission of local air pollutants*

Table 4 shows the estimates of CO, HC, $NO_X$, $SO_2$ and $PM_{10}$ emissions during 2005–2050 in the base case.

In the case of air transport, it should be noted that not all the jet fuels consumed in the Kathmandu Valley would share in the total local pollutants emissions. Studies suggest that only a fraction of the fuel consumed in the landing and take-off (LTO) of the aircrafts can be considered responsible to generate emissions within the boundary of the country/city. A study conducted on emission estimation of aircrafts at Turkish airports suggests that the fuel consumed by aircrafts in LTO cycles is approximately 0.23% of the total energy consumption (Kesgin, 2006). Considering this percentage share, the jet fuel consumed in the LTO cycles of aircrafts in the Kathmandu airport is estimated to be 4.83 TJ (i.e., 0.23% of 2100 TJ) in 2005.

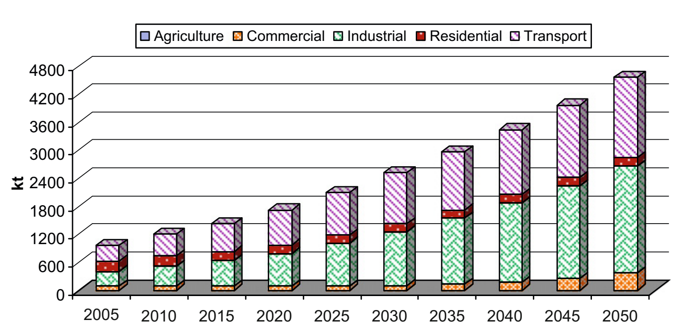


**Fig. 2.** Sectoral $CO_2$ emission in the base case, kt.

[7] Given that there is a decreasing trend in the use of agricultural residues and animal waste, in this study it is assumed that the use of agricultural residues and animal waste will be reduced to zero by 2040 and 2030, respectively.

[8] Other renewables include biogas, charcoal and solar.

**Table 4**
Sectoral shares in local air pollutant emissions under the base case, %.

| Local pollutants | Sector | Year | | | | | | Ratio 2050/2005 |
|---|---|---|---|---|---|---|---|---|
| | | 2005 | 2010 | 2020 | 2030 | 2040 | 2050 | |
| CO | Agriculture | < 0.01 | 0.02 | 0 | 0 | 0 | 0 | 0 |
| | Commercial | 4 | 3 | 3 | 2 | 2 | 2 | 0.6 |
| | Industrial | 4 | 3 | 1 | 1 | 1 | 1 | 0.3 |
| | Residential | 40 | 33 | 26 | 19 | 13 | 8 | 0.2 |
| | Transport | 52 | 61 | 71 | 78 | 84 | 89 | 1.7 |
| | **Total in kt** | **28.1** | **30.7** | **40.2** | **57.6** | **80.0** | **109.4** | 3.9 |
| HC | Agriculture | < 0.01 | < 0.01 | 0 | 0 | 0 | 0 | 0 |
| | Commercial | 0.11 | 0.09 | 0.06 | 0.05 | 0.06 | 0.10 | 1.0 |
| | Industrial | 1.2 | 1.0 | 0.7 | 0.7 | 0.9 | 1.3 | 1.1 |
| | Residential | 24.1 | 10.5 | 7.2 | 6.8 | 6.3 | 5.0 | 0.2 |
| | Transport | 74.5 | 88.3 | 92.0 | 92.5 | 92.7 | 93.6 | 1.3 |
| | **Total in kt** | **12.4** | **14.4** | **23.7** | **34.7** | **42.4** | **46.9** | 3.8 |
| $NO_X$ | Agriculture | < 0.01 | 0.02 | 0 | 0 | 0 | 0 | 0 |
| | Commercial | 2.1 | 1.8 | 1.4 | 0.8 | 1.1 | 1.7 | 0.8 |
| | Industrial | 54.1 | 47.3 | 38.2 | 41.1 | 43.9 | 44.7 | 0.8 |
| | Residential | 7.3 | 6.2 | 4.5 | 2.9 | 2.1 | 1.5 | 0.2 |
| | Transport | 36.5 | 44.7 | 55.9 | 55.1 | 53.0 | 52.0 | 1.4 |
| | **Total in kt** | **5.7** | **6.4** | **7.9** | **12.1** | **16.7** | **22.5** | 3.9 |
| $SO_2$ | Agriculture | 0.1 | 0.04 | 0 | 0 | 0 | 0 | 0 |
| | Commercial | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.5 |
| | Industrial | 76.6 | 77.7 | 81.2 | 85.3 | 88.4 | 89.9 | 1.2 |
| | Residential | 8.8 | 6.9 | 3.1 | 1.1 | 0.1 | 0.1 | 0.0 |
| | Transport | 14.4 | 15.2 | 15.6 | 13.5 | 11.4 | 9.9 | 0.7 |
| | **Total in kt** | **1.4** | **1.9** | **2.9** | **4.6** | **6.5** | **8.6** | 6.2 |
| $PM_{10}$ | Agriculture | < 0.01 | 0.02 | 0 | 0 | 0 | 0 | 0 |
| | Commercial | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.5 | 2.1 |
| | Industrial | 38.4 | 32.4 | 13.1 | 16.5 | 21.5 | 26.7 | 0.7 |
| | Residential | 43.7 | 39.3 | 46.3 | 42.2 | 37.1 | 28.3 | 0.6 |
| | Transport | 17.6 | 28.0 | 40.3 | 41.1 | 41.1 | 44.5 | 2.5 |
| | **Total in kt** | **2.6** | **2.3** | **2.3** | **2.9** | **3.4** | **3.8** | 1.5 |

CO, HC and $NO_X$ emissions are found to increase by almost 4 times whereas $SO_2$ and $PM_{10}$ emissions are found to increase by 6.2 and 1.5 times, respectively, during 2005–2050. The transport sector accounts for the highest share in total CO and HC emissions whereas the industrial sector is the highest contributor of $NO_X$ and $SO_2$ emissions in 2005. The share of the transport sector in the total $NO_X$ emissions is found to continuously increase, whereas that of the industrial and residential sectors would decrease to 45% and 1%, respectively, by 2050.

The share of the industrial sector in $SO_2$ emissions is estimated to rise to 90% by 2050 mainly due to the increasing use of coal in the brick industries. The transport sector share is found to have a decreasing trend, and the share would be reduced to around 10% by 2050. The residential, commercial and agricultural sectors together would have a negligible share in the total $SO_2$ emissions by 2050. This is mainly because of the increasing share of electricity use and fuel efficient technologies in these sectors. The air quality monitoring studies conducted in the Kathmandu Valley concludes that $SO_2$ concentration at present is well below the national air quality standard.

$PM_{10}$ is the most critical local level pollutant in the Kathmandu Valley. The ambient concentration of $PM_{10}$ emission is reported to already exceed the national air quality standard as well as the WHO guidelines (Dhakal, 2006). The emission of $PM_{10}$ is estimated to increase by about 50% during 2005–2050 in the base case; i.e., from 2.6 kt in 2005 to 2.9 kt in 2030 and 3.8 kt by 2050. The residential, industrial and the transportation sectors are found to be the major sources of $PM_{10}$ emissions accounting for over 99% of the $PM_{10}$ emission. The emission of $PM_{10}$ from the transport sector is found to increase by 2.5 fold in 2050 from the emission level in 2005. The industrial sector's emission of $PM_{10}$ after 2010 is found to be lower than that in 2005 mainly because of the use of the more efficient brick making technologies. By the end of the study period, the major contributors for $PM_{10}$ emissions are from the transport sector (44.5%), followed by the residential (28.3%), Industrial (26.7%) and the commercial sectors (0.5%).

The share of the residential sector in overall pollutant emissions would decrease significantly by the year 2050 mainly because of the increasing shares of electricity and LPG and decreasing share of kerosene use in residential cooking and water heating. Increasing use of solar energy in residential water heating is also a factor to cause this reduction of share in residential sector.

## 6. Effects of $CO_2$ emission reduction targets (ERTs)

The cumulative $CO_2$ emissions during 2005–2050 in the base case are estimated to be 124,322 $ktCO_2$. The changes in the sectoral fuel mix and technology mix under the selected cumulative $CO_2$ emission reduction targets (i.e., ER10, ER20 and ER30) are discussed next.

### *6.1. Total energy mix and sectoral energy consumption*

The cumulative final energy consumption (FEC) during 2005–2050 would experience a decrease of 1.0%, 2.8% and 4.6% in ER10, ER20 and ER30 cases, respectively, as compared to the base case (see Table 5). As can be seen from the table, there would not be much changes in the FEC until 2020 between all the three alternative scenarios as compared to the base case.

As a result of $CO_2$ emission limits, the share of the petroleum products in the cumulative FEC would decrease from 28% in the base case to 27% in ER30 case, while coal and lignite use shows a 49% reduction and LPG and CNG would decrease by only about 1%

**Table 5**
Total final energy consumption under the base and ERT cases, PJ

| Scenario | 2005 | 2010 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| Base case | 24 | 26 | 36 | 53 | 73 | 100 |
| ER10 | 24 | 26 | 36 | 53 | 72 | 98 |
| ER20 | 24 | 26 | 36 | 52 | 70 | 95 |
| ER30 | 24 | 26 | 35 | 50 | 68 | 94 |

**Table 6**
Total cumulative energy mix during 2005–2050, PJ.

| Energy type | Base case | ER10 | ER20 | ER30 |
|---|---|---|---|---|
| Petroleum products | 770 | 754 | 729 | 724 |
| LPG and CNG | 240 | 240 | 240 | 238 |
| Coal and lignite | 574 | 466 | 394 | 291 |
| Electricity | 777 | 889 | 991 | 1073 |
| Hydrogen | 0 | 0 | 7 | 26 |
| Biomass | 300 | 308 | 314 | 317 |
| Other renewables | 41 | 41 | 41 | 41 |
| **Total** | **2703** | **2698** | **2715** | **2710** |

under ER30 (see Table 6). On the contrary, the share of biomass would increase from 11% in the base case to 12% under ER30 while electricity use is estimated to increase by almost 1.38 fold under ER30 (i.e., 38% higher than that in the base case). It is interesting to observe that hydrogen fuel vehicles would be adopted from 2045 under ER20 while they would be introduced earlier (from 2035 onwards) under ER30. The share of hydrogen fuel in the cumulative energy consumption during the entire study period is estimated to be 0.2% under ER20 and 1% under ER30.

As a result of $CO_2$ emission reduction target, the use of LPG in the commercial sector would decrease while the electricity use would increase significantly whereas the share of kerosene would not change during 2005–2050.

The share of coal in cumulative energy consumption of the industrial sector is found to decrease to 49% in ER30 from 88% in base case, while that of the electricity is found to increase to 34% from 3.3% share in the base case. The share of biomass (especially, the agricultural residues) is found to increase with the level of $CO_2$ emission reduction target whereas the share of fuelwood would not change much. LPG has a very small share in the energy mix of this sector in the base case and its share is expected to increase to 3.2% under ER30.

In the residential sector, the share of coal would be reduced to zero under ER30. The shares of biomass, LPG and kerosene shares would be almost constant under ER10 to ER30. There would be no significant change in the shares of electricity and other renewables.

In the transport sector, the share of electricity would increase from nearly 12% in the base case to 24% under ER30. The share of diesel is found to be more or less constant in all the ER cases considered. The shares of gasoline, LPG and CNG are found to decrease with an increase in the $CO_2$ emission target. It is interesting to note that fuel cell vehicles are adopted only under ER20 and ER30. The fuel cell vehicles account for only 0.8% of total cumulative energy consumption of the transport sector in ER20 while they account for 3.4% under ER30. This is because fuel cell vehicles are more energy efficient than the natural gas vehicles.

### 6.2. Total emissions

Total (cumulative) $CO_2$ emission during 2005–2050 is found to decrease from 124,322 kt in the base case to about

**Table 7**
Sectoral shares in cumulative $CO_2$ emissions during 2005–2050, %.

| Sectors | Base case | ER10 | ER20 | ER30 |
|---|---|---|---|---|
| Agricultural | 0.01 | 0.01 | 0.01 | 0.01 |
| Commercial | 6 | 5 | 6 | 7 |
| Industrial | 46 | 42 | 40 | 38 |
| Residential | 8 | 8 | 9 | 11 |
| Transport | 40 | 44 | 45 | 45 |
| **Total emission, kt** | **124,322** | **111,890** | **99,458** | **87,028** |

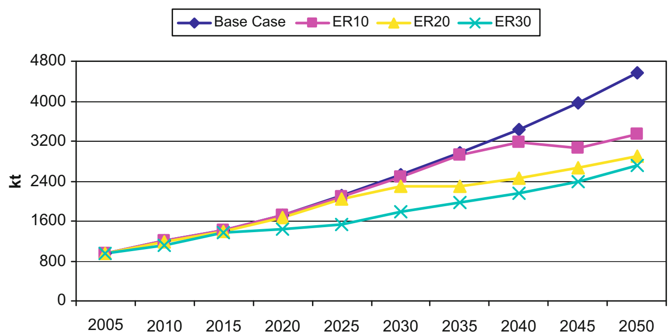


**Fig. 3.** Yearly $CO_2$ emissions under base case and different $CO_2$ ERTs, kt.

87,026 kt under ER30 (see Table 7). The industrial sector share in $CO_2$ emission is found to decline from 46% in the base case to 38% in ER30, while the transport sector share is found to increase from 40% in the base case to 45% in ER30. The residential share in total $CO_2$ emission is found to increase to 11% in the ER30 case compared to the share of 8% in the base case. The shares of the commercial and agriculture sectors in total $CO_2$ emissions do not show much variation with the emission reduction target.

Fig. 3 shows the yearly $CO_2$ emissions under the base case and different $CO_2$ emission reduction cases. As can be seen, a substantial reduction in $CO_2$ emission would take place only after 2040 under ER10, whereas a significant reduction in $CO_2$ emission would have to start much earlier i.e., after 2030 and 2020 under ER20 and ER30, respectively.

The per capita $CO_2$ emissions would increase from 0.5 $tCO_2$/capita in 2005 to 0.8 $tCO_2$/capita in 2030 and 1.2 $tCO_2$/capita in 2050 under the base case. The per capita $CO_2$ emissions in 2030 would be reduced to 0.7 $tCO_2$/capita and 0.6 $tCO_2$/capita under ER20 and ER30 cases, respectively; there would be no change in the per capita emission under ER10 in 2030 from that in the base case. In 2050, the per capita $CO_2$ emissions would be increased by 65%, 43% and 33% under ER10, ER20 and ER30 cases, respectively, as compared to the value of 0.5 $tCO_2$/capita in 2005.

### 6.3. Co-benefits of $CO_2$ emission reduction

The present study shows that the least cost strategy to attain $CO_2$ emission would generate co-benefits in the form of lower emissions of local pollutants, i.e., CO, HC, $NO_X$, $PM_{10}$ and $SO_2$. The CO, HC, $NO_X$ and $SO_2$ emissions exhibit significant reductions only from 2040 onwards under ER20 and from 2030 onwards under ER30 (Table 8). Interestingly, there would not be much change in $PM_{10}$ emissions under the $CO_2$ emission reduction cases. The highest reductions in the CO and HC emissions would take place in the transportation sector as hydrogen fuel vehicles would be cost effective from 2045 and 2035 under ER20 and ER30, respectively. The highest reduction of $SO_2$ emission would take

**Table 8**
Local pollutant emissions during 2005–2050 under the base case and ERT cases, $10^3$ t

| Local pollutants | Cases | Year | | | | | | % Cumulative reduction, 2005–2050 |
|---|---|---|---|---|---|---|---|---|
| | | 2005 | 2010 | 2020 | 2030 | 2040 | 2050 | |
| CO | Base | 28 | 31 | 39 | 57 | 80 | 109 | - |
| | ER10 | 28 | 31 | 40 | 58 | 80 | 106 | 0.4 |
| | ER20 | 28 | 32 | 41 | 58 | 73 | 54 | 13.9 |
| | ER30 | 28 | 35 | 41 | 52 | 31 | 16 | 41.5 |
| HC | Base | 12 | 14 | 24 | 35 | 42 | 47 | - |
| | ER10 | 12 | 15 | 24 | 35 | 42 | 46 | 0.1 |
| | ER20 | 12 | 15 | 24 | 35 | 40 | 37 | 5.3 |
| | ER30 | 12 | 16 | 24 | 33 | 34 | 33 | 12.1 |
| $NO_X$ | Base | 6 | 6 | 8 | 12 | 17 | 22 | - |
| | ER10 | 6 | 6 | 8 | 12 | 16 | 17 | 8.0 |
| | ER20 | 6 | 6 | 8 | 11 | 12 | 14 | 19.8 |
| | ER30 | 6 | 6 | 7 | 8 | 13 | 17 | 21.6 |
| $SO_2$ | Base | 1 | 2 | 3 | 5 | 6 | 9 | - |
| | ER10 | 1 | 2 | 3 | 5 | 6 | 5 | 16.3 |
| | ER20 | 1 | 2 | 3 | 4 | 4 | 5 | 27.3 |
| | ER30 | 1 | 2 | 2 | 3 | 3 | 5 | 41.4 |
| $PM_{10}$ | Base | 3 | 2 | 2 | 3 | 3 | 4 | - |
| | ER10 | 3 | 2 | 2 | 3 | 3 | 4 | 1.6 |
| | ER20 | 3 | 2 | 2 | 3 | 3 | 3 | 2.9 |
| | ER30 | 3 | 3 | 2 | 3 | 3 | 3 | 4.6 |

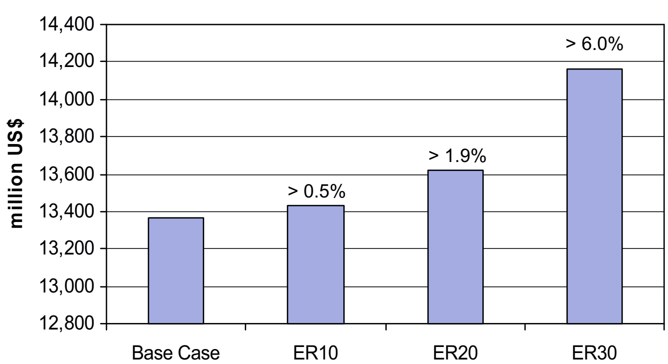


**Fig. 4.** Total discounted cost under different cases. (*Note*: Percentage figures denote an increase in the system cost under the ERT cases as compared to the base case.)

place in the residential sector, followed by the industrial and commercial sectors.

### 6.4. *Total system cost*

The total system cost[9] would increase by 68 million US$, 256 million US$ and 798 million US$ under ER10, ER20 and ER30, respectively, as compared to the base case i.e., an increase of 0.5%, 1.9% and 6.0% in ER10, ER20 and ER30 cases, respectively (see Fig. 4). The incremental $CO_2$ abatement cost during the planning period would be 5.6 US$/t$CO_2$, 10.3 US$/t$CO_2$ and 21.4 US$/t$CO_2$ under ER10, ER20 and ER30 cases, respectively.

[9] The total system cost refers to the discounted system cost, net of taxes and subsidies. The discounted system cost includes annualized investment cost of technologies, fixed and variable operation and maintenance cost of technologies, costs of domestic resource extraction/mining and imports and fuel and material delivery costs.

## 7. Conclusion and final remarks

The study shows that the total energy consumption in the Kathmandu Valley would grow at an average growth rate of 3.2% during 2005–2050 in the base case. There would be a significant inter-fuel substitution during the period in that the share of petroleum products (including LPG and CNG) would decrease from 40% in 2005 to 34% in 2050 in the base case while, the share of electricity would increase from around 10% to 38% during the same period. The overall energy consumption per capita in the Kathmandu Valley would increase from 12.7 GJ/capita in 2005 to 25.6 GJ/capita in 2050, while the residential energy consumption per capita would decrease from 6.5 GJ/capita to 5.9 GJ/capita during the study period.

The shares of transport, industrial and commercial sectors in total energy consumption of the Kathmandu Valley would increase from 21.6%, 19% and 8% in 2005 to 30%, 25% and 22% by 2050 while the share of the residential sector would experience a drastic reduction from 51% in 2005 to 23% by 2050. Residential sector played a dominant role in the total energy consumption share in 2005 whereas transport sector is found to take up the largest share by 2050 followed by the industrial, residential, commercial and agricultural sectors.

This study shows that there would be a nearly 5 fold increase in $CO_2$ emissions in the base case during the time span of 2005–2050. Three sectors, namely, transport, industrial and residential together would account for 90% of the total $CO_2$ emissions in 2005 and 92% by 2050. The combined shares of transport and industrial sectors in total $CO_2$ emissions would increase from 67% in 2005 to 88% by 2050. The commercial sector would account for 9.8% of total $CO_2$ emission in 2005 and about 8% in 2050.

As a consequence of the $CO_2$ emission reduction targets, the role of electricity would increase significantly in the Kathmandu Valley; i.e., the use of electricity in ER30 would be 38% higher than that in the base case. There would be a major increase in electricity use in the transport sector under ER30; i.e., the share of electricity in transport sector would increase from 12% in the base case to 24% in ER30. The study shows that cleaner transport technologies, i.e., hydrogen fuelled vehicles would be introduced only from the year 2040 under ER20, while such vehicles would have to be adopted much earlier, i.e., from 2035 onwards under ER30.

The study shows that the industrial sector will play a major role in $CO_2$ emission reduction. Most of the $CO_2$ reduction under ER20 and ER30 will come from the industrial sector (around 30% and 42% reduction in ER20 and ER30, respectively, as compared to the base case). This is mainly due to the adoption of efficient Hoffman kilns in brick industries, LPG boilers and efficient electric motors in food, beverages and textile industries. Increasing use of electricity to provide services such as motive power and process heat is also the cause of this emission reduction.

This study shows that an imposition of $CO_2$ emission reduction target of 10% would increase the total cost by 0.5%, while the corresponding figures under ER20 and ER30 would be 1.9% and 6%, respectively. The incremental $CO_2$ abatement cost corresponding to ER10, ER20 and ER30 would be 5.6 US$/t$CO_2$, 10.3 US$/t$CO_2$, 21.4 US$/t$CO_2$, respectively. This indicates the levels of $CO_2$ reduction potential in the Kathmandu Valley if the carbon price in the international market were to exceed the above mentioned incremental abatement cost figures.

It should be noted that this study has used emission factors from various international sources in the absence of country specific information. Lack of sufficient historical time series energy and GDP data of the Valley has prevented us from using rigorous econometric approach to estimate the household income elasticity and sectoral output elasticities. This highlights the need to establish a comprehensive economic, energy and environmental database for the Valley in order to improve the assessments of energy and environmental implications of climate and other policies in the Valley.

## Acknowledgement

We would like to thank two anonymous reviewers of the journal for their helpful comments. However, we are only responsible for any remaining errors in the paper.

## Appendix A

See Table A1 here.

**Table A1**
Service demand classification.

| Sector/sub-sector | Energy service |
|---|---|
| Agriculture | Irrigation |
| Commercial | Space cooling/heating, lighting, cooking, water heating, others |
| Industrial (brick, textile, food and beverages, others) | Process heat, motive power, boiler, lighting |
| Transportation | Air freight, air passenger, road freight, road passenger |
| Residential | Cooking, space cooling/heating, lighting, refrigeration, television, water heating, agro processing, others |

## Appendix B

See Table B1 here.

**Table B1**
Estimated sectoral fuel consumption in Kathmandu Valley in 2005 (Unit: TJ).
*Sources*: CAAN, 2005; CBS, 2004, 2006; CES, 2006;MOF, 2006;NEA, 2005, 2006;WECS, 1994a, 1994b, 1995, 1997, 1998, 1999a, 1999b, 2001, 2005, 2006a, 2006b; and unpublished data on sectoral electricity consumption and petroleum product sales in the Kathmandu Valley collected from NEA and NOC, respectively.

| Fuel type | Agricultural | Commercial | Industrial | Residential | Transport | Total |
|---|---|---|---|---|---|---|
| **Biomass** | **0** | **207** | **780** | **7626** | **0** | **8614** |
| Fuelwood | 0 | 207 | 654 | 5945 | 0 | 6806 |
| Agricultural residue | 0 | 0 | 126 | 1618 | 0 | 1744 |
| Animal dung | 0 | 0 | 0 | 63 | 0 | 63 |
| **Other renewables** | **0** | **0** | **0** | **13** | **0** | **13** |
| **Fossil fuels** | **12** | **1314** | **2673** | **3211** | **4671** | **11,880** |
| Coal | 0 | 0 | 2489 | 23 | 0 | 2512 |
| Gasoline | 0 | 0 | 0 | 0 | 1038 | 1038 |
| Diesel | 12 | 0 | 32 | 0 | 1460 | 1504 |
| Kerosene | 0 | 1106 | 107 | 2258 | 0 | 3471 |
| Air turbine fuel | 0 | 0 | 0 | 0 | 2060 | 2060 |
| LPG | 0 | 208 | 0 | 929 | 113 | 1250 |
| Others | 0 | 0 | 45 | 0 | 0 | 45 |
| **Electricity** | **5** | **532** | **344** | **1138** | **18.6** | **2038** |
| **Total** | **17** | **2053** | **3797** | **11,988** | **4690** | **22,544** |
| **Share (%)** | **0.08** | **9.11** | **16.84** | **53.17** | **20.80** | **100** |

## References


Adhikari, D.P., 1997. Energy and environmental implications of alternative transport options: the case of Kathmandu Valley, Nepal, Unpublished Master Thesis, Asian Institute of Technology, Bangkok.

Anandarajah, G., 2000. Least cost emission mitigation options for the urban transportation system: the case of Kathmandu Valley, Nepal, Unpublished Master Thesis, Asian Institute of Technology, Bangkok.

Bose, R.K., Shukla, M., 1999. Elasticities of Electricity Demand in India. Energy Policy 27 (3), 137–146.

Centre for Energy Studies (CES), 2006. Assessment of Alternative Energy Supply Options in the Urban Residential Sector during the Load Shedding Hours. Institute of Engineering, Pulchowk, Lalitpur, Nepal.

Central Bureau of Statistics (CBS), 2003. In: Populations Projections for Nepal 2001-2021. National Planning Commission Secretariat, Kathmandu.

Central Bureau of Statistics (CBS), 2004. Nepal Living Standards Survey 2003/04. Statistical Report, Volume Two, National Planning Commission Secretariat, Kathmandu.

Central Bureau of Statistics (CBS), 2006. In: Statistical Year Book of Nepal. National Planning Commission Secretariat, KathmanduStatistical Year Book of Nepal. National Planning Commission Secretariat, Kathmandu.

Civil Aviation Authority of Nepal (CAAN), 2005. Civil Aviation Report 2005, Kathmandu.

Devkota, S.R., 1992. Energy utilization and air pollution in Kathmandu Valley, Nepal, Unpublished Master Thesis, Asian Institute of Technology, Bangkok.

Dhakal, S., 2003. Implications of transport policies on energy and environment in Kathmandu Valley, Nepal. Energy Policy 31 (14), 1493–1507.

Dhakal, S., 2006. In: Urban Transportation and the Environment in Kathmandu Valley, Nepal. Integrating Global Carbon Concerns into Local Air Pollution Management, Institute for Global Environmental Strategies (IGES), Japan.

Economopoulos, A.P., 1993. In: Assessment of Sources of Air, Water and Land Pollution, Part One: Rapid Inventory Techniques in Environmental Pollution. World Health Organization (WHO), Geneva.

Energy Information Administration (EIA), 2009, International Energy Outlook, Office of Integrated Analysis and Forecasting, U.S. Department of Energy, Washington, D.C.

Environment and Public Health Organization (ENPHO), 2001. Ambient air quality monitoring in the Kathmandu Valley, Kathmandu.

Gautam, C., 2006. Final report on action program on air Quality Management of Kathmandu Valley, Government of Nepal, Ministry of Environment, Science and Technology, Kathmandu.

Giri, D., Murthy, K.V., Adhikary, P.R., Khanal, S.N., 2006. Ambient air quality of Kathmandu Valley as reflected by atmospheric particulate matter concentrations ($PM_{10}$). International Journal of Environmental Science and Technology 3 (4), 403–410.

International Centre for Integrated Mountain Development (ICIMOD), 2007. Kathmandu Valley Environment Outlook (KVEO), Kathmandu.

International Energy Agency (IEA), 2006. Energy Technology Perspectives 2006: Scenarios and Strategies to 2050, Paris.

Intergovernmental Panel on Climate Change (IPCC), 1996. IPCC Guidelines for National Greenhouse Gas Inventories, website: http://www.ipcc-nggip.iges.or.jp/EFDB/find_ef.php (downloaded on 8th September 2009).

Japan International Cooperation Agency (JICA), 1993. The Study on Kathmandu Valley Urban Road Development, Final Report, Part A: Master Plan Study, Ministry of Works and Transport, Department of Roads, Kathmandu.

Kesgin, U., 2006. Aircraft emissions at Turkish airports. Energy 31 (2–3), 372–384.

Ministry of Finance (MOF), 2006. Economic Survey: Fiscal Year 2005/2006, Kathmandu.

Ministry of Water Resources (MoWR), 2009. Ten Years Hydropower Development Plan (2010/20), Part I, Main Report, Ten Years Hydropower Development Implementation Task Force, Government of Nepal, Kathmandu.

National Institute for Environmental Studies (NIES), 2006. Asia-Pacific Integrated Model (AIM): Enduse Manual, Manual-1, Tsukuba, Japan.

Nepal Electricity Authority (NEA), 2005. Corporate Development Plan, FY2004/05 – 2008/09, Kathmandu.

Nepal Electricity Authority (NEA), 2006. Nepal Electricity Authority: FY 2005/2006, A Year in Review, NEA, Kathmandu.

Nepal Oil Corporation (NOC), 2004. *Prabhaat* 2061—The Annual Publication, Kathmandu.

Pradhan, D.L., 1994. Policy analysis of selected transport sector options for mitigating air pollution: the case of Kathmandu Valley, Unpublished Master Thesis, Asian Institute of Technology, Bangkok.

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.

Ruehle, B., 2004. Global Long-Term Demand for Transportation, Interim Report, IR-06-010, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Sharma, C.K., 1997. Short communication urban air quality of Kathmandu Valley "Kingdom of Nepal". Atmospheric Environment 31 (17), 2877–2883.

Shrestha, R.M., Malla, S., 1996. Air pollution from energy use in a developing country city: the case of Kathmandu Valley, Nepal. Energy 21 (9), 785–794.

Sothea, K., 2007. Emission inventory and modeling for air quality management in Phnom Penh City, Cambodia, Unpublished Master Thesis, Asian Institute of Technology, Bangkok.

Swiss Development Corporation (SDC), 2007, Vertical Shaft Brick Kiln Technology Transfer Programme, Energy and Environmental Performance of VSBK—An Overview, Kathmandu.

Water and Energy Commission Secretariat (WECS), 1994a. Energy Resource and Consumption Profile of the Central Development Region of Nepal, Volume I: Main Text, Kathmandu.

Water and Energy Commission Secretariat (WECS), 1994b. Energy Resource and Consumption Profile of the Central Development Region of Nepal, Volume II: District Profile, Kathmandu.

Water and Energy Commission Secretariat (WECS), 1995. Perspective Energy Plan: Supporting Document No.2, Energy Resources Base of Nepal, Kathmandu.

Water and Energy Commission Secretariat (WECS), 1997. Update and Compilation of Energy Resources and Consumption Profile of Nepal, Volume III: Annexes, Kathmandu.

Water and Energy Commission Secretariat (WECS), 1998. Study for Industrial Energy Survey: Traditional and Modern Sector of Nepal, Kathmandu.

Water and Energy Commission Secretariat (WECS), 1999a. Detailed Energy Consumption Survey in the Commercial Sector of Nepal, Volume II: Annex III, Kathmandu.

Water and Energy Commission Secretariat (WECS), 1999b. Detailed Energy Consumption Survey in Transport Sector of Nepal, Volume I, Kathmandu.

Water and Energy Commission Secretariat (WECS), 2001. Agriculture Sector Energy Consumption in Nepal, Kathmandu.

Water and Energy Commission Secretariat (WECS), 2005. Detailed Energy Consumption Survey in Urban Residential Sector of Nepal, Kathmandu.

Water and Energy Commission Secretariat (WECS), 2006a. Energy Synopsis Report, Kathmandu.

Water and Energy Commission Secretariat (WECS), 2006b. Energy Usage Pattern in the Industrial Sector of Central Development Region, Kathmandu.

Webster, M., Paltsev, S., Reilly, J., 2008. Autonomous efficiency improvement or income elasticity of energy demand: does it matter? Energy Economics 30, 2785–2798.

United Nations Development Programme (UNDP), 2004. Nepal Human Development Report 2004, Empowerment and Poverty Reduction, Kathmandu.

United Nations (UN), 2008, World Urbanization Prospects: The 2007 Revision, Highlights, New York.

United States Environmental Protection Agency (USEPA), 2009. AP 42, Vol. I, Fifth Edition, website: http://www.epa.gov/ttnchie1/ap42/ (downloaded on 8th September 2009).