Aligning Low-Carbon Society Scenario with City Development Goals in Bhopal, India

Kei GOMI[1*], Aashish DESHPANDE[2] and Manmohan KAPSHE[3]

[1]*Graduate School of Engineering, Kyoto University*
Kyoto daigaku-Katsura, Nishikyo-ku, Kyoto 606-8530, Japan
[2]*National Institute of Technical Teachers' Training and Research (NITTTR)*
Shamla Hills, Bhopal, Madhya Pradesh 462002, India
[3]*School of Planning and Architecture, Sports Complex, Maulana Azad National Institute of Technology, (MANIT), Bhopal, Madhya Pradesh 462051, India*
**e-mail: gomi.kei.5r@kyoto-u.ac.jp*

Abstract

This study presents a low-carbon society (LCS) scenario in a rapidly growing city, Bhopal, India. The city currently has problems with sprawling development and associated traffic increase as well as providing energy to the city dwellers and businesses. The city has a unique topographic configuration in which different parts of the city are interspaced by hills and lakes. The new developments are not particularly eco-friendly and planned interventions are needed, if Bhopal wants to continue as a cleaner and greener city. We developed simulations of two possible scenarios, namely "business as usual" (BAU) and "low-carbon society" (LCS) for Bhopal in 2035, and quantified emission reduction potentials of various countermeasures using the AIM/ExSS model. An LCS scenario in which CO_2 emissions are mitigated by 41% from BAU was developed considering these issues. The future scenario development and modeling outcome suggest that the largest mitigation potential can be achieved through measures for energy efficiency improvement followed by fuel shift and integrated transport management. The overall vision of the LCS approach is to make Bhopal a more livable entity to all its residents. Towards realising this vision, seven actions have been suggested that can impact the existing energy consumption pattern as well as GHG emissions in the future. These actions, though, identified separately for the ease of communication, are inseparably linked in the LCS framework and can only work in conjunction towards achieving the vision.

Key words: city planning, climate change mitigation, low-carbon city, scenario development

1. Introduction

Today, we are faced with a series of global problems which are harming the biosphere and human life in alarming ways that may soon become irreversible. Particularly, emissions in cities continue to pose a significant threat to health, the environment and the quality of life of millions of people across nations. More than half of the world's population now lives in urban areas and contributes more than 80% of anthropogenic greenhouse gas emissions. Many aspects of urban change in the last 50 years are unprecedented, including not only the level of urbanisation and the size of the world's urban population but also the size and number of very large cities. These urban changes are dramatic – there are dozens of cities whose populations have grown tenfold in 30 years. This has led to rapid growth of the so called 'million cities' and 'mega cities'. Most of the world's largest cities are now in Asia.

It is projected that in 2015, worldwide, there will be more than 300 cities with over one million inhabitants each, and that most of these cities will be in developing countries. Between 1980 and 2000, Lagos, Dhaka, Tianjin, Hyderabad and Lahore, among others, joined the list of the 30 largest cities in the world, and by 2010, the Indian city of Mumbai is projected to become the second largest city in the world, after Tokyo (Moor & Warah 2002).

Interestingly, over the years, it is environmental problems that have been drawing more attention from researchers. In the recent past, due to emerging concerns of climate change, environmental issues have taken prominence as cities are likely to face this additional burden that is challenging their long term sustainability.

Similar to the cities in developing nations, in Indian cities too, rapid industrialization, urbanization and development of transport networks have led to economic development at the cost of the environment. The domes-

tic sector is the largest consumer of energy in India and diversity in consumption patterns, income levels and technology choices make the situation complex. This situation gets further compounded by the high influx of population to urban areas, unplanned urban development and industrial growth. The major concern today is the less than desired penetration of clean and efficient technologies in urban areas. Local urban bodies are entrusted with the responsibility of providing services from basic infrastructure development to waste collection and have to assume a larger role to act as leaders in sustainable development pathways.

Many cities in Asia are now taking actions to enhance their institutional and technical capabilities to design and implement climate change mitigation and adaptation strategies. There is a need to assess how far individual cities can contribute to emission reductions strategies. In this direction, this study explores and analyses the role of rapidly urbanizing metropolitan cities in India towards moving on low-carbon pathways. For this purpose, a study of Bhopal City, located in central India, is being carried out.

International discussions have lately been focused on how the world community must reduce greenhouse gas (GHG) emissions by 60 percent by the year 2050, to prevent global average temperatures from rising above 2°C over pre-industrial levels. As each individual country will take the development path on the basis of its local resource endowments, it becomes imperative to focus on the possible incentives that can help developing countries move towards a lower-carbon future. Care needs to be taken to account for the barriers that can retard the process. This translates into formulation of an integrated approach to sustainable development and requiring realigning of development and climate priorities.

1.1 Low-carbon society : concept

The main characteristic of the LCS approach here is to encourage societies in transition to address not only the environmental challenges of climate change but also social, economic and political challenges among others. An LCS is a society sustainably developed or developing on the basis of close, reasonable and harmonious coordination of economic and social development, and environmental protection. In this society, environmental protection will be given the same level of attention as other socioeconomic development issues. An LCS framework is not merely an approach to reducing GHG emissions but it also helps to achieve national development targets especially those related to effective sustainable development.

With rapid urbanization, in the coming years, India faces challenges in economic development which have to be met with the limited resources available, with minimal externalities and large uncertainties with regard to climate change. From this perspective, the LCS approach gives alternative options for the future flow of energy through infrastructure and other behavioral and lifestyle choices.

1.2 Objective

To analyse the possibilities of reducing GHG emissions in the future, a sustainable development future scenario has been drawn for Bhopal that is expected to take it in the direction of a low-carbon society. For managing energy emissions and driving the urban eco-system towards balance, the city has to work as an organic whole and the effects of all significant activities must be made apparent. In this process, the citizens and policymakers make informed choices. The governance and management process is taken to be rooted in sustainability and makes decisions which not only address the interests of the present stakeholders but also of future generations.

The primary objectives for a city in transition towards LCS are outlined as –

- Sustainability and low-carbon emissions in line with national policies
- Readiness for the future and resilience to change
- Conservation and green orientation for quality of life
- Economic and socially competitive clean and green industries
- An efficient transport system
- Community participation in city development

1.3 LCS study for Bhopal

The urban population of Bhopal has increased at an average decadal growth rate of over 70% in the last four decades. Bhopal, being a growing urban center in India, is a prototype city and has therefore been selected as a suitable case study for implementation of the LCS framework. The study area has been delineated to include the entire district of Bhopal, which encompasses considerable area in the rural-urban fringe. The planning area of the city of Bhopal constitutes a large part of the district. The development of the district thus holds great opportunities at this juncture, standing at the crossroads of a rural-urban interface, which if explored in the right perspective, could lead to a more sustainable vision.

1.4 About Bhopal

Bhopal, the capital city of the state of Madhya Pradesh, is one of the many cities in India growing at a very fast pace. Historically, the identity of the city of Bhopal has been linked with the feudal State of Bhopal as its capital and its large man-made lakes.

After the reorganization of states in 1956, Bhopal was declared to be the capital of Madhya Pradesh. By then, it had already acquired a complex urban structure. However, it was only after 1956 that the spectacular growth of Bhopal started and it began to sprawl across the adjoining areas. Low-density development in the past has helped it to continue with green cover. The afforested hills have also helped keep the city water bodies clean. This natural balance is now being disturbed due to faster and somewhat thoughtless development. The new developments are not particularly eco-friendly and planned interventions are needed if Bhopal wants to continue as a cleaner and greener city. Table 1 provides basic information on

Table 1 Profile of the Bhopal district.

Demography	Population (2005)	2.1 million
	Population growth rate (1991-2005)	3.2%/year
	Urbanization rate	80.5%
Geography	Location	Latitude: 77.35N Longitude: 23.25E Altitude: 550-660 MSL
	Temperature	Maximum: 45 degrees Celsius Minimum: 6 degrees Celsius
	Average rainfall	900-1220 mm per year
	Area	2772.4 km^2 Urban plan area: 601 km^2
Economy	DGDP (2005)	70 billion INR
	Per capita DGDP (2005)	33 thousand INR
	DGDP growth rate (2001-2005)	2.6%/year

the district.

1.4.1 Geography

Bhopal is situated on the Malwa Plateau, spreading across the central part of India. It lies in hilly terrain, sloping towards the north and south east. It has an average elevation of 576 meters above mean sea level (MSL), which is higher than the North Indian plains, where the land rises towards the Vindhya Range to the south. Bhopal has an uneven elevation and a number of small hillocks within its boundaries, and it also includes large water bodies and forested areas in close proximity to the urban area. Bhopal City also has a unique topographic configuration in which the different parts of the city are interspaced by hills and lakes providing large open spaces within the city.

1.4.2 Demography

Bhopal had a population of 85,000 in 1956 at the time it was declared the state capital. The city became a metropolis with a population of 1.063 million in 1991. The population of Bhopal City has increased at an average decadal growth rate of over 70% during the last four decades. As per the Census 2011 provisional estimates, the population of Bhopal District in 2011 was 2.36 million. Estimates indicate that the population of Bhopal District will grow to around 4.5 million by 2035.

1.4.3 Land use

The land use in Bhopal is represented in seven broad categories of residential, commercial, industrial, public and semi-public, public utility, recreational and transportation. The maximum share of land allocations in the Bhopal Development Plan – 1991, was under the residential category, having 45%, followed by recreational (15%) and transportation (13%) (GoMP, 1974). The plan area has increased considerably; however, the land-use distribution has remained more or less the same in the Bhopal Development Plan – 2005 (GoMP, 1995).

1.4.4 Economy

On the economic front the city is growing as a multi-functional capital city. In recent years, Bhopal has seen a decline in traditional industries, especially the engineering support and component manufacture that originally grew up around Bharat Heavy Electricals Limited (BHEL). The service sector is becoming dominant and provides the majority of employment in Bhopal. The District Gross Domestic Product (DGDP) has grown from 45 billion INR in 2001-2002 to 70 billion INR in 2005-2006 at an annualized short-term growth rate of 2.59% (Indicus Analytics, 2009).

For the year 2005-06, the tertiary sector contribution to the DGDP was more than 75% of the economy. Occupations in the tertiary sector have been continuously increasing over last four decades and the percentage of workers in the secondary sector has declined substantially, whereas that in the primary sector share has declined marginally.

1.4.5 Transport

Like all major cities in India, Bhopal has also witnessed very high vehicular growth. In the last two decades, total motor vehicles have grown by more than three times, and this growth is driven by two wheelers, which have grown by more than three times during this period. However, since 2003-2004, with rising income and prosperity, the share of four wheelers plying the roads has been growing rapidly.

The transport infrastructure in Bhopal is being transformed with widening of roads, overpass bridges at railway crossings, flyovers for fast transit, multistory parking at various locations, and pedestrian subways at major traffic points. Bhopal Municipal Corporation (BMC) under the Jawaharlal Nehru National Urban Renewal Mission (JNNURM) scheme has initiated the Bus Rapid Transport System (BRTS) plan for Bhopal in a phased manner (Bhopal Municpal Corporation, 2005; Bhopal Municipal Corporation, 2006).

1.4.6 Energy and CO_2 emissions

Energy consumption in Bhopal is growing rapidly. The electricity consumption for the year 2007-2008 in Bhopal was about 940.83 million kWh (Divisional Planning and Statistics Office, 2008) of which Bhopal urban was consuming more than 580 million kWh. As per the Census 2001, 97% of the households in Bhopal District have access to electricity as a source of lighting. The share of the residential sector has been highest, with 58% of the total electricity consumption, followed by commercial, with 19%, and others, with 18%. The industrial sector accounts for 5%. In the total final energy consumption, fuel wood, LPG and kerosene constitute almost 70%, and the balance is distributed amongst coal, petroleum, electricity, etc. The sector-wise energy consumption distribution in 2005 is shown in Fig. 1, with the results of future projections. Since the largest energy consumer is the residential sector, for emissions reduction, the primarily residential sector needs to be targeted.

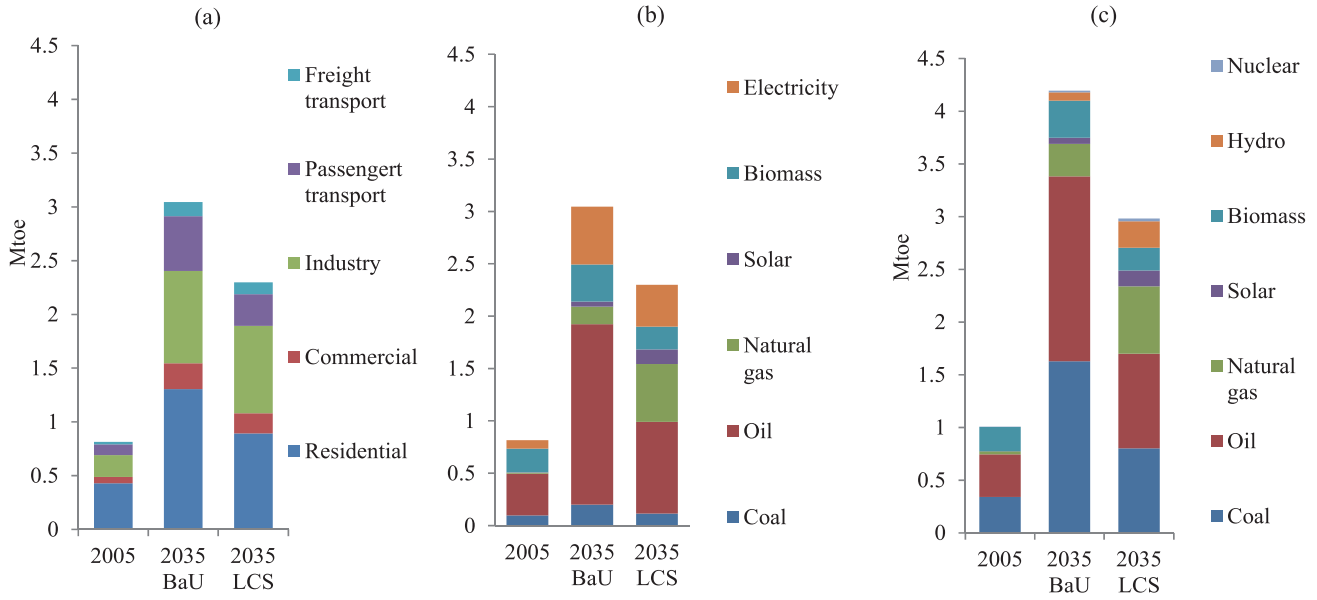

Fig. 1 Final energy demand by sector (a) and by fuel (b) and primary energy demand (c).

2. Methodology : Backcasting

This study applies a problem formulation methodology commonly used in LCS studies, where the socioeconomic assumptions of the target year, environmental load emissions, and measures for reduction are collectively called the 'future society image.' Suitable actions for the study area are then identified that are needed to transform the present condition into the identified 'future society image' (Becker *et al*., 1982). To create a local low-carbon society scenario, the concept of 'back casting' (Robinson, 1982) is used, which first sets a desirable goal, and then seeks the ways to achieve it. In this process, to formulate the framework of an LCS scenario for a region, a problem outline is drawn that establishes the coverage areas, base and target year, targeted activities, environmental targets and number of scenarios. This is followed by description of socioeconomic assumptions for developing a qualitative future image and quantification of the parameters. The parameters of socioeconomic assumptions, the economic growth rate of the region, export value by industry and population characteristics, considered to have large influences on GHG emissions, are then used as exogenous variables for the AIM/ExSS model. The AIM/ExSS model (Gomi *et al*. 2010) can capture the emission reductions of each countermeasure, thereby showing the reduction potential of specific policy prescriptions and identifying potential high emission reduction countermeasures.

As a first step, in order to capture the current status of Bhopal and to calibrate the AIM/ExSS, socioeconomic and energy data of the base year (2005) were collected (Table 2).

In the next step, for the present research, the study area as stated above was the Bhopal District with an urban-rural mix. Different areas of Bhopal District having different growth rates, diverse levels of infrastructure facilities, different energy consumption levels, fast-changing economic activities, occupational patterns and land use were reflected in the socioeconomic assumptions.

Finally, interventions considered feasible to be introduced in each target year were collected. These included, but were not limited to, energy-saving technology, changes in traffic structure, increasing use of renewable energy, energy-saving actions, sources of absorption, etc. Standards, expense minimization, stakeholders' receptiveness and technical feasibility were considered in order to ascertain suitable combinations of interventions and measures. With possible values of technical parameters applied (energy efficiency, technology shares, etc.), CO_2 emissions were projected in a reiterative process until the target was met. Based on these conforming measures, actions and policy recommendations were formulated and suggested.

3. Scenarios

3.1 Framework of the scenarios

The time horizon for achieving LCS targets was set for the year 2035. The objective was to align city development plans and policies with national and global targets. The target was for the LCS to achieve a reduction of 40% in 2035 from BAU emissions. The BAU scenario of 2035 was computed envisaging the continuation of present government policies, existing technologies, lifestyles and energy consumption patterns. Using historic trends, in the transport and residential sector, the energy and emission scenario was drawn for three decades, assuming that all the past growth rates would continue in the future. In this scenario no specific interventions were taken. The BAU scenario shows us a projected picture bringing out the extent of problems in the future. For analyzing the possibilities of reducing the GHG emis-

sions in the future, a sustainable development future scenario was drawn for Bhopal that was expected to take it towards a low-carbon society. In this process the citizens and policymakers would make informed choices. The governance and management process was taken to be rooted in sustainability in which decisions were made which not only addressed the interests of the present stakeholders but also of future generations.

Table 3 shows the list of assumptions used in both of the scenarios and Table 4 shows parameters and data sources for the assumptions in the scenarios.

3.2 Socioeconomic scenarios

3.2.1 Demography

The energy consumption and emissions of a city are dependent on the demographic characteristics and economic development of the region. With its rapid population increase, Bhopal has grown from a small town to a hub of many economic activities. Development has touched every aspect of life in the city, from potable water and sewage systems to roads and the vehicles that ply them. Using the growth rates from the United Nations (UN) medium term population projections for India, UN World Urbanization Prospects 2009, Census of India, and

Table 2 Information sources for the base year (2005).

	Sources
Population	· Divisional Planning and Statistics Office, Bhopal Division Publication, (2008)
	Jawaharlal Nehru National Urban Renewal Mission (2005)
Input-output table	· Central Statistical Organisation (2009)
	· GoMP (2009)
	· Indicus Analytics (2009)
	· Divisional Planning and Statistics Office (2008)
Transport volume	· Bhopal Municipal Corporation (2006)
	· Ministry of Urban Development, Government of India (2005)
	· Road Transport Office Bhopal, Ministry of Road Transport, Government of Madhya Pradesh (2008)
	· Wilbur Smith Associates South Asia Pvt. Ltd. & Ministry of Urban Development, Government of India (2008)
	· Barter *et al*. (2003)
	· EMBARQ Network & Center for Sustainable Transport (CST) Asia (2009)
	· Bhopal Municipal Corporation (2005)
	· Ministry of Road Transport & Highways, Government of India (2008)
Land use and floor area	· GoMP (1974)
	· GoMP (1995)
Energy balance table	· Department of Food & Civil Supplies, Government of Madhya Pradesh (2008)
	· OECD (2007)
	· ICLEI South Asia (2008)
	· Office of the Registrar General & Census Commissioner, Ministry of Home Affairs, Government of India (2005)
	· Divisional Planning and Statistics Office Bhopal Division Publication (2008)
	· National Sample Survey Organisation, Ministry of Statistics and Programme Implementation, Government of India (2006)

Table 3 Assumptions of the scenarios.

		2035BAU	2035LCS
Demography	Population	4.5 million	
	Household size	4 persons per household	
Economy	DGDP growth rate	5.8%/year	
	Industrial structure	Tertiary industry grows faster than other industries. Growth of primary industry is slower than others.	
Passenger transport	Modal share	Passenger cars 24%, motorbikes 40%, trains 0%, buses 6%, walking 26%, bicycles 2%	Passenger cars 13%, motorbikes 21%, trains 3%, buses 29%, walking 29%, bicycles 2%
	Trip distance	Same as 2005	20% reduction from BAU for passenger cars and motorbike
Final energy demand	Cooking fuels of residential and commercial sectors	Less share of biomass for cooking and water heating fuel than 2005 More use of air-conditioning (cooling) in households	
	Energy efficiency of devices	0% to 91% improvement in energy efficiency of the devices	90% to 340% improvement in energy efficiency of the devices
Power supply	Efficiency of conversion	10% improvement from 2005	20% improvement from 2005
	Transmission and distribution losses	10% reduction from 2005	20% reduction from 2005
	Shares of fuels	Increase in hydro (5%) and solar (0.6%), decrease in coal (83%)	Increase in hydro (24%) and solar (1.0%), decrease in coal (60%)

future estimates for Madhya Pradesh, we assumed that the population of Bhopal District would grow from 1.8 million to 4.5 million by 2035. With the changing lifestyles and increasing prevalence of the nuclear family system the household size was assumed to decrease to 4 from 5.1 (Census, 2001).

3.2.2 Economy

Table 5 summarizes the variables projected by the AIM/ExSS in each of the scenarios. Based on economic growth assumptions, the AIM/ExSS model projected that the Bhopal economy would grow rapidly with the district GDP rising from INR 70 billion in 2005 to 400 billion in 2035. Using an input-output framework, the model estimated changes in the structure of the economy with a shift towards the service sector from 60% in 2005 to 60.8% in 2035. The secondary sector (mining, manufacturing and construction) share increased slightly from 36% in 2005 to 36.9% in 2035. This shift is attributed to the decline in the primary sector share from 4.0% to 2.3% in the same period.

3.2.3 Commercial buildings

With large-scale investments in the real estate, especially in the commercial sector, the building sector needed special consideration in the case of Bhopal. The total floor space for commercial activities was projected to grow from 61 km^2 in 2005 to 344 km^2 in 2035 as per the rise in the tertiary sector's contribution to the district economy.

3.2.4 Transport

The motor vehicle density was expected to rise with increases in motor vehicle fleets and population growth. The passenger transport demand would grow from 5 billion passenger-km in 2005 to 25 billion passenger-km level in 2035 (Fig. 2) and the freight transport demand would grow to 3.5 billion ton-km in 2035 from 0.6 billion ton-km in 2005.

Table 4 Parameters and data sources for scenario assumptions.

❖ **Economic Parameters**	
SAM Estimation Projections for changes in economic structure	• EconomyWatch (2010) India Economic Indicators for Years 2011- 2015 (Forecast) (2010) • Expert opinion is used to validate the GDP growth rates in future periods. • The sectoral shares in DGDP of used sectors are determined using past series CAGR and projections for India in those sectors. • Expert opinion is used to validate the DGDP growth rates and sectoral share projections in 2035. • From the future share projection, the absolute values for DGVA by the different sectors are estimated.
❖ **Demographic Parameters**	
Population	• National Commission on Population (2006) • United Nations Population Fund (2009) • Population Division, Department of Economic and Social Affairs, United Nations (2009)
❖ **Transport Parameters**	
Transport sector composition (Passenger and Freight)	• Bhopal Municipal Corporation (2006) • Ministry of Urban Development, Government of India (2005) • Ministry of Urban Development, Government of India and Wilbur Smith Associates South Asia Pvt. Ltd.(2008)

Table 5 Main variables projected by the AIM/ ExSS.

Variable	Unit	2005	2035 BaU	2035 LCS	2035BaU /2005	2035LCS /2005	2035LCS /2035BaU
Number of households	thousand	386	1,136	1,136	2.94	2.94	1.00
DGDP	billion INR	70	383	383	5.47	5.47	1.00
Per capita DGDP	thousand INR	181	337	337	1.86	1.86	1.00
Industrial output	billion INR						
Agriculture		5	16	16	3.30	3.30	1.00
Forestry		0	0	0	1.09	1.09	1.00
Fisheries		0	0	0	0.71	0.71	1.00
Mining		2	9	9	4.60	4.60	1.00
Manufacturing		26	144	144	5.58	5.58	1.00
Construction		17	97	97	5.61	5.61	1.00
Electricity, gas and water supply		4	28	28	6.33	6.33	1.00
Banking & Insurance		2	12	12	5.57	6.18	1.00
Other services		69	384	384	6.18	5.57	1.00
Total		125	689	689	5.57	5.51	1.00
Commercial floor area	km^2	61	344	344	5.63	5.63	1.00
Passenger transport demand	million passenger-km	5,204	24,742	20,496	4.75	3.94	0.83
Freight transport demand	million ton-km	617	3,591	3,532	5.82	5.73	0.98
Final energy demand	ktoe	815	3,044	2,299	3.73	2.82	0.76
CO_2 emissions	$ktCO_2$	2,504	11,797	6,916	4.71	2.76	0.59
Per capita CO_2 emissions	tCO_2	1.2	2.6	1.5	2.20	1.29	0.59

3.3 Energy consumption and CO_2 emissions

3.3.1 BAU scenario

Based on scenario quantification using macro-economic data, future energy demand and corresponding GHG emissions in 2035 were estimated. The final energy demand in Bhopal was projected to rise more than three times to 3 million toe in 2035 where the share of the residential sector would be 43% followed by industry with 28% and the transport sector with 21% (Fig. 1(a)). About 81% of the primary energy would be met by coal and oil resources in the year 2035. Gas followed with 7%, more than half of which would be consumed in the industry sector. CO_2 emissions in this scenario would be 11.8 $MtCO_2$, an increase of 4.7 times from 2005. A sectoral analysis of GHG emissions showed that the contributions from the building sector (residential and commercial) for Bhopal would rise by more than 5 times compared to the year 2005 in the BAU scenario (Fig. 3). Per capita CO_2 emissions increased to 10.4 tCO_2 from 6.5 tCO_2 in 2005.

3.3.2 LCS scenario

In the year 2035, for the low-carbon society scenario, total final energy demand declined by 34% from BAU as a result of energy efficiency improvement in the energy demand sectors (Fig. 1(a)). The primary energy mix would shift towards cleaner fuel with the share of renewables (solar, biomass and hydro) more than doubling from 4% in BAU to 14% (Fig. 1 (c)). In this scenario, coal and oil would decline by half in quantity whereas natural gas would grow together with renewable energy sources. The share of nuclear and hydro was assumed to follow the national averages in the respective scenarios. With this energy demand mix, the GHG emissions would decline to 6.9 $MtCO_2$ (Fig. 3). The corresponding residential sector emissions would decline from 5.6 to 2.6 $MtCO_2$ commercial sector emissions, from 1.4 to 0.76 $MtCO_2$; transport sector emissions, from 1.83 to 1.2; and industrial sector emissions, from 2.98 to 2.3 $MtCO_2$. In the residential and commercial sectors, this reduction was due to improved energy efficiency in end-use devices and a shift towards cleaner fuel. In the case of the transport sector, the reduction came from travel demand management, enhanced vehicle efficiency, modal shift, increased use of public transport and improved transport systems. The industrial sector emissions reduction was achieved by improvements in end-use devices both in electrical and non-electrical equipment, boilers and furnaces, fuel switch from coal and oil to gas and clean electricity. The per capita GHG emissions contribution would be more than two times from 1.2 tCO_2 in base year 2005 to 2.6 tCO_2 in the 2035 BAU scenario and would decline to 1.5 tCO_2 in 2035 LCS scenario.

3.4 Mitigation potential

In the 2035 LCS scenario, the model projected that the total GHG emissions in Bhopal would be reduced to 6.9 $MtCO_2$ from 11.8 $MtCO_2$ in the BAU scenario. This would account for more than 40% GHG emissions reductions. Figure 4 shows contributions to emission reduction by mitigation options.

The largest reduction, of 1.9 $MtCO_2$, would come from energy efficiency improvements followed by 1.6 $MtCO_2$ from improvements in the power supply. Energy efficiency improvements would include applications of energy-efficient technologies in buildings, passive and active methods of reducing energy consumption, the use of energy-efficient appliances and vehicle efficiency improvements. Improvements in the power supply would include conversion efficiency improvement, reduction of transmission and distribution losses and a fuel shift to renewable energy. On the energy demand side, energy efficiency improvements in buildings from residential and commercial sectors would provide 33% of the total emissions reduction potential with 1.6 million tCO_2 in the LCS scenario, followed by reduction in energy service demand (5%), a modal shift in transport (5%) and energy efficiency improvement in the transport sector (5%).

Bhopal is an administrative capital with rising population and a higher tertiary sector share in its occupational pattern, so in pursuit of low-carbon society development, it would require an aggressive portfolio of policy measures.

Key policy measures would be needed for improving energy intensity (attainable by reducing energy service demand and making lifestyle changes) along with access

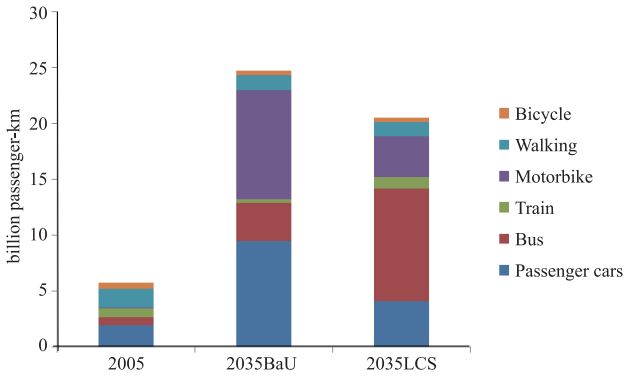

Fig. 2 Passenger transport demand.

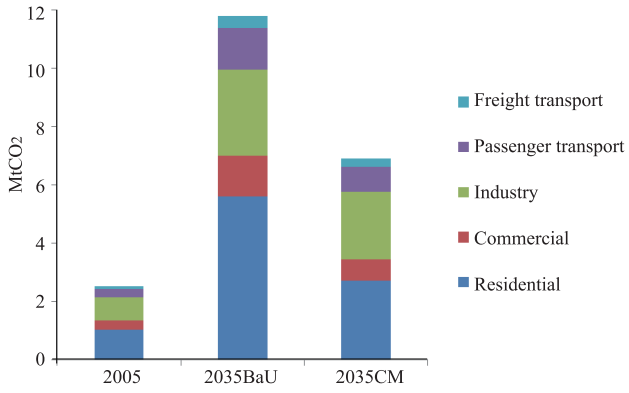

Fig. 3 Projected CO_2 emissions.

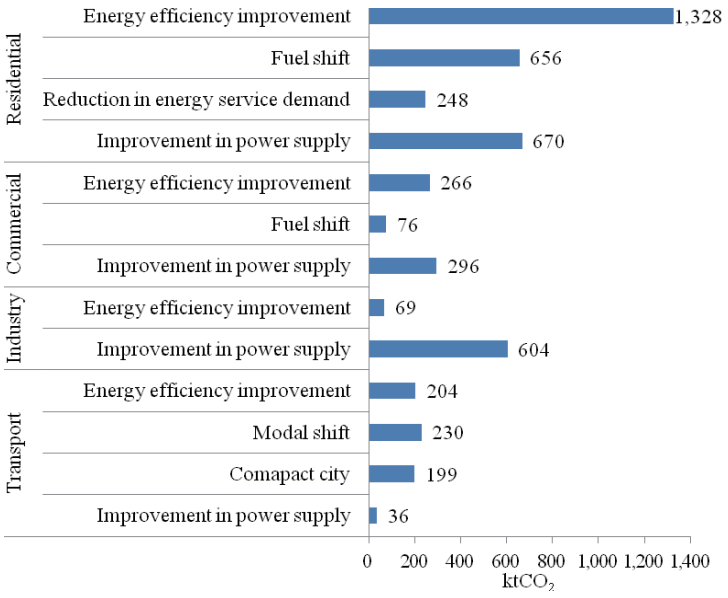

Fig. 4 Contribution of mitigation options.

to low-carbon power (hydro, nuclear), fuel switches in the industrial and transport sectors, providing convenient public transport and measures promoting end-use device efficiency, specifically in the transport, industrial and residential sectors.

4. Seven Actions towards an LCS

In pursuit of developing a low-carbon society by 2035 in Bhopal, the menu of policies and measures fosters numerous objectives, and these policy priorities change and evolve constantly with the challenges of the day. The overall vision of the LCS approach is to make Bhopal a more livable entity to all its residents.

The LCS approach demands greater efficiency of energy consumption as well as reduction in GHG emissions. Pursuit of these goals presents wide-ranging issues in the urban transportation, industrial, residential and commercial sectors. Many of the measures in these areas overlap each other.

There are seven actions that could be taken which would be the key steps that could influence the existing energy consumption pattern and GHG emissions in the future. These actions have been defined with an understanding of the inherent strengths and potential of the Bhopal District which can be explored at this time of rapid development. A sustainable path taken now could guide tomorrow's growth in a more holistic and inclusive manner with little need for post-action course correction.

These actions, though, identified separately for the ease of communication, are inseparably linked within the LCS framework and can only work in conjunction with each other towards achieving the vision. Further, these actions are conceptual in nature, derived from the modeling outputs in an integrated manner, and do not attempt to provide quantification of the LCS vision.

4.1 Action 1: Green Governance: Government Initiatives towards an LCS

The success of the LCS vision lies first and foremost in the government's will to embrace sustainability as an intrinsic focus in all its future plans and policies. This would mean incorporation of various measures at the policy level and in the implementation mechanisms.

4.2 Action 2: Holistic Habitat: Energy Efficiency in Buildings

Holistic Habitat would encompass all measures affecting the building and construction industry.

4.3 Action 3: Sustainable Style: Low-Carbon Lifestyle

Adopting sustainability as a way of life and not an alternative path is imperative for the success of the LCS vision.

4.4 Action 4: Cellular City: Multi-Nuclei Land Use Planning

The city of Bhopal, by virtue of its topography multiple nuclei and natural settings has historically developed as a city with multiple nuclei with natural barriers separating various zones. This natural formation can be used to the best advantage to develop a cellular city form and structure. This would imply developing compact multi-functional districts or townships (depending on the scale of the settlement) within an overall cohesive framework.

4.5 Action 5: Form and Flow: Integrating Transport with City Structure

In keeping with the multi-nuclei land use planning, the integration of transport systems connecting the cells as well as intra-cell transport is critical for reduction of emissions in the LCS scenario.

4.6 Action 6: Nurturing Nature: Leveraging the Natural and Historic Assets

Bhopal is fortunate to be endowed with large natural resources in the form of its many lakes and wooded hills, which give it a unique identity and define its many zones as well. It also has an old fortified city area as a historic resource. Protecting and leveraging this natural advantage is the next important step.

4.7 Action 7: Rural Riches: Promoting a Better Life in Rural Areas

A considerable part of the Bhopal District is still rural in nature and would be transformed to urban areas in the near future. At this juncture, it is important to carry forward the good practices of rural living even in the transition to urbanization.

5. Discussion and Concluding Remarks

Solutions to environmental problems require many changes in current practices, and technological, institutional and human factors are often resistant to change. The environmental policies involve multiple stakeholders with multiple, conflicting interests and concerns that have a range of implications for present and future generations. The concerns about the environmental costs of economic development are now both widespread and intense.

To attain the status of low-carbon city, Bhopal will have to make efforts to reduce its emissions in the future. Measures will be needed in every walk of life for harnessing renewable materials and energy sources and also to reduce the use of natural resources by using them more efficiently and productively, cutting or eliminating pollution and toxic wastes and delivering equal or superior performance compared with conventional offerings.

Bhopal has grown from a small town to a hub of many economic activities. It is a synthesis of the old and the new with bustling bazaars in the old city area and modern industrial centers. At present, land use planning, patterns of development and appropriate infrastructure provision have not kept pace with the economic growth of the city. Due to its rapid rate of urbanization, the city fabric is being stressed with growing transport concentration and rising energy consumption.

Bhopal with its development planning proposals and efforts of its civic society along with a host of government and non-government agencies is well poised to become a role model for central India, with its clean and green surroundings, tourist-friendly transport system, green pathways, energy-efficient and environment-friendly industry and good governance.

Based on the results of the present study, it can be envisaged that a city like Bhopal can move onto the path of becoming a low-carbon society city, able to address the issues of increasing energy consumption and emissions. This will be possible only if needed steps and planning measures are taken in coming years to address the infrastructure bottlenecks and by adoption of cleaner technologies. It is expected that the policymakers will be able to accommodate these requirements, addressing the environmental concerns, and Bhopal will emerge as the first low-carbon society state capital in India.

This study is of especial significance because the pathways to achieve a low-carbon society are open for developing countries, and a framework for a low-carbon society from the perspective of developing countries is evolving. It could be said that fast-growing Indian cities will have an opportunity to contribute to climate change mitigation by developing on a low-carbon pathway.

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Kei GOMI

Kei GOMI's profession is integrated modeling and scenario development for analyzing national and regional GHG emissions and mitigation scenarios. Since 2005, he has been involved in modeling for development of low-carbon society scenarios for Shiga Prefecture and the Kyoto City government and in joint research and training with researchers in Malaysia, India, Vietnam, Indonesia, China, South Korea, Thailand, Bangladesh and Cambodia on national and local mitigation scenarios. He received his PhD in Global Environmental Studies from Kyoto University. He had been a Research Fellow of the Japan Society for the Promotion of Science since 2008 and he has been working in his current position since April, 2010.

Aashish DESHPANDE

Aashish DESHPANDE is a Professor in the Department of Management at the National Institute of Technical Teacher's Training & Research (NITTTR), Government of India, Bhopal. He holds an MBA and a PhD degree from the Faculty of Management Studies, Barkatullah University, Bhopal. He is a recipient of an Eco-Frontier Fellowship (Ministry of the Environment, Japan) at the National Institute for Environmental Studies (NIES), Japan. He has served as Head of the Department of Management Studies at the Maulana Azad National Institute of Technology, Bhopal. He has contributed to India's National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) and has more than 15 research contributions and publications to his credit. His teaching and research interests include international finance, climate change scenario and policy analysis, energy - economy - environment models, and low-carbon society scenario development at regional and local level. Professor Deshpande has executed or contributed to a number of externally funded projects and national and international collaborative research projects. He has been associated with various national and international development agencies.

Manmohan KAPSHE

Manmohan KAPSHE is an architect and urban planner. He is a Fellow of the Indian Institute of Management, Ahmedabad, India. He has more than twenty years of teaching experience in Architecture, Planning, Energy and Management courses at various levels in different institutes. He is presently working as a Professor in the Department of Planning at the School of Planning and Architecture (SPA), Bhopal, India. Prof. Kapshe was a Lead Author for the 'Working Group-II contributions to the fourth assessment report,' contributing author to the '2006 Guidelines for National Greenhouse Gas Inventories,' and expert reviewer for the 'Special Report on Carbon Dioxide Capture and Storage' of the Intergovernmental Panel on Climate Change (IPCC). Prof. Kapshe has carried out research and consultancy assignments with many national and international agencies. His current research interests include regional and sectoral analysis of emissions, spatial analysis using GIS, and analysing the effects of climate change on human settlements and infrastructure. He has authored a book, contributed chapters to various books and published a number of papers in national and international journals.

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