Benefits of Low Carbon Development Strategies in Emerging Cities of Developing Country: A Case of Kathmandu

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ABSTRACT

Kathmandu is one of the fastest growing cities in South Asia facing various challenges related to climate change, local pollutants emissions and energy security of supply. This study analysed the greenhouse gas mitigation potential in different economic sectors of the city by using Long-range Energy Planning (LEAP) frame work. It shows that the effect of implementing various low carbon development strategy options can reduce 35.2% of total greenhouse gas emission from energy use as compared to the base case scenario in 2030. This indicates the need for exploring the possibility of utilizing the global climate funds and adopting voluntary mechanisms for greenhouse gas mitigation. The estimated demand side technology investment cost of low carbon measures for different sectors ranges from less than USD 1/tonne CO_2e for residential sector to USD 99/tonne CO_2e for transport sector. The low carbon options also results co-benefits in terms of significant reduction in emission of local pollutants and improvement of energy security. As Government of Nepal has envisioned following low carbon economic development path on the long run, there is the need of establishment of regulatory framework, institutional framework and development of clear action plans for realizing the implementation of low carbon development strategy measures in the country.

KEYWORDS

Low carbon development strategy, Greenhouse gas, Co-benefits, LEAP, Kathmandu.

INTRODUCTION

The growing dependence on imported fossil fuels has been a matter of serious international concern from energy security perspective, especially for the low income net energy importing developing countries. The fluctuating price of fossil fuels, specially oil and gas, has increased the economic vulnerability for such countries. The consumption of such fuels is mostly concentrated in the fast growing urban areas of the country acting as the focal point for Greenhouse Gas (GHG) emissions. Ongoing international concern for climate change due to GHG emissions are attracting an increasing attention on rapidly growing cities of developing countries due to their expected future share in global emission of GHGs. There are several studies related to low carbon development path for major cities, however such studies from the perspective of emerging cities from the developing world are limited. The effects of utilizing woody biomass for reducing dependence on imported fossil fuels and decreasing GHG emissions in residential heating were studied by Sawauchi *et al.* [1] for Nishiwaga, Japan. Snakin [2] has used a regional engineering model for assessing possibility of improving the quality and quantity of space heating energies and related GHG emissions for North Karelia, Finland. Gustavsson *et al.* [3] studied the energy systems which could significantly reduce emissions of acidifying gases and CO_2 from non-mobile sources for Western Scania, Sweden by using an end-use accounting model. Oberheitmann [4] analysed the impact of the Low Carbon City plan on energy demand and CO_2 emission until 2050 for Wuxi city of China by using econometric model. Dienst *et al*. [5] studied the GHG mitigation potential of introducing low carbon strategic options in different economic sectors of Wuxi city by using integrated qualitative and quantitative modelling approach. Similarly, Yao *et al*. [6] have developed the evaluation index by using principal component analysis and analytic hierarchy process for analysing the low-carbon city development of Shenzhen city, China.

The case of Kathmandu Valley, a main city of Nepal, can be a good example for studying the implications of introducing low carbon development strategies in emerging cities of developing world. The Valley is the dominating urban area of Nepal which constitutes half of the total urban population and major consumer of the fossil fuels. With rapid population growth and increasing economic activities, the demand for commercial energy (mostly fossil fuels) has been growing faster in the Valley than in the rest of the country. The country has to meet its entire demand for petroleum products through import and the convertible foreign currency for procuring them already surpass the entire earning through merchandise export since 2007/08 [7]. In order to reduce dependence on imported fossil fuels there is a need for diversifying the energy mix through a greater use of its indigenous energy 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 [8, 9]. However, less than 2% of the country's economically feasible hydropower potential remains exploited at present. In the recent years, increasing local air pollution has been emerging as a major environmental concern in the Valley [10, 11]. Thus, introduction of the Low Carbon Development Strategy (LCDS) measures, such as promotion of an indigenous clean and renewable energy resources and efficient technologies could be important strategic options in the reduction of imported fossil fuels consumption. 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 local air pollutants as well as employment generation [12].

The country's Hydropower Development Plan of 1992 and 2001 emphasized the use of electricity in different economic sector to reduce fossil fuel consumption and diversify the use of electricity. Furthermore, the Government of Nepal (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 [13]. 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 [14].

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 [15]. The GoN has recently introduced the Climate Change Policy 2010, which states the main objectives as:

- Promotion of the use of clean and renewable energy resources in the country;
- Adoption of climate friendly socio-economic development by following a low carbon development path [16].

The new Industrial Policy 2011 emphasizes the adoption of new technology and cleaner production processes to promote sustainable development of industrial sector in the country [17]. The 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. Recently, the GoN has come up with the long-term plan to introduce electric railway system in Kathmandu valley [18].

There exist a number of studies that focus on emission of local pollutants and air quality in the Kathmandu Valley [10, 19]. There also exist several studies that analyse energy use and associated emissions from the transport sector of the Kathmandu Valley [11, 20]. All of these studies are either sector specific or did not cover elaborate end-use technology level analysis. Shrestha and Rajbhandari [21] analysed the implication of emission reduction targets using least cost optimization model but did not analyse the elaborate economic sector wise emission reduction potential, cost and resulting environmental emissions.

This study analyses the energy, environmental and economic implications of adopting different low carbon development strategies at the sectoral level of end-use service demands. The outcome of the study will be helpful for low carbon economic development planning of the Kathmandu.

METHODS

Development of energy systems model

A bottom up supply side optimization and accounting integrated energy system model based on Long-range Energy Planning (LEAP) frame work was developed for this study [22]. The integrated city level energy system model of Kathmandu consists of mainly four modules, namely: energy resources, transformation process, end-use service demand and environmental emissions. The primary energy supply module represents extraction of primary energy from indigenous energy resources (mainly biomass and other renewable energy resources) 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 major GHG emissions (CO_2, CH_4 and N_2O) and local pollutants (CO, SO_2, NO_X, Non-methane Volatile Organic Compound (NMVOC) and PM10) are dealt with in the environmental emissions module.

The model is formulated to estimate the annual total socio-economic costs during the study period. LEAP performs cost-benefit calculations from a societal perspective by counting up all of the costs in the energy system and then comparing the costs of any two scenarios. LEAP can include demand costs (expressed as total costs, costs per activity, or costs of saving energy relative to some scenario), transformation capital costs, transformation fixed and variable operating and maintenance costs, costs of indigenous resources, costs of imported fuels, benefits of exported fuels, externality costs from emissions of pollutants, other miscellaneous user-defined costs such as the costs of administering an efficiency program [22]. The model produces energy balance based on fulfilment of each type of service demand and availability of energy resources.

Projection of energy-using service demands

Demands for energy-using services for the base year 2012 were established on data obtained from various national and international sources. The major sources used for primary energy resource potential in the country are NEEP [23] and WECS [24, 25]. The electricity generation for national grid based electricity supply in the country is almost entirely hydro-based [8, 21]. The demands and technology stocks for the base year are estimated by using information from AEPC [26], CBS [27], NEEP [28] and WECS [9, 25, 29, 30, 31]. Data on energy technologies are mainly adopted from various sources [11, 18, 32-37].

The demands for different sectoral end use services are projected using standard econometric approaches. The end use service demands in residential sector and land passenger transport were estimated by:

$$ESD_{i,t} = ESD_{i,0} \times (1 + \alpha_{1i} \times ((POP_{r,t}/POP_{r,0}) - 1) + \alpha_{2i} \times ((GDP_{r,t}/GDP_{r,0}) - 1)) \quad (1)$$

The freight transport demands were estimated from:

$$ESD_{i,t} = ESD_{i,0} \times (1 + \alpha_{2i} \times ((GDP_{r,t}/GDP_{r,0}) - 1)) \quad (2)$$

The end use demands in other sectors were estimated using:

$$ESD_{i,t} = ESD_{i,0} \times (1 + \alpha_{3i} \times ((VA_{i,t}/VA_{i,0}) - 1)) \quad (3)$$

where:

- $ESD_{i,t}$ − level of service demand type i in year t for every sectors or sub-regions;
- $POP_{r,t}$ − population of ‘r’ region in year t;
- $GDP_{r,t}$ − aggregate GDP in year t for region ‘r’ i.e., Kathmandu and RON;
- $VA_{i,t}$ − value added in the specific ‘i’ sector in year t;
- 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 (r, t), POP (r, t), VA (i, t)). In case of air passenger transport demand, GDP per capita is used instead of GDP in eq. (2).

Other studies using the partial equilibrium modals have adopted similar approaches for the service demand projections [21, 35, 38-42].

Description of scenarios

This study analyses six scenarios: the base case and five alternative sectoral low carbon development strategy scenarios. The base case is referred as “Business as usual” scenario and it considers the energy system development to meet future service demands at the minimum cost without any GHG emission limiting policy intervention.

In the base case, the real GDP (at constant 2000/2001 prices) of Nepal is assumed to grow at an Annual Compounding Growth Rate (ACGR) of 4.9% during 2010-2015, 5.8% during 2015-2020 and 6.4% during 2020-2030 following recent 13th 3-Years Development Plan (2013/14-2015/16). This assumed GDP growth rate is justifiable as its average value was around 5% during 1990 to 2010. Sectoral GDP VA growth rate for agriculture sector is considered as that mention in the Agriculture Development Strategy under formulation (4% in 2015 to reach 6% by 2030). Industrial sector growth rate is adjusted to maintain same share as that in 2010 (15.47%). Service sector growth rate is considered same as that in 13th 3-Years Plan. Following this service sector share is expected to increase from 49.7% to 55.6% between 2010 to 2030. Agriculture sector share would decrease from 34.8% in 2010 to 28.9% in 2030 under the growth rate mentioned in Agriculture Development Strategy under formulation. Share of the industrial sector remains same as mentioned above. Following various available literatures the share of Kathmandu in the National sectoral GDP is considered 33.8%, 19.5% and 2.7% in the commercial, industrial and agriculture sector respectively [43, 44]. The GDP of Kathmandu is expected to grow from USD 1,898 million in 2012 to USD 6,014 million in 2030 (Figure 1).

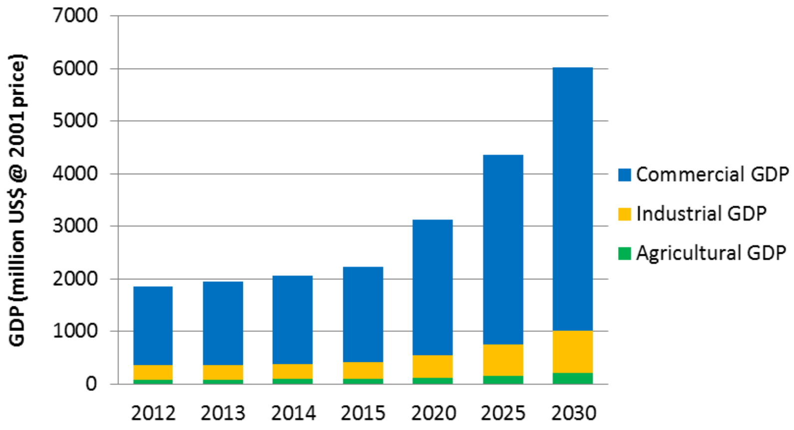


Figure 1. GDP projection of Kathmandu for 2015 to 2030

The projection of population is based on CBS [45] till 2020 and thereafter following UNPD [46] under medium variant growth scenario. The population of Kathmandu is expected to grow from 2.5 million in 2012 to 4.7 million in 2030 at average annual exponential growth rate of 3.5% (Figure 2).

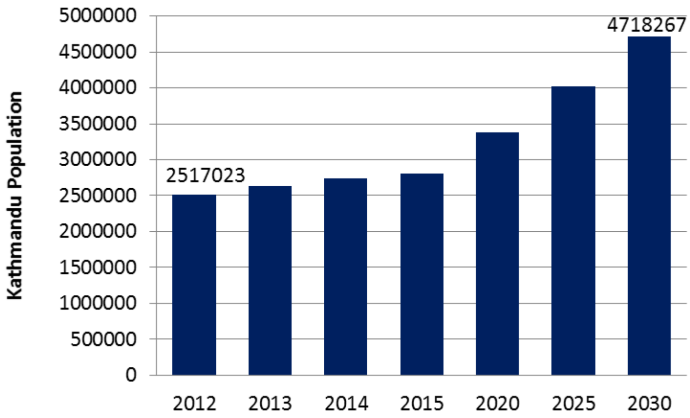


Figure 2. Physiographic and economic disaggregation of population

Availabilities of primary energy resources are based on WECS [24, 25, 47]. The prices of biomass are adopted from NEEP [23] and WECS [9, 24, 25] and change in the prices during 2010-2030 are based on EREC/GREENPEACE [48]. Prices of the imported petroleum products, lignite and coal for 2010 are based on MOF [7], NOC [49] and TERI [34]. Future prices of the petroleum products are projected following EIA [50]. In the case of prices of lignite and coal, the ACGR value of 0.9% is used after 2010 [51]. Price of electricity is taken from NEA [8].

Emission factors for the major GHG emissions i.e., CO_2, CH_4 and NO_2, are based on IPCC [52], while that for local pollutants i.e., SO_2, NO_X, CO, NMVOC and PM10 are mostly based on the emission database of LEAP software and other sources [11, 53-57]. The global warming potential for CH_4 and N_2O has been considered as 25 and 298 respectively [58].

Detailed disaggregation of service demands of Kathmandu are given in Appendix. In the residential sector, energy service demands consist of cooking, lighting, space heating, space cooling, water heating, water pumping, agro-processing and animal feed preparation and other electrical appliances. The end use service demands consist of lighting, space heating, space cooling, water heating, water pumping and other electrical appliances in the commercial sector. In the residential and commercial sectors, technologies based on different fuels and energy efficiency are considered to meet above service demands.

Similarly, in the transport sector the non-fossil fuel based technology options like electric vehicles are also considered. Recently, the government has emphasized to introduce electric railway system in the country [18]. This study also considers the availability of electric surface rail MRT for the Kathmandu valley from 2020 under low carbon policy intervention scenarios.

In the industrial sector, motive power, thermal process heating, process cooling, boiler, lighting and other applications are considered. For the motive power, both conventional and efficient electrical options are considered, where as in the case of thermal applications, different fuel based options (coal, biomass, and diesel) together with conventional and efficient options are considered in the model.

Demands for water pumping for irrigation, land tilling and thrashing have been considered in the agriculture sector. Technology options based on different fuels and efficiency levels are considered for water pumping, land tilling and thrashing services.

Besides the base case, five alternative sectoral low carbon development strategy scenarios are considered in the study. They are:

- Industrial sector based "LCS-IND" scenario: The policy measures are considered as gradual fuel switching from emission intensive fossil fuels to cleaner electricity in motive power, process heating and boiler applications. The fuel switching process gradually starts from 10% in 2020, attains 25% in 2025 and finally reaches 50% by 2030. In addition fuel efficient technology options would penetrate for those applications starting from 25% of the conventional technology in 2020, followed by gradual increased in the share to reach 50% in 2025 and 100% by 2030. All other assumptions remaining the same as in the base case;
- Residential sector based "LCS-REG" scenario: Gradual fuel switching from less efficient fossil fuels to more efficient electricity in cooking, space heating and water boiling applications where as there will be gradual penetration of improved cook stoves replacing inefficient traditional biomass cook stoves in rural areas. The fuel switching starts from 10% in 2020, attains 25% in 2025 and finally reaches 50% by 2030. All other assumptions remaining the same as in the base case;
- Commercial sector based "LCS-COM" scenario: Gradual fuel switching from less efficient fossil fuels to more efficient electricity in cooking, space heating and water boiling applications. The gradual fuel switching process starts from 10% in 2020, reaches 25% in 2025 and finally reaches 50% by 2030. All other assumptions remaining the same as in the base case;
- Transport sector based "LCS-TRN" scenario: Introduction of energy efficient Electric Passenger Vehicles (EV) by gradually replacing conventional fossil fuel based vehicles in different passenger transport modes (2-wheelers, 3-wheelers, car, bus, microbus and taxi). The penetration of the electric passenger vehicles consists of 10% of the share of non-electric vehicles in 2020, followed by gradual increased in the share to reach 15% in 2025 and 20% by 2030. In addition there will be gradual shift from conventional non-electric vehicles (passenger + freight)

to Electrified Mass Transport (EMT) beginning with modal shift of 10% of the base case non-electric vehicles to EMT in 2020, followed by gradual increased in the share to reach 15% in 2025 and 20% by 2030;

- Agriculture sector based “LCS-AGR” scenario: Fuel switching from fossil fuel based devices to electric devices would take place for irrigation pumping and thrashing applications with penetration of 10% in 2020, 25% in 2025 and reaching the share of fuel switch to 50% by 2030. In addition there will be introduction of energy efficient technology options begins to penetrate to reach 25% of the share in 2020, followed by gradual increased in the share to reach 50% in 2025 and 100% by 2030 for the land tilling applications and remaining fossil fuel based irrigation pumping, and thrashing applications.

RESULT AND DISCUSSIONS

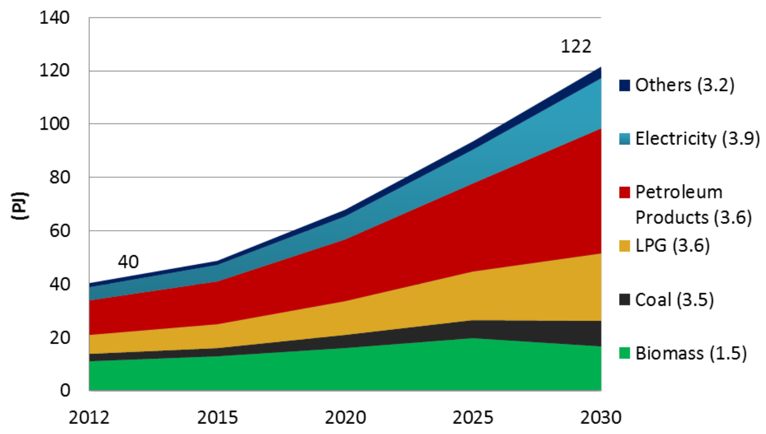
Analyses of the base case results

In this section, the evolution of overall energy system development as well as their associated environmental and other implications is discussed.

Total final energy consumption

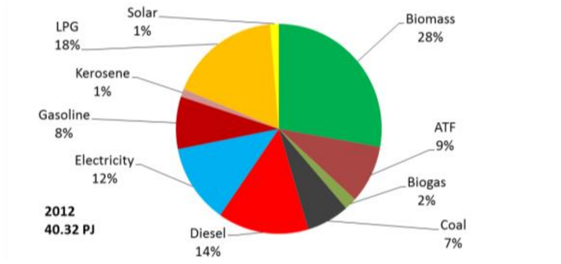
The Total Final Energy Consumption (TFEC) is estimated to grow at 6.3% (i.e., from 40 PJ in 2012 to 122 PJ in 2030) as shown in Figure 3. There would be fast growth at the rate of 7.3% in the consumption of imported fossil fuels consisting of petroleum products, LPG and coal during the study period. This indicates that future energy supply will be more and more dependent on the imported fossil fuels raising question related to energy supply security and economic vulnerability. The use of electricity would increase at the rate of 7.8% and that of the consumption of biomass would increase at an average annual growth rate 2.2%.

The share of biomass energy resources would decrease (from 27.8% in 2012 to 13.7% in 2030), while there would be an increase in the share of petroleum products (from 32.5% to 38.4%), electricity (from 12.2% to 15.6%), LPG (from 17.5% to 21.0%), coal (from 6.7% to 7.8%), and others (from 3.3% to 3.5%) as compared to that in the base case during 2012 to 2030 (Figure 4). The sectoral final energy consumption would grow at 7.4%, 7.0%, 6.3%, 5.3% and 5.1% in the transport, commercial, industrial, residential and agriculture sectors respectively as shown in Table 1. The share of transport and commercial sectors in TFEC increases while that of other sectors decreases.



Note: Figure in parenthesis indicates ratio of the values for 2030 and 2012

Figure 3. Base case total final energy consumption in Kathmandu during 2012-2030



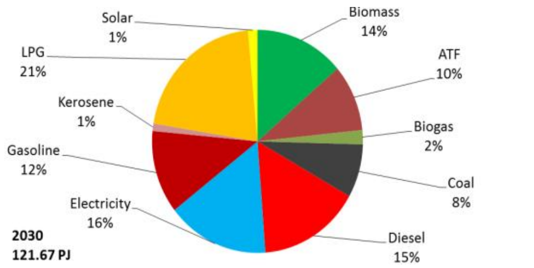


Figure 4. Fuel wise share of total final energy consumption in Kathmandu during 2012-2030

Table 1. Final energy consumption in Kathmandu during 2012-2030 (PJ)

Sector	2012	2015	2020	2025	2030	Ratio 2030/2012
Residential	18.2	21.8	29.5	39.6	46.2	2.5
Commercial	4.3	5.3	7.5	10.5	14.6	3.4
Industrial	5.7	6.7	9.1	12.4	16.9	3.0
Agriculture	0.1	0.1	0.2	0.2	0.3	2.4
Transport	12.0	14.8	21.4	30.7	43.7	3.6
Total	40.3	48.7	67.8	93.5	121.7	3.0

Greenhouse gas emissions

In the base case, annual GHG emissions would increase at annual growth rate of 6.95% during the study period (i.e., from 4,456 thousand tons CO_2e in 2012 to 14,946 thousand tons CO_2e in 2030) as shown in Table 2. This growth rate is higher than the growth rate of TFEC mostly due to increasing share of fossil fuel in the energy mix in the later period. Similarly emission of other local pollutants would grow in the range of 3.01% (for PM10) to 5.32% (for CO) as shown in the Table 2 indicating severity of local pollution in days ahead in the Kathmandu valley under business as usual scenario.

Table 2. Greenhouse gas and local pollutants emissions from energy use in Kathmandu during 2012-2030 (thousand tons CO_2e)

Emission	2012	2015	2020	2025	2030	Ratio 2030/2012
CO_2	1,723.68	2,110.26	3,017.59	4,288.09	6,043.73	3.5
CH_4	2.80	3.26	4.20	5.31	4.74	1.7
N_2O	8.93	10.88	15.39	21.64	29.48	3.3
Total GHG	4,456.16	5,433.63	7,709.65	10,869.33	14,945.91	3.4
CO	94.12	112.32	151.88	203.60	239.30	2.5
NOx	28.86	33.77	43.99	56.47	67.70	2.3
NMVOC	0.11	0.13	0.17	0.23	0.26	2.4
PM10	0.89	1.00	1.20	1.38	1.52	1.7
SO_2	2.77	3.14	3.85	4.58	4.74	1.7

Sectoral GHG emission reduction potential and their co-benefits in Kathmandu

All the five economic sectors namely, industrial, commercial, transport, agriculture and residential sectors, were individually studied for estimating the technical potential of reducing GHG by introducing various energy efficient technologies and fuel switching.

GHG emission reduction potential in industrial sector

Under the industrial sector, GHG emission reduction potential was studied considering fuel switching and energy efficiency improvement strategic options for motive power, process heating and boiler applications.

The strategic options includes following:

- The fuel switching from fossil fuel to electricity will takes place gradually starting from 10% in 2020, 25% in 2025 and finally reaching 50% by 2030 for motive power, process heating and boiler applications under LCS-IND as compared to the base case;
- In addition energy efficient technology options would penetrate for those applications starting from 25% of the conventional technology in 2020, followed by gradual increased in the share to reach 50% in 2025 and 100% by 2030 as compared to the base case.

The study shows that in the industrial sector, GHG mitigation strategic options considered in the study could reduce 12.3% of the industrial sector GHG emission in 2020, could reduce by 28.8% in 2025 and 54.8% in 2030 (Figure 5).

There would be significant reduction in the local pollutants emissions due to the GHG mitigation measures under LCS-IND as compared to base case scenario as shown in the Table 3. The reduction of local pollutants under LCS-IND ranges from 3.9% reduction for CO to 12.3% reduction for SO_2 in 2020 as compared to the base case. Similarly in 2030, the reduction of local pollutants ranges from 22.2% decrease for CO to 55.0% for SO_2.

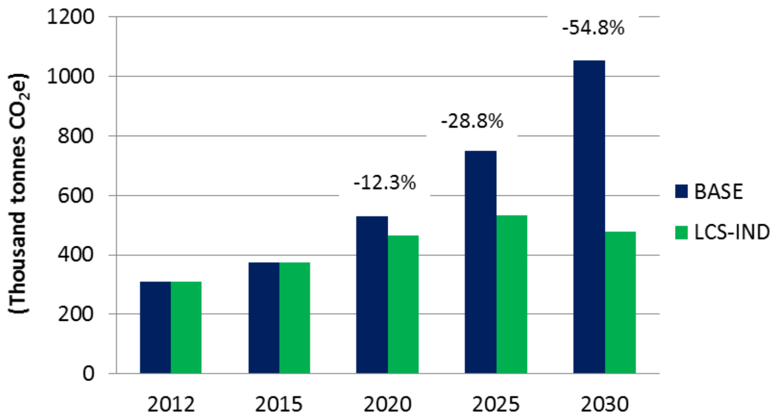


Figure 5. GHG reduction under industrial sector GHG mitigation measures in Kathmandu

Table 3. Local pollutants emissions reduction under LCS-IND (Thousand tonnes CO_2e)

	2020		2025		2030	
	BASE	LCS-IND	BASE	LCS-IND	BASE	LCS-IND
CO	4.704	4.519	5.946	5.324	7.470	5.808
NO_X	1.170	1.044	1.580	1.175	2.134	1.072
NMVOC	0.272	0.248	0.361	0.283	0.480	0.275
PM_{10}	0.067	0.059	0.094	0.067	0.131	0.059
SO_2	0.277	0.243	0.387	0.276	0.540	0.243

GHG emission reduction potential in residential sector

The GHG mitigating potential of the residential sector was studied by considering fuel switching for the cooking and water boiling activities.

The strategic options includes following:

- Gradual fuel switching from less efficient fossil fuels to more efficient electricity in cooking and water boiling applications in the urban areas of the valley. The fuel switching will takes place gradually starting from 10% in 2020, 25% in 2025 and finally reaching 50% by 2030 under LCS-REG as compared to the base case;
- There will be gradual penetration of improved cook stoves replacing inefficient biomass cook stoves in the rural areas under LCS-REG as compared to the base case.

The study finds that in the residential sector under LCS-REG scenario, the above GHG mitigation strategic options can reduce altogether 7.6% of the total sectoral GHG emission in 2020 and 19.9% of the emission in 2020 as compared to the base case (Figure 6). In 2030, sectoral GHG emission can be mitigated by 38.7% in the residential sector under LCS-REG as compared to the base case.

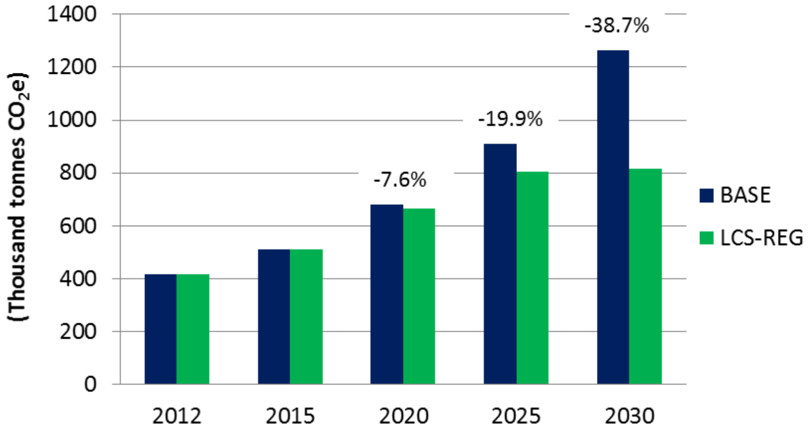


Figure 6. GHG reduction under residential sector GHG mitigation measures in Kathmandu

In terms of co-benefits related to the emission of local pollutants emission, there would be significant reduction in their emission under LCS-REG as compared to base case as shown in the Table 4. The reduction of local pollutants under residential sector GHG mitigation measures ranges from 0.002% reduction for PM10 to 13.2% reduction for NO_X in 2020 under LCS-REG as compared to the base case. Similarly in 2030, the reduction of local pollutants ranges from 0.02% reduction for PM10 to 36.00% for NO_X.

Table 4. Local pollutants emissions reduction under LCS-REG (Thousand tonnes CO_2e)

	2020		2025		2030	
	BASE	LCS-REG	BASE	LCS-REG	BASE	LCS-REG
CO	78.066	78.028	95.127	94.664	81.339	110.619
NOx	1.111	0.965	1.275	0.939	0.678	0.659
NMVOC	28.786	28.363	34.243	32.889	35.514	35.506
PM10	1.081	1.081	1.230	1.230	1.317	1.316
SO2	0.047	0.046	0.056	0.054	0.066	0.058

GHG emission reduction potential in commercial sector

Under the commercial sector, the GHG emission reduction potential was studied for cooking and water boiling applications.

The strategic options includes following:

- Gradual fuel switching from less efficient fossil fuels to more efficient electricity in cooking and water boiling applications. The fuel switching will takes place gradually starting from 10% in 2020, 25% in 2025 and finally reaching 50% by 2030.

The study shows that in the commercial sector, altogether 9.1% of the sectoral GHG emission can be mitigated in 2020 and 22.8% can be mitigated in 2025 under LCS-COM as compared to the base case. By 2030, 45.8% of the commercial sector GHG emission can be avoided by adopting the mentioned mitigations measures as compared to the base case (Figure 7).

In terms of the emission of local pollutants, there would be significant reduction in their emission under LCS-COM as compared to base case as shown in the Table 5. The reduction of the emissions of the local pollutants under LCS-COM ranges from 0.02% reduction for PM10 to 5.4% reduction for SO_2 in 2020 as compared to the base case. Similarly in 2030, the reduction of local pollutants ranges from 0.2% reduction for PM10 to 31.6% for SO_2.

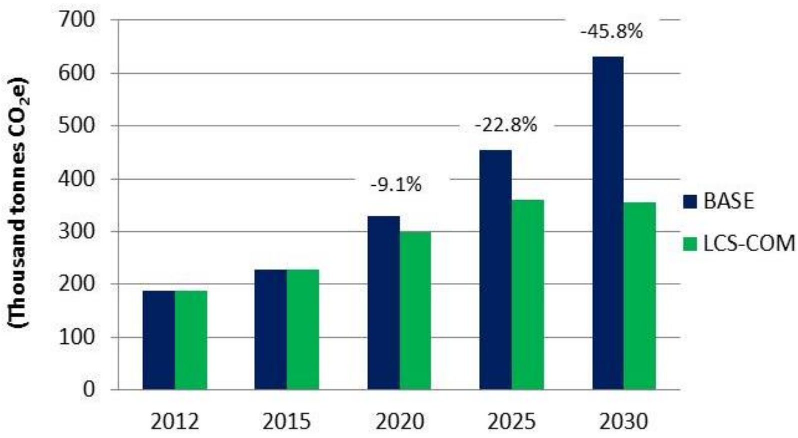


Figure 7. GHG reduction under commercial sector GHG mitigation measures in Kathmandu

Table 5. Local pollutants emissions reduction under LCS-COM (Thousand tonnes CO_2e)

	2020		2025		2030	
	BASE	LCS-COM	BASE	LCS-COM	BASE	LCS-COM
CO	8.083	7.848	11.033	10.214	14.838	12.587
NO_X	0.139	0.135	0.191	0.174	0.256	0.210
NMVOC	3.153	2.999	4.247	3.699	5.631	4.090
PM_{10}	0.051	0.051	0.060	0.060	0.068	0.068
SO2	0.004	0.003	0.005	0.004	0.006	0.004

GHG emission reduction potential in transport sector

GHG mitigation potential of the transport sector was studied by considering introduction of the efficient electric vehicles and model shift to electrified mass transport system.

The strategic options includes following:

- Introduction of energy efficient electric passenger vehicles by gradually replacing conventional fossil fuel based vehicles in different passenger transport modes (2-wheelers, 3-wheelers, car, bus, microbus and taxi). The penetration of the electric vehicles consists of 10% of the share of non-electric vehicles in 2020, followed by gradual increased in the share to reach 15% in 2025 and 20% by 2030;

- In addition there will be gradual shift from conventional non-electric passenger vehicles to electrified passenger mass transport (MRT) beginning with modal shift of 10% of the base case non-electric passenger vehicles to EMT in 2020, followed by gradual increased in the share to reach 15% in 2025 and 20% by 2030;
- In addition there will be gradual shift from conventional non-electric freight vehicles to electrified freight mass transport (train) beginning with modal shift of 10% of the base case non-electric freight vehicles to EMT in 2020, followed by gradual increased in the share to reach 15% in 2025 and 20% by 2030.

The study shows that in the transport sector, the GHG mitigation strategic options considered in the study could reduce 12.2% of the industrial sector GHG emission in 2020, could reduce by 18.5% in 2025 and 25.0% in 2030 under LCS-TRN as compared to the base case (Figure 8).

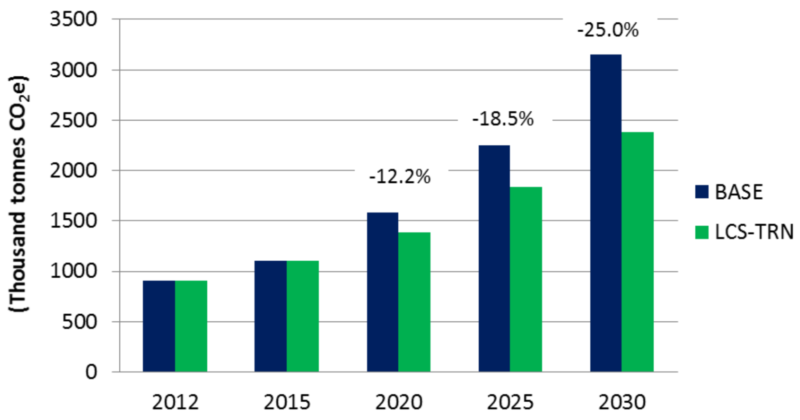


Figure 8. GHG reduction under transport sector GHG mitigation measures in Kathmandu

In terms of co-benefits related to the emission of local pollutants, there would be significant reduction in their emission under LCS-TRN as compared to the base case (Table 6). The reduction of local pollutants under the transport sector GHG mitigation measures ranges from 14.2% reduction for SO_2 to 19.0% reduction for CO in 2020 as compared to the base case. Similarly in 2030, the reduction of local pollutants ranges from 28.6% reduction for SO_2 to 38.3% for CO.

Table 6. Local pollutants emissions reduction under LCS-TRN (Thousand tonnes CO_2e)

	2020		2025		2030	
	BASE	LCS-TRN	BASE	LCS-TRN	BASE	LCS-TRN
CO	60.922	49.326	91.349	65.175	135.466	83.544
NO_X	12.780	10.964	18.345	14.389	26.077	18.493
NMVOC	11.735	9.543	17.560	12.615	25.993	16.190
SO_2	1.855	1.592	2.614	2.055	3.643	2.600

GHG emission reduction potential in agriculture sector

Under the agriculture sector, GHG reduction potential was studied for irrigation pumping, land tilling and thrashing applications.

The strategic options includes following:

- Fuel switching from fossil fuel based devices to electric devices would take place for irrigation pumping and thrashing applications with penetration of 10% in 2020, 25% in 2025 and reaching the share of fuel switch to 50% by 2030;
- In addition there will be introduction of energy efficient technology options begins to penetrate to reach 25% of the share in 2020, followed by gradual increased in the share to reach 50% in 2025 and 100% by 2030 for the land tilling applications and remaining fossil fuel based irrigation pumping, and thrashing applications.

The study shows that in the agriculture sector, altogether 8.2% of the sectoral GHG emission can be mitigated in 2020 and 18.0% can be mitigated in 2025 under LCS-AGR as compared to the base case. By 2030, 34.3% of the commercial sector GHG emission can be avoided by adopting the mentioned mitigations measures as compared to the base case (Figure 9).

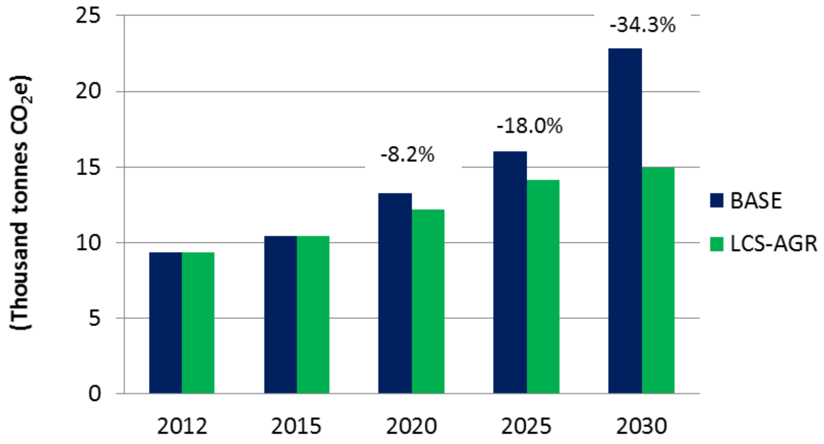


Figure 9. GHG reduction under agriculture sector GHG mitigation measures in Kathmandu

There would be significant reduction in the local pollutants emission due to the GHG mitigation measures under LCS-AGR as compared to the base case scenario (Table 7). The reduction of local pollutants emissions under agriculture sector GHG mitigation measures ranges from 8.2% reduction for NO_X to 10.6% reduction for CO in 2020. Similarly in 2030, the reduction of local pollutants ranges from 34.2% reduction for NO_X to 44.9% for CO.

Table 7. Local pollutants emissions reduction under LCS-AGR (Thousand tonnes CO_2e)

	2020		2025		2030	
	BASE	LCS-AGR	BASE	LCS-AGR	BASE	LCS-AGR
CO	0.108	0.097	0.140	0.106	0.186	0.102
NOx	0.192	0.177	0.249	0.204	0.330	0.217
NMVOC	12.186	11.180	15.785	12.929	20.925	13.709

Total GHG emission reduction potential in Kathmandu valley

The combined effect of application of all the sectoral GHG mitigation strategic measures from the five economic sectors indicates altogether 10.8% of total GHG emissions can be reduced as compared to the base case scenario in 2020 as shown in Figure 10. The GHG reduction reaches to 21.0% and 35.2% in 2025 and 2030 respectively as compared to the base case.

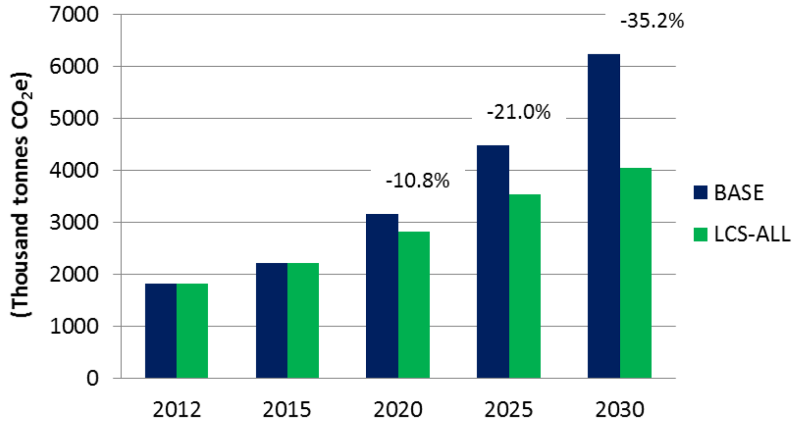


Figure 10. Cumulative total GHG mitigation under low carbon measures in all the economic sectors

Co-benefits related to local pollutants emission reduction

This study shows that LCDS in the Kathmandu valley not only helps to mitigate climate change mitigation from reduction of GHG emissions but also results significant contribution in the reduction of local pollutants emissions leading to the health and other socio-economic benefits. The reduction of total local pollutants emissions under the application of all the sectoral GHG mitigation strategic measures from the five economic sectors ranges from 0.69% reduction for PM10 to 13.70% reduction for NO_X in 2020 as compared to the base case. Similarly in 2030, the reduction of local pollutants ranges from 4.77% reduction for PM10 to 31.71% for SO_2 (Table 8). This indicates the need for study on the integration of the low carbon policies and local environment protecting policies for the effective and efficient implementation of those policies.

Table 8. Local pollutants emissions reduction under LCS-ALL (Thousand tonnes CO_2e)

	2020		2025		2030	
	BASE	LCS-ALL	BASE	LCS-ALL	BASE	LCS-ALL
CO	151.883	139.818	203.595	175.484	239.298	212.660
NOx	15.393	13.284	21.639	16.881	29.475	20.652
NMVOC	56.132	52.333	72.197	62.415	88.543	69.770
PM10	1.199	1.191	1.384	1.357	1.515	1.443
SO_2	2.183	1.885	3.062	2.388	4.255	2.906

Economic cost of GHG mitigation

The estimated technology investment costs of low carbon strategies for different sectors have quite a varying range of cost as shown in Table 9. The low carbon measures of residential sector show the least demand side technology investment cost for GHG mitigation, followed by the measures of industrial, commercial and agriculture sectors. The strategic measures of transport sector are found to be the most expensive for GHG mitigation.

In terms of GHG mitigation potential, transport sector leads followed by industrial, residential and commercial sectors. The measures from the agricultural sector show relatively lower GHG mitigation potential. This indicates the need for exploring the possibility of utilizing the global climate funds and creating an enabling environment to utilize voluntary mechanisms for mitigating the GHG emission in the city level there by utilizing co-benefits related to reduction in the emission of local pollutants.

Table 9. GHG mitigation cost and potential for different economic sectors in Kathmandu

	2020		2025		2030	
	GHG mitigation cost [USD/tonne CO_2e]	GHG mitigation potential [thousand tonnes CO_2e]	GHG mitigation cost [USD/tonne CO_2e]	GHG mitigation potential [thousand tonnes CO_2e]	GHG mitigation cost [USD/tonne CO_2e]	GHG mitigation potential [thousand tonnes CO_2e]
LCS-IND	0.317	65.39	0.274	215.35	0.242	578.24
LCS-REG	0.002	54.43	0.002	200.82	0.001	514.57
LCS-COM	3.043	29.96	3.027	106.57	3.011	299.05
LCS-TRN	96.292	192.50	98.145	416.13	99.619	794.62
LCS-AGR	7.793	1.09	6.133	3.10	5.164	7.83

Co-benefit of energy security

The implementation of LCDS for different economic sectors also results co-benefit in terms of reduction in imported fuel dependency. All the LCS scenarios show improvement in the energy security by reduction in the share of imported fuel in the total final energy consumption as shown in Figure 11. The highest improvement in energy security is shown by the transport sector GHG mitigation measures (LCS-TRN) and lowest by agriculture sector GHG mitigation measures (LCS-AGR) in 2020 and 2025. Similarly, the residential sector GHG mitigation measures results highest reduction and the agriculture sector mitigation measures results lowest reduction in the consumption of imported fuels in 2030.

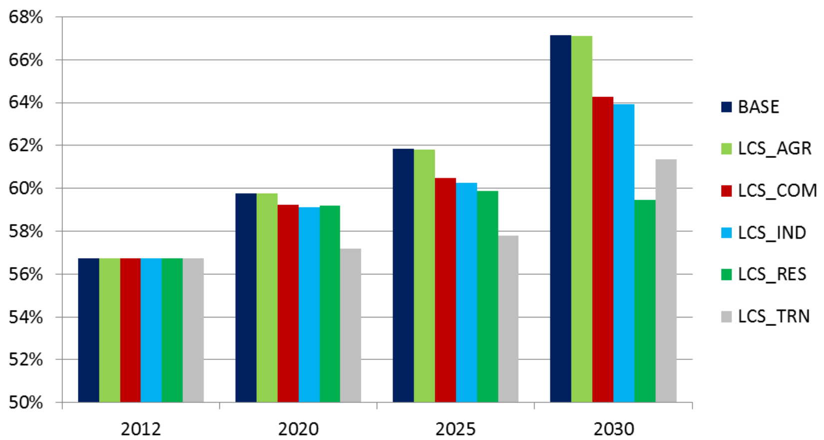


Figure 11. Change in net fuel import dependency

CONCLUSION AND RECOMMENDATIONS

Kathmandu being one of the fast growing cities in the South Asia faces with various challenges related to the climate change, local pollutants emissions and energy security of supply. This study analyzed the GHG mitigation potential in different economic sectors (namely, industrial, commercial, residential, transport and agriculture sectors) of the valley by using bottom-up energy accounting Long-range Energy Planning (LEAP) framework.

It shows that the effect of implementing various LCDS options from all the five economic sectors can reduce 10.8% of total GHG emission from energy use as compared to the base case scenario in 2020 and the GHG mitigation potential reaches to 35.2% by 2030. This indicates the need for exploring the possibility of utilizing the global climate funds and creating an enabling environment to utilize voluntary mechanisms for decreasing GHG emission thus supporting the Global Climate Change mitigation. The estimated demand side technology investment cost of LCDS for different sectors ranges from USD 0.002/tonne CO_2e for residential sector to USD 96.29/tonne CO_2e for transport sector in 2020. In 2030, the demand side technology investment cost ranges from USD 0.001/tonne CO_2e for residential sector to USD 99.62/tonne CO_2e for transport sector.

Similarly the additional co-benefit in terms of reduction of local pollutants emission from introduction of the low carbon strategic options in all the sectors consists of decrease in CO emissions by 7.9% in 2020 which will reach 11.1% in 2030 as compared to the base case. The emissions of NO_X, NMVOC and SO_2 would decrease by 13.7%, 6.8% and 13.7% respectively in 2020 as compared to the base case. Their emissions reductions reach to 29.9%, 21.2% and 31.7% for NO_X, NMVOC and SO_2 respectively by 2030. Similarly, the emission of PM10 would reduce by 0.69% in 2020 and decrease by 4.8% in 2030 under the GHG mitigation measures from all the sectors as compared to the base case. This indicates the need for study on the integration of the low carbon policies and local environment protecting policies for the effective and efficient implementation of those policies. As Government of Nepal has envisioned following low carbon economic development path on the long run, there is the need of establishment of regulatory framework, institutional framework and development of clear action plans for realizing the implementation of LCDS in the country. Ministry of Environment, Science and Technology can act as the focal institution for the implementation of LCDS as it is also the Designated National Authority for the development of projects for the Clean Development Mechanism in Nepal. The implementation of LCDS for different economic sectors also results co-benefit of energy security improvement in terms of reduction in imported fuel dependency and decrease in economic vulnerability.

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APPENDIX

This appendix contains level of disaggregation of the service demands and associated fuel considered in the Kathmandu-LEAP model.

Detail disaggregation of service demands

Sector	Service demand	Fuel
Agriculture	Irrigation pumping	Diesel, gasoline, electricity
	Land tilling	Diesel
	Thrashing	Diesel, gasoline, electricity
Commercial	Air conditioning Cooking Lighting Space heating Water boiling Water pumping Electrical appliances Others	Electricity, biomass, kerosene, LPG
Industrial	Motive power Process heating Process cooling Boiler application Lighting Others	Diesel, coal, electricity, biomass
Residential	Agro-processing and animal feed preparation Cooking Lighting Space cooling Space heating Water boiling Water pumping Electrical appliances Others	Biomass, electricity, kerosene, LPG, solar
Transport	Freight-air plane	Aviation turbine fuel
	Pick up, tractor, truck	Diesel
	Passenger-air plane	Aviation turbine fuel
	Bus, micro bus, cars, taxi, 3-wheelers, 2-wheelers	Diesel, gasoline, electricity, LPG