Spatial analysis of low carbon development 2050: A case of residential sector, Bhopal, India

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Abstract. Indian cities are witnessing economic development, urbanization and lifestyle changes, leading to increase in Greenhouse Gas (GHG) emissions. In cities, sectors contributing to GHG emission are residential sector, transport and waste sector. In order to reduce emission, it is important to assess how individual city can contribute to emission reduction to become a Low Carbon Society (LCS). In this paper, we have analyzed residential sector of Bhopal City at ward level for demand side management through energy efficiency and lifestyle change. Two LCS, countermeasure scenarios CM1 and CM2 along with a Business as Usual scenario are developed and emission reduction potential is quantified using the AIM/Enduse model up to year 2050. The quantitative results are represented in spatial format using Geographical Information System (GIS) software providing a better understanding for decision makers.

1. Introduction
Urbanization has direct relation with climate change. In general, the more urbanized a nation, the higher are the greenhouse gas (GHG) emissions per person [1]. Urbanization in India was slow till 1971 i.e. only 19.91% of population was residing in urban areas. As per Census 2011, 31.16% of the country’s people now live in urban areas, up 3.35% from a decade ago. The decadal population growth rate for urban India was 31.8%, while for rural India it was 12.2%, a drop of almost 6%.

Cities all over the world are responsible for up to 70% of GHGs while occupying just 2% of land area. As cities are engines of growth, energy consumption has increased due to lifestyle change mainly in residential sector. The current challenge is to have economic development with efficient use of resources and achieving energy conservation and low carbon emission.

India ranks 5th in aggregate GHG emissions in the world, behind USA, China, EU and Russia in 2007 [2]. In India, most of the urban growth has been caused by accretion to the existing towns particularly the large cities, while the pace of growth of new cities has been slow. The number of metropolitan cities (+1 million) has risen sharply, from 35 to 53 during 2001-2011. Likewise, class 1 cities (+100,000) now account for 70.2% of the country’s urban population.

In cities energy intensive lifestyles with changes in consumption pattern have resulted in higher amount of waste. Thus, there is an urgent need to enhance the mitigation and adaptation strategies and make our cities low carbon. In this direction the paper aims to analyze the role of residential sector in an urban settlement in moving towards Low Carbon Society (LCS). The residential sector has a rural and urban spread, and therefore it combusts both fossil fuel as well as biomass which together emitted 12.6% of the total GHG emitted from the energy sector [2]. Energy consumed in the residential sector is primarily used for cooking, lighting, heating, cooling and household appliances.

Previous studies of Bhopal at district level show that energy consumption in residential sector is largest and emission reduction in residential sector needs to be targeted [3]. In this paper we have tried to analyze residential sector of Bhopal Municipal Corporation area (Urban) at ward level for demand side management through energy efficiency and lifestyle change.
2. Methodology

The study comprises of optimizing the energy utilization and minimizing the carbon emission for low carbon society scenarios. Asia Pacific Integrated Model (AIM/Enduse), a bottom up Technology Optimization approach commonly used for developing LCS scenarios is used. This represents the quantitative data in spatial form essential for decisions and actions at policy and implementation level.

The model has been developed for projecting GHG emissions and evaluating policy measures to reduce them. Model first estimates energy service demands based on socio-economic factors such as population, household details, economic growth, and lifestyle, and then calculates what kind of technology will be used to what extent. It also helps to evaluate the effectiveness of various policies.

In this study a framework of LCS Scenario is developed where area under Bhopal Municipal Corporation is taken as region for residential sector analysis (Figure-1). Time horizon for achieving LCS target was set for the year 2050, taking 2011 as base year. Energy uses and corresponding emissions for eight different services - Cooking, Lighting, Heating, Cooling, Space Heating, Space Cooling, Washing and Other Appliances is estimated under the three scenario explained below. There are a total of 46 technologies for meeting the demand of these eight services (Table-1).

3. Description of scenarios

Two low carbon LCS Counter Measure scenario’s CM1 and CM2 along with a Business as Usual (BAU) scenario are developed and emission reduction potential of various counter measures is quantified for Bhopal up to year 2050. In BAU the present trends of energy consumption, demographic changes and policy measures are considered to continue in future. In CM1 Scenario, new technologies are introduced with limitation of maximum share. In this scenario energy taxes are introduced and the discount rate remains the same. Emission taxes are not introduced. In CM2 Scenario, new technologies are introduced with limitation of maximum share. In this scenario high taxes on emission and energy are introduced.

4. Bhopal profile

Bhopal the capital city of Madhya Pradesh (India), is located at an average elevation of 427 meters in the central India (23°16’N, 77°22’E). This city is well connected with all other major cities of India. The city has a Municipal area (administrative area) of 298 square kilometres. The hilly terrain of Bhopal has led to low density city development.

4.1. Demography

Bhopal Municipal Corporation includes 70 municipal wards, of which Kaliasot, Gandhi Nagar and Narela Shankari encompasses major area of the city. The population of Bhopal city, in 1951 was 102,333 [4] which has increased to 1,785,237 as per census 2011 [5]. The population has increased tremendously after Bhopal became capital of Madhya Pradesh.

4.2. Landuse

The present city structure of Bhopal is identifiable in terms of self-contained sub- cities/townships. The land use in Bhopal is represented in seven broad categories (Table-2). The development plan (2005) envisages 8190 Hectare. land area for residential development. It contributes 46.48% of the total proposed developed area. The land utilization rate for residential use is 3.2 hectare per thousand persons. The pressure of urban development is seen on the roads connecting nearby settlement in east and south-east direction. On these roads new colonies and group housing societies have started developing (Figure-1). The pattern which has emerged since the establishment of the State Capital includes around 20% ownership housing and 80% Govt. Housing. Ownership housing is mainly seen in terms of plotted development and more recently in terms of residential flats.
| S. No. | Services            | Technology          | Fuel                  |
|--------|---------------------|---------------------|-----------------------|
| 1      | Cooking             | Biogas Stove        | Biogas                |
|        |                     | Cowdung Stove       | Cowdung               |
|        |                     | Charcoal Stove      | Charcoal              |
|        |                     | Coal Stove          | Coal                  |
|        |                     | Biomass (crop Residue) Stove | Biomass        |
|        |                     | Efficient Fuel wood Stove | Fuel wood           |
|        |                     | Efficient Kerosene Stove | Kerosene             |
|        |                     | Electric Stove (existing) | Electricity        |
|        |                     | LPG Stove           | Liquid Petroleum Gas |
|        |                     | Efficient non-commercial Fuel wood Stove | Non-Commercial wood |
|        |                     | Traditional non-commercial fuel wood stove | Non-Commercial Fuel wood |
|        |                     | Solar Cooker        | Solar                 |
|        |                     | Traditional Fuel wood Stove | Fuel wood         |
|        |                     | Traditional Kerosene Stove | Kerosene           |
|        |                     | High Efficiency LPG stove rural | Liquid Petroleum Gas |
| 2      | Lighting            | LED                 | Electricity           |
|        |                     | CFL                 | Electricity           |
|        |                     | Incandescent Lamp   | Electricity           |
|        |                     | Kerosene Lamp       | Kerosene              |
|        |                     | Solar Lamp          | Solar                 |
|        |                     | Tube light          | Electricity           |
| 3      | Heating             | Electric Geyser Storage | Electricity       |
|        |                     | Gas Geysers         | Electricity           |
|        |                     | Solar Water Heater  | Solar                 |
|        |                     | Electric Geyser Instant | Electricity       |
|        |                     | Solar Water Heater Efficient | Solar              |
| 4      | Cooling             | Refrigerator ( Large ) | Electricity       |
|        |                     | Refrigerator ( Medium) | Electricity       |
|        |                     | Refrigerators (Small ) | Electricity       |
|        |                     | Refrigerator ( Medium) High Efficiency | Electricity       |
| 5      | Space Heating       | Biomass Based       | Biomass               |
|        |                     | Coal Based          | Coal                  |
|        |                     | Electric Heater     | Electricity           |
| 6      | Space Cooling       | Air Conditioner Split | Electricity       |
|        |                     | Air Conditioner Window | Electricity       |
|        |                     | Ceiling Fan         | Electricity           |
|        |                     | Desert Cooler       | Electricity           |
|        |                     | Table Fan           | Electricity           |
| 7      | Washing             | Washing Machine Front loading Full Auto Rural | Electricity       |
|        |                     | Washing Machine Top loading Full Auto Rural | Electricity       |
|        |                     | Washing Machine High Efficiency | Electricity       |
|        |                     | Flat Screen Television | Electricity       |
| 8      | Other Appliances    | LCD Television      | Electricity           |
|        |                     | Television          | Electricity           |
|        |                     | Plasma Television   | Electricity           |
|        |                     | Television High efficiency new | Electricity       |
Table 2. Land use distribution.

| S. No. | Category                  | Proposed Development 2005 | Percentage |
|--------|---------------------------|---------------------------|------------|
| 1      | Residential               | 8190                      | 46.48      |
| 2      | Commercial                | 650                       | 3.71       |
| 3      | Public Semi public        | 1258                      | 7.18       |
| 4      | Public utilities, facilities | 488                      | 2.78       |
| 5      | Industrial                | 1389                      | 7.93       |
| 6      | Transportation            | 2600                      | 14.85      |
| 7      | Recreational              | 2925                      | 16.71      |
| Total  |                           | 17500                     | 100.00     |

Source: [6]

Figure 1. Land use Plan 2005. Source: BDP, 2005 [6].

4.3. Economy

Bhopal is multifunctional capital city with large number of persons engaged in various state and central government organizations. In recent years, Bhopal has seen the decline of traditional industries, especially the engineering support and component manufactures. The housing, banking, insurance and education sectors are growing fast in Bhopal. The work force participation rate is 29.6%. It was observed that among the main income earners of all households nearly 78.7% were engaged in clerical/sales/services, 10.2% in non-classified activities and 10% in occupied professional/managerial positional category. Out of the total income earners involved in non-classified activities majority (70.2%) belonged to the low income and economically weaker section [7].

4.4. Housing

Housing makes significant visual impact on the overall appearance of the city and its urban form. The number of households existing in Bhopal as per 1991 census was 119755 which have increased to 371722 in 2011. The average family size was 5.45 persons per household in 2001 which has reduced to 4.8 persons per household [5,8,9,10].

Electricity is one of the major sources of lighting, approximately 97% of total household have access to electricity. Census 2011 provides the details of energy consumption in cooking service on the basis of type of fuel. (Liquid Petroleum Gas) LPG is the major source of energy for 69% of households and only 0.1% of household use electricity as major source of energy for cooking. Details of energy used for cooking and lighting is shown in Table-3.
Table 3. Households by source of Lighting and Cooking.

| S. No. | Fuel Type                        | Number of households (Cooking) | Number of households (Lighting) |
|--------|----------------------------------|--------------------------------|---------------------------------|
| 1      | Electricity                      | 424                            | 361,013                         |
| 2      | Kerosene                         | 57,066                         | 8,627                           |
| 3      | Solar energy                     | -                              | 428                             |
| 4      | Other oil                        | -                              | 631                             |
| 5      | Fire-wood                        | 48,700                         | -                               |
| 6      | Crop residue                     | 2,351                          | -                               |
| 7      | Cowdung cake                     | 1,588                          | -                               |
| 8      | Coal, Lignite, Charcoal          | 888                            | -                               |
| 9      | LPG/PNG                          | 257,759                        | -                               |
| 10     | Biogas                           | 662                            | -                               |
| 11     | Any other                         | 298                            | 377                             |

Source: [5]

5. Results

The simulations show that the GHG emission and energy consumption for Residential sector increases in all the scenarios. The CO₂ emissions in Residential sector of Bhopal in 2010 were around 0.21 million tons of CO₂ which rise by around 2.5 times to 0.54 million tons CO₂ in the target year 2050 under the BAU. It was observed that Bhopal has 47% CO₂ emission reduction potential over BAU level in the CM1 LCS whereas this increases to 56% in CM2 LCS for residential sector. CM1 displays the possible energy demand reduction potential of 27%.

The simulation assessment of CM2, shows that in this scenario due to high emission and energy taxes, technologies using energy with minimum emissions such as solar energy are selected. In reality it is not possible to bring out such drastic change in the choice of technologies over a short period of time. Some realistic limit for maximum allowable energy supply from renewable energy may need to be assigned. Figure-2 and 3 show the energy and emissions for all the scenarios.

Figure 2. Energy demand for all scenarios.

Figure 3. Emissions for all scenarios.

Figure 4. CO₂ Emissions at ward level for BAU in 2010 and 2050.
Spatial analysis of emission at ward level for residential sector in 2050 shows that the wards on western, eastern and south-eastern periphery have higher level of emission. This may be due to the new developments of residential areas in these wards. These new developments are occupied by people with higher income groups and therefore have higher per household energy consumption resulting in higher emission. Ward 52 has highest level of emission followed ward 69 and 70. Some of the wards in the old city area such as ward 8, 15 and 38 also have higher level of emission. This may be due to high density development in these areas. In the LCS Scenario CM1 and CM2, the emissions reduce substantially and it may be possible to maintain a lower level of emissions in the city. However, the new developments on the periphery continue to have higher levels of emissions (Figure-4 and 5).

6. Conclusion
The simulations for energy demand and emissions for BAU and LCS scenarios are carried out based on the technologies and service demand assumptions using AIM/Enduse Model. The spatial analysis is done using the GIS software at ward level. Certain wards with high density residential areas show higher energy and emissions. Policy paths formulated in these scenarios show the likely rise in energy consumption, technology shift and CO₂ emission in residential sector of Bhopal. The study demonstrates that significant emission mitigation can be achieved in LCS compared to the BAU scenario.

With increasing concerns on environmental issues and rising public awareness the LCS scenario assumes a greater significance. The precise decisions on government policies for promoting the use of renewable energy and improved technology for lighting and cooking have a major contribution to make. The passive heating and cooling through architectural interventions will also reduce the energy consumption considerably.

An important component of the transition process to a low carbon city is behavioural change. Under the broader theme of achieving low carbon cities, strategies to persuade citizens to change to a low carbon lifestyle are also important.

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