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Low carbon mobility plans: A case study of Ludhiana, India

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Abstract

Transportation is one of the driving forces of any economy. The reliance on petroleum as a fuel is a main source of concern. The major share of transport sector in petroleum has many consequences. India is the world's 4th largest emitter, responsible for ~5% of the world's carbon emissions, the major contribution of this emission is from transport sector. In this study a low carbon mobility options for Ludhiana city as a case study is presented. In order to understand the impact of these options a stated preference survey is carried out. The shift to low carbon modes (bicycles, walk and public transport) is quantified. Shifts from petroleum driven vehicles to electric is also discussed. The projection to the future the per capita emissions of each of the scenarios: Scenario 1: Lanes for bus, bicycle and walk, Scenario 2: Scenario 1 plus improved buses, Scenario 3: Scenario 2 +policy against cars, Scenario 4: Electric vehicles (electric equivalents of two-wheelers and cars). It is found from the study that the emissions are least for scenario 3 (when there are parking policies imposed against cars in addition to improved transit policy and buses along with independent lanes for buses, and dedicated paths cycling and walking

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1. Introduction

Transport plays a crucial role in development and constitutes a significant share of world energy consumption. Transportation primarily relies on petroleum, which supplies nearly 95 per cent of the total energy use of world transport and accounts for nearly 60 per cent of oil consumption. Hence, the transport sector has also been largely responsible for the pollution and GHG emissions. In 2005, the total final consumption of petroleum products for the world was 3,420 million tonnes of oil equivalent (mtoe), of which 60.4 per cent was consumed by the transport sector. Within the transport sector, road transport consumes the largest share of 76.0 per cent. Of the GHG emissions from the transport sector, carbon dioxide (CO₂) comprises the lion's share. In 2005, the share of

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CO₂ emission from the transport sector was about 23 per cent of the world's energy-related CO₂ emissions. Further, among all the end-use sectors, the growth of transport-related CO₂ emissions has been highest over the past three decades.

India is the world's 4th largest emitter, responsible for ~5% of the world's carbon emissions. Domestically India pledged to endeavour to reduce the emissions intensity of its GDP by 20-25% by 2020 in comparison to the 2005 level of emissions – these targets however are not legally binding. It is formally engaging with the Copenhagen Accord and the Cancun Agreement.

Some of the causes of increase in emission levels are.

- Motorization of Rural Transport
- Increase in Freight Traffic
- Distorted Transport Planning
- Relative Decline in Rail Transport Share in both Intra-city and Inter-city Passenger and Freight Traffic.
- Poor Standards of Fuel Efficiency and Emission
- Price Distortions in Automobile Fuel
- Declining Share of Non-motorized Transport (NMT)
- Heavy Dependence of Transport on Oil
- Absence of Adequate Low Carbon Substitutes

India is in transition towards peak mobility demand amid rapid economic growth, population growth and a rise in incomes. One of the greatest challenges faced by the transport sector is having in place the right infrastructure and services to fulfil the mobility needs, while reducing negative impacts locally and globally. India as an emerging economy is potentially a role model for future developing countries and has the capacity to design and implement a sustainable low carbon transport model. A low carbon transport strategy requires an integrated approach to identify measures that will achieve net benefits in enhancing mobility. Thus there is a need to identify the methodology which would help in sustaining the mobility needs without further increase in emissions. Knowing the low carbon mobility options it may be worthwhile to test any such option to identify the best alternative. In this endeavour it is important to build scenarios, through some existing choices and propose new ones.

Rest of the paper is presented in four sections. The identification of a low carbon mobility strategy is presented in the next section. Following this the translation of the mobility strategy through stated preference questionnaire is presented next. The process of administering survey and the results there in are presented in the next section. The emissions resulting from various low carbon mobility scenarios are identified for making the best plans are presented in the following section. Summary of the paper is presented at the end.

2. Review of low carbon mobility strategies

The purpose of this review is to find out the present state of knowledge pertaining to low carbon mobility and to identify the key issues to be addressed in this study. Various published materials have been reviewed here so as to obtain sufficient background knowledge for the present study and also to collect material which is essential for formulating the results of the study. The following aspects are covered:-

- a. Transport emissions: facts and figures
- b. Technological improvement measures
- c. Emission reduction scenarios.
- d. Calculation of emission levels: parameters and methods

2.1 Transport Emissions

Transport emissions are one of the reasons for CO₂ presence in the urban environment. The increase in the emissions is in many ways directly related to the development of emerging economies such as India. Timilsina and Shreshta (2009) studied the reasons behind the increase in CO₂ emissions in transport sector in Asia. This study finds that economic development, population growth, and transportation energy intensity, are responsible for driving up transport sector CO₂ emissions in Bangladesh, the Philippines, and Vietnam. In contrast, only economic development and population growth are responsible in the case of China, India, Indonesia, Republic of Korea, Malaysia, Pakistan, Sri Lanka, and Thailand. They further suggest that in order to address the CO₂ emissions reduction, a rapid switching to clean fuels and shifting to public transportation modes, such as bus, rail and water transportation, could help achieving this objective.

All the sectors of transport modes have to take part in emission reduction, as evident from Figure 1 the major onus would be on road transport (ITF Climate Change, 2010). Thus, this research focuses on challenges and opportunities of reducing energy consumption and CO₂ emissions from road transport in India. Table 1 shows that the GHG emissions saving of public transit per average passenger kilometer over individual modes of transit.

Table 1. GHG Emissions (Source: ITF Climate Change, 2010)

Mode of transport	Average Capacity (passenger/vehicle)	GHG emissions per average passenger-km
Pedestrian	1	0
Bicycle	1.1	0
Gasoline scooter (4-stroke)	1.2	64
Gasoline Car	1.2	244
Diesel Car	1.2	143
Diesel Bus	65	15
CNG Bus	65	16

2.2 Technological improvement measures

In addition to the above measures for improving public transportation facilities, various technological measures can be brought about to bring about low carbon mobility. These are as listed below :

a. Change in fuel used

- i) CNG
- ii) Ethanol
- iii) Biodiesel
- iv) Synthetic fuels can be produced from coal, natural gas, and biomass via the Fischer-Tropsch process, also known as coal-to-liquids (CTL), gas-liquids (GTL) and biomass-to-liquids (BTL), respectively. Synthetic fuels have similar characteristics to conventional fuels and can be used in existing vehicles and infrastructure.

b. Change in vehicle technology, such as changes in the drive train.

- i) Electric vehicles.
- ii) Hybrid vehicles.
- iii) Vehicles with fuel cells.

2.3 Emission reduction scenarios

There are presently only a few major studies of how GHG emissions can be reduced in the transport sector. Most studies only cover transport emissions at the national or sub-national level, not at a global level. However, the International Energy Agency (IEA) and the World Business Council on Sustainable Development (WBCSD) have offered global-level emissions reduction scenarios for the transport sector. There are three major emissions reduction scenarios for the transport sector. These are:

- a. Transport, Energy and CO₂: Moving Towards Sustainability (International Energy Agency, 2009)
- b. Mobility 2030: Meeting the Challenges to Sustainability (World Business Council on Sustainable Development (WBCSD), 2004)
- c. Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions (Cambridge Systematics, Inc., 2009)

2.4 Calculation of emission levels

Three parameters are taken into consideration to determine the amount of GHG emission (E) from the transportation sector:-

- a. The vehicle fuel consumption (F),
- b. Miles travelled (A)
- c. Carbon content of the fuel (C).

This is called the EFAC equation

$$E = \text{Emissions}_{(\text{Carbon})} = \underbrace{\left(\frac{\text{Gallons}}{\text{Mile}}\right)}_{\text{Fuel Consumption}} \underbrace{\left(\frac{\text{miles traveled}}{\text{Vehicle}}\right)}_{\text{Activity}} \underbrace{\left(\frac{\text{mass C}}{\text{gallon}}\right)}_{\text{Carbon Content}} = F \times A \times C \quad (1)$$

In all, there are four ways of estimating emissions from vehicular activity using commonly available data with local authorities. Depending on the available data, the user can choose to utilize the best. The key is to establish a baseline with available data instead of waiting for data availability. The four equations are shown below:

$$\text{Emissions (tons/year)} = \text{Number of Vehicles} * \text{Vehicle km travelled (km/year)} * \text{Emission factor (gm/km)} * 10^{-6} \text{ (tons/gm)} \quad (2)$$

$$\text{Emissions (tons/year)} = \text{Fuel Consumption per mode (liters/year)} * \text{Fuel Efficiency (km/liter)} * \text{Emission factor (gm/km)} * 10^{-6} \text{ (tons/gm)} \quad (3)$$

$$\text{Emissions (tons/year)} = \text{Passenger trips per mode (trips/year)} / \text{Passengers per km} * \text{Emission Factor (gm/km)} * 10^{-6} \text{ (tons/gm)} \quad (4)$$

$$\text{Emissions (tons/year)} = \text{Concentration } (\mu\text{g}/\text{m}^3) * \text{Vehicular Contribution } (\%) * \text{City Cross Sectional Area } (\text{m}^2) * \text{Average Wind Speed } (\text{m}/\text{sec}) * 60 * 60 * 24 * 365 \text{ (sec/year)} * 10^{-12} \text{ (tons}/\mu\text{g)} \quad (5)$$

2.5 Low Carbon Mobility(LCM) strategies for urban areas

The LCM strategies for cities vary. Globally there is an increasing perception on policies that would bring sustainability through such measures. Banister (2011) suggests that there is a considerable potential for lowering the carbon emissions by transport in cities. These range from creative planning of new developments and the regeneration of existing areas, through high densities, and proximity to work and facilities in neighbourhoods that provides safety and security. Nakamura and Hayashi (2012) discuss the strategy of avoid, shift and improve in

case of cities. They identify the linkages between the technology, regulation and information economy to help achieve the targets. China has become increasingly aware like many other countries in developing LCM strategies. The concept of low carbon towns is espoused by Li et al (2012). The approaches to develop low carbon towns include economic, social, layout, technology, and reuse. Each of these are introduced in the context of typical town planning and management in China.

2.6 Methodology for Achieving Low Carbon Mobility

From the review presented the following aspects emerge:

- Encourage the use of transit and NMT and improve infrastructure for the same.
- Impose low-carbon fuel standards.
- Congestion Pricing
- Land use and smart growth strategies
- Create incentives to develop low-carbon fuel infrastructure.
- Multimodal freight
- Transforming Consumer and Local Government Behaviour.
- Create incentives to advance new mobility options and enhanced regulation of transit.

In order to test some of these strategies there needs to be a study done to ascertain the effect of the policies on the low carbon mobility options. In the next section, the details of the case study are presented.

3. Case Study of Ludhiana city: low carbon mobility choices

In order to elicit user response for the low carbon mobility options, a stated preference survey is carried out. This process tries to find the changes in mode shares which may occur due to changes in choices which are caused by changes in attributes of modes. The survey was carried out in Ludhiana City in order to assess respondent opinion on parameters perceived important as discussed in the previous section. The questionnaire was designed accordingly. Towards this end, a stated set of choices are presented. The alternative choice for various modes includes: car, two-wheeler (motorised), bicycle, walk, paratransit, and transit.

The mode choice is done using multinomial logit (MNL) model (Koppelman & Bhat, 2006; Hensher et. al, 2005). The utility of each of the six modes is quantified through the attributes of the primary mode given below:

- Travel time
- Travel cost
- Frequency (Bus)
- Comfort
- Safety

Further, the utility associated with the attributes of the user/decision maker are: income of the household and number of automobiles in the household. The total utility of one of the choices (Car for example) is given by:

$$U = V(S_t) + V(X_c) + \varepsilon_c \quad (6)$$

Where $V(S_t)$ = deterministic part of the utility function related to the user and $V(X_c)$ is the part of utility function related to the attributes of the primary mode; ε_c random component or error term.

The utilities associated with the nest have similar components as the principal modes. However, for the mode related attributes, the following are considered. The attributes of the user are similar to those considered in the primary nests.

- Purchase price
- Running cost
- Range till refuelling/recharging
- Incentive (in terms of subsidy or discount)

3.1 Ludhiana city characteristics

- a. Vehicle ownership per 1000 persons: Ludhiana despite being a small urban center has higher automobile ownership (automobiles per 1,000 persons) than cities like Mumbai and Kolkata; 530 in Ludhiana as per 2005 data as compared to 69 in Mumbai and 64 in Kolkata whereas the national average is 72.
- b. Vehicle density Vehicle density per square km is one of the highest among million plus cities. One of the highest per sq km.
- c. Two wheeler ownership Ludhiana is one of the leading cities in two-wheeler ownership.
- d. Per capita energy consumption Per capita energy consumption is among the highest in the country. The per capita energy consumption of Ludhiana has reached the highest level at around 3.0 GJ per capita per year in 2005.
- e. Public private transport ratio As per 2005 calculations, Ludhiana displays an abysmally low value of .93 versus 11. 1 for Cochin, in terms of public to private passenger km ratio.
- f. Carbon intensity (kg CO₂ per capita) Calculations based on 2005 data show an extraordinary imbalance in per capita energy consumption with Ludhiana displaying a consumption of close to 2 GJ per person of energy use for personal vehicles. This is five times more than large metropolitan regions like Mumbai and Chennai and two times more than emerging cities like Bangalore and Hyderabad.
- g. Reasons for increase in automobile use
 - i. Population increase
 - ii. Greater affluence
 - iii. Lack of proper public transport pivotal cause

3.2 Questionnaire design

The experiment was designed as a combination of stated preference survey and a stated choice experiment. The stated preference data was to be used to assess respondent opinion on various parameters of the model and the stated choice experiment was designed to find out respondent choices for various projected scenarios. Further, the questionnaire design is as follows:-

- a. Questions 1-9 Personal attributes, including vehicle ownership and travel pattern.
- b. Questions 10-15 Private modes vs. public transport
- c. Question 16 NMT
- d. Questions 17-20 IC engine vehicles vs. electric vehicles

The mode choice experiment for four choice cards were shown pertaining to four scenarios. The respondents were shown four choice cards, each pertaining to a certain scenario:-

- i) Card 1: The first choice card, Card 1, was designed to seek user response in terms of mode choice when improved lanes for buses, cycling, and walking were provided. At the same time, the travel time for private modes was projected to have increased due to increased congestion.

- ii) Card 2: The second choice card, Card 2, was designed to seek user response in terms of mode choice when transit policy was also improved in addition to measures proposed in Card1.
- iii) Card 3: The third choice card, Card 3, was designed to seek user response in terms of mode choice when policies were made against use of cars in addition to measures proposed in Card2.
- iv) Card 4: The fourth choice card, Card 4, was designed to seek user response in terms of mode choice between an IC Engine vehicle and an electric vehicle.

Scenario 1 is the outcome of implementing the policy of Card 1 and so on.

3.2 Sampling issues

Some of the relevant data is presented here. The aspects that decide the sample size are error tolerance, confidence level and response percentage. The required minimum number of samples for the population of the city of Ludhiana with a confidence level of 95% and the response ratio of 50% was found to be 216 (Table 2).

3.3 Results of the choice model

The calibration of the choice model considering attributes of modes is done using NLOGIT software. The parameter estimates show appropriate signs for the attributes:

Table 2. Population vs. Sample size

Parameter	Population (Census of India, 2011)	Sample
Size (n)	1,613,878	216
Sex Ratio (Male/Female) (%)	54.2:45.8	51.38:48.61
Literarcy	85.38%	100%

- a. The values of coefficient of travel time and travel cost are negative as expected, with, frequency, comfort and safety having positive values.
- b. The coefficient of household income is maximum for two wheelers followed by paratransit. It is negative for buses, bicycling and walking, as expected
- c. The coefficient of motorised vehicles is maximum for two wheelers (Car being the reference mode), followed by walking, and negative for buses, bicycling and paratransit.
- d. For walking, the positive coefficient of motor vehicles is unexpected. However, this is probably due the reason that a large number of data has come from students and residents of cantonment (defence personnel township), for whom walking is not necessarily dependent on household income.

For the policy experiments the following observations are made:

- a. Independent paths for low carbon modes lead to an increase in people choosing the same, as seen from the response to Card 1
- b. While improvement in the quality of buses and increased frequency increases bus usage substantially, they also tend to take away share from NMT, as seen from the reduction in NMT share between Card 2 and Card 3.
- c. Policies against cars are likely to lead to increase in usage of two wheelers and not of transit as expected, as is seen from the variation in Car and two wheeler usage between Card 2 and Card 3 (Table 3)
- d. There is much higher preference for electric two wheelers than electric cars, probably due to the purchase price.
- e. Results shown in Table 4 for all users is a better indicator of shift from IC engine to electric vehicles, as compared to those which considers only existing car and two wheeler users.

The next section presents the implications of various scenarios in terms of the emission levels.

4. Emission calculations and comparison of various scenarios

Modal shifts have emerged due to various policy experiments depicted by cards as discussed in previous section. Further effect of these policies on the emission levels need to be calculated to understand the final outcome of such experiments. The emission calculations are made for the present and the future scenarios (for year 2030). There are a number of assumptions involved in these calculations. The actual emission values of the past are plotted along with the projected emission levels. Effects of the low carbon mobility interventions are compared.

Table 3. Summary of distributions of mode choices (in %ges)

	Car	2W	Bus	3W/Taxi	Bicycle	Walk
Present mode	10.57	38.76	17.18	4.40	18.50	8.81
Card 1 (Separate lanes for Bus and NMT)	21.29	24.53	25.92	0.92	23.14	4.16
Card 2 (Card 1 + better buses)	18.51	22.68	41.67	0.92	12.5	3.7
Card 3(Card 2 + Policy against car users)	10.64	30.55	40.27	0.92	12.5	5.09

Table 4. Summary of distribution of choices (in %ges) when electric vehicles are considered

	Car	Electric car	TW	Electric TW
Card 4 (choice between IC and Electric engine) All users	19.9	6.01	34.72	39.35
Card 4 (choice between IC and Electric engine) Only existing Car and TW users	84	16	64	36

4.1. Present Scenario

The calculations for present emissions based on the above are shown in Table 5. The calculations are based on current registration data and assume a distribution of small, medium and large cars as 60%, 25% and 15% respectively, for purposes of mileage to be used in calculation of fuel consumption.

Future vehicle user numbers are based on population estimates and mode shares calculated from stated preference survey data. The vehicle numbers are then calculated using assumed occupancy figures, giving suitable consideration to the number of daily trips made by public transport. The daily emissions are then calculated using standard values, reducing the values for considered improvement in efficiency. The total annual emissions including per capita emissions are then calculated.

Table 5. Existing vehicle emissions

Mode	Annual CO2	Annual CO2	Annual CO2
	×10 ⁶ , (tons)	×10 ⁶ , (tons)	×10 ⁶ , (tons)
	Scenario-1	Scenario-2	Scenario-3
Car	0.153	0.013	0.076
2 Wheeler	0.080	0.074	0.100
Bus	0.082	0.132	0.127
3W	0.020	0.004	0.004
TOTAL (kg/capita/yr)	119.07	79.262	109.271
Scenario-4 (kg/capita/yr)	100.13	69.03	92.16

4.2. Future Scenario:

These scenarios are those depicted in card 1, 2 and 3 of the SP survey, as discussed in Section 3. Further assumptions are as given below.

- i) No technological changes considered initially in vehicle engines, except improvement in engine efficiencies.
- ii) Number of petrol and diesel engine cars assumed to be in the 40 : 60 ratio
- iii) Two wheelers assumed to be a combination of scooters, mopeds and four stroke motor cycles, running on petrol.
- iv) Buses assumed to be running on diesel and three wheelers on petrol.
- v) The present mileage for cars calculated as a weighted mean of mileages of small, medium and large cars, using percentage figures of the same.
- vi) The same is done for two wheelers, taking the weighted mean of scooter, moped, and four stroke motorcycle mileage.
- vii) Based on global technology penetration projections and diffusion rates, improvement in engine efficiencies are assumed as 25.6 g/km for petrol engine cars, 23.85 g/km for diesel engine cars, 6.25 g/km for two wheelers, 7 g/km for petrol auto rickshaw, and 16.75 g/km for CNG/LPG auto rickshaw. The reduction in emission due to improved efficiency in buses is assumed to be 218.75 g/km.

Scenario 4

- i) Change in technology to electrical vehicles considered.
- ii) Number of electric cars and electric two wheelers based on mode shares calculated from stated preference survey data (Card 4).
- iii) Choices of existing car and two wheeler users considered for SP data
 - i) Ratio of cars to electric cars is 0.84:0.16.
 - ii) Ratio of two wheelers to electric two wheeler is 0.64:0.36.
- iv) Emissions of electrical vehicles not considered on life cycle basis.

Emission Calculations: Scenario 4: The emission calculations for Scenario 4 are a comparison of the scenario where only petrol and diesel are used as fuels and where electric engines are considered as alternate technologies for cars and two wheelers. The calculations below take into consideration choices of only car and two wheeler users. It is seen that the emissions are least for scenario 3 (when there are parking policies imposed against cars in addition to improved transit policy and buses along with independent lanes for buses, and dedicated paths cycling and walking). In Scenario 2, there is a marginal increase in emission levels, as compared to scenario 1 because improvement in buses tends to take away share from NMT too, and since walking and cycling are zero carbon modes, taking away share from them in favour of buses increases emissions marginally. However, it is clear that in case policies are to be made in terms of increased parking charges, and increased distance to parking,

such policies will have to be made for all private modes and not only cars, if transit and non motorized modes are to benefit from the same.

5. Summary and Conclusions

- i) This study has used existing data to firstly derive carbon emissions arising from transport use within Ludhiana and secondly to derive a set of carbon emissions scenarios based on stated choices, making suitable assumptions.
- ii) It is seen that the emissions are least for scenario 2 (i.e., when there is improved transit policy and buses along with independent lanes for buses, and dedicated paths cycling and walking).
- iii) When policies against cars are made in addition to the above, in scenario 3, there is an increase in emission levels, though it is still lesser than scenario 1. This is due to the increase in two wheeler usage in such a scenario.
- iv) Thus, it is clear that in case policies are to be made in terms of increased parking charges, and increased distance to parking, such policies will have to be made for all private modes and not only cars, if transit and non motorized modes are to benefit from the same.
- v) The number of respondents is 216, which corresponds to a margin of error of 6.68% for a confidence level of 95 % and a response ratio of 50 %.
- vi) The study can be extended by obtaining more stated preference data in order to reduce the margin of error by increasing the sample size.
- vii) In order to develop an effective low carbon mobility plan for the city, it is essential that effective policy be used in conjunction with the latest technological changes. The methods suggested in the low carbon methodology in section 2 can be used to design an effective roadmap for the same.

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