

Choosing between Global and Local Emission Control Strategies in Urban Transport Sector, Which way to go?

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Abstract

Cities are engrossed with response strategies for the control of local pollution from transport sector. However, as the transport sector has been growing as major GHG contributor, and there is an increasing scope for investment and support from the international financial institutions, cities often get into confusion on whether to go by local emission control strategies (LEMS) or adopt GHG mitigation strategies (GEMS).

This paper presents a comparison between GHG mitigation strategies and local emission control strategies and their potential in controlling non-target pollutant emissions in concurrence with their economic performance. Comparative analysis based on multiple constraint optimization model for Mumbai transport system planning for the next 20 years and incremental cost analysis had revealed that strategies targeting the mitigation of total suspended particulate matter (TSP) could also reduce carbon dioxide (CO₂) emissions (as non-target emission) and vice-versa. Co-benefits of emission reduction from local emission control strategies are higher compared to that of GHG mitigation strategies.

In the incremental cost analysis, both GHG mitigation strategies and local emission control strategies were found performing comparably. Thus, local emission control strategies with better emission reduction potential and also better local acceptance are more favourable than GHG mitigation strategies in long term transportation planning. Therefore, it is recommended that the development projects in urban transportation planning and management may consider local emission control strategies rather than GHG mitigation strategies. The co-benefits (CO₂ reduction) of local emission control strategies would still play the attraction for international funding agencies to invest in transport sector and also for CDM opportunities.

Key words: Co-benefits, GHG mitigation, incremental cost analysis, local emission control, transportation planning, total suspended particulates

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1. Introduction

Transportation is growing as one of the major contributors for Greenhouse Gas (GHG) emissions with about 18% of the anthropogenic carbon emissions coming from transportation sector. It is expected to grow further with traffic volumes bulging out with time. This has attracted international attention and in the recent past, due to the development of global environmental issues, research in urban transportation is increasingly concentrated towards the GHG mitigation strategies. In spite of the fact that worsening transportation systems lead to severe local problems like congestion, accidents, increasing travel time and distance and air pollution, more efforts are focused towards GHG mitigation from this very important sector. This resulted in increased inputs to reduce GHG emissions, putting less emphasis on local and more serious pollution. This phenomenon is gaining strength particularly with a view that the developed countries would come forward to invest on infrastructure development in the developing world under various Kyoto mechanisms.

Though adopting GHG mitigation strategies attracts more funding sources, it would be difficult satisfy the local policy makers and users, unless the local pollution is also controlled. At the same time, transport sector needs external support for its development and GHG mitigation strategies are an attraction to involve the developed countries and international financing agencies (Proost and Braden, 1998). In order to help the policy makers to go for the best bargains in long term transportation planning this paper analyses the incremental costs and benefits (in terms of co-benefits) of both GHG mitigation strategies and local emission control strategies in transportation planning for Mumbai, over a period of 20 years (1998-2020). Such comparative analysis would help decision makers while choosing the mitigation strategies to achieve environmentally sustainable transport systems with the least financial burden. This would provide a strong basis for the policy makers to put forward their interest without compromising on the interests of international development agencies that are willing to invest on transport sector in developing countries.

2. Overview of Mumbai Transport System

Mumbai is a rapidly growing urban centre with increased economic and commercial activity. The growth driven by rural-urban migration coupled with geographical constraints have resulted in many problems namely increasing travel demand and travel time, congestion and environmental pollution (WB, 1997). The population of Mumbai has increased from about 3 million in 1951 to about 11.9 million in 2001², a near four-fold increase (MMRDA, 2005). Increase in per capita income from Rs. 4359 (\$96³) in 1980 to 5525 (\$121.69) in 1989 (BMRDA, 1995) resulted in increased stock of personalized transportation modes. Car ownership has increased from 15 to 30 cars per 1000 population. With limited infrastructure development, this has further resulted in insufficient road availability to cater for the increasing travel needs. Vehicles growth is not in proportion with the road length and that resulted in increasing number of problems in Mumbai road transport system. Between 1984 and 1997, road length has increased from 1431 to 1752 km (by 321 km) where as the number of vehicles per kilometer length of road has increased from 278 to 416. As a consequence, congestion levels have increased substantially (Brandon and Hommann, 1996).

Major share of the Mumbai transportation needs are catered for by the suburban railway services provided by the Western and Central Railways and bus services provided by the BrihanMumbai Electric Supply and Transportation Undertaking (BEST). Public transport accounts for more than 80% of the journeys/trips with the rail system and buses having almost equal share between them. However, in terms of passenger kilometers, railways carry nearly four times the traffic carried by the buses because of higher average carrying capacity. Suburban rail services are operating along a network of some 300 km of electrified broad gauge provided by two zones of the Indian Railways transporting about 5.2 million suburban passengers per day through some 2000 daily electric motive unit (EMU) services (BMRDA, 1995). However, increasing per capita income, relatively higher affordability and availability of easy financing schemes in Mumbai have resulted in increased personalized vehicles with alarming trends of growth (Yedla, 2005).

² Population of Mumbai urban agglomeration is 16.36 million (2001)

³ 1 USD is equivalent to 45.4 Indian rupees

2.1 Pollution

Between 1981 and 2003, the number of registered vehicles has increased from 308,881 to 1,123,562 and the personal vehicles are expected to grow by five times in the next twenty years time (MMRDA, 2005; IGIDR, 2002). This has resulted in increased pollution generation in Mumbai. Air pollution measurement programs over the last decade showed a definite increase in average suspended particle matter (SPM by 24%) and oxides of nitrogen (NO_x by 20%) concentrations (CPCB, 1999; WB, 1997) and traffic emissions contribute the major fraction of the overall air pollution (Yedla, 2005). SPM concentrations (annual average and maximum of 24 hours) are much higher than WHO air quality guidelines of 140 microgram/ m^3 at many measuring sites in Mumbai viz. Chembur, Andheri. At certain times, the WHO air quality guideline for sulfur dioxide (SO_2) (80 micrograms/ m^3) is also exceeded. Emission of various pollutants from urban transportation is expected to grow 3-5 times in the next twenty years (IGIDR, 2002). Hence, it is essential to plan the transport sector expansion for the next 20 years and develop policies accordingly. Such planning should be aiming at energy saving, emission mitigation and improved transportation networks. However, it involves huge financial flow and involvement of international funding agencies will be unavoidable. GHG mitigation is one such dimension to the urban transportation system, which could catalyze the process of international involvement but that should not over ride the importance for local emission mitigation. In this context, the present study provides valuable input on which strategy to follow for uncompromised achievement of both goals of development and GHG mitigation with the involvement of international agencies and also targeting the mitigation of environmental pollution.

3. Methodology

Transportation planning involves fleet augmentation and infrastructure development. Assuming that infrastructure development costs would be comparable for different strategic choices in transportation planning, costs involved in augmenting the existing fleet was considered alone in the present planning study. Projected travel demands and number of vehicles for the next twenty years was taken from an earlier study by the author (IGIDR, 2002). New vehicles would be added to the existing fleet over the planning period so as to meet the projected travel demand. Distribution of different modes of vehicles to be added is carried out by means of a least-cost optimization modal. This is done while satisfying a set of constraints and minimizing the total costs involved. The costs considered include capital cost

and operational and maintenance costs of the vehicles that are added during the planning horizon and the operational and maintenance cost of the existing vehicles for the passenger transportation. All the costs are expressed as a total net present value to the base year. Linear Interactive Discrete Optimizer (LINDO) linear optimization model was used to determine the least-cost vehicular mix. The objective function and set of constraints are shown below (detailed formulation of objective function can be found in Yedla et al., 2005, Ram et al. 2005):

Objective function

To minimize total costs (capital, operational and maintenance cost) of new vehicles and operating and maintenance costs of existing as well as new vehicles.

$$\sum_{i=1}^I \sum_{d=1}^D \sum_{v=1}^V X_{idv} (C_{idv} - S_{idv}) + \sum_{i=1}^I \sum_{d=1}^D \sum_{v=-}^t \sum_{t=1}^T V_{idvt} * O_{idvt}$$

Variable

- X_{idv} —number of vehicle, mode i device d to be commissioned in year v
- V_{idvt} —km traveled by vehicle mode i , device d , vintage v , year t

Parameters

- C_{idv} --Discounted capital cost of a vehicle mode i , device d , vintage v
- S_{idv} --Discounted salvage value of a vehicle mode i , device d , vintage v
- O_{idvt} --Operating cost of vehicle mode i , device d , vintage v , year t

Travel demand constraint: The total travel service provided by existing and new vehicles in any year should be greater than or equal to the forecasted demand.

Vehicle capacity constraint: The total vehicle-km service provided by any type of vehicle should not exceed its maximum vehicle-km capacity of the total stock of that type of vehicle (i.e., existing and new units added).

Vehicle stock constraint: For candidate vehicles, total number of vehicles added to the transport system should not exceed the maximum limit on the number of vehicles that could be added during the planning horizon (which depends on maximum feasible penetration rate).

Emission constraint: Annual emission constraints: total emissions of the particular pollutant by all types of vehicles in a year should not exceed the target level of emission of that year; Overall emission constraints: total carbon dioxide emissions by all types of vehicles during

the planning horizon should not exceed the target level, depends on overall emission reduction.

The modal validation was done by Ram et al. by applying it for the control of oxides of nitrogen (NO_x) in Chinese cities (Ram et al., 2005). Total cost was optimized against a set of constraints like travel requirement constraints, capacity constraints and emission constraints to find the optimal solution. This least cost vehicular mix model was based on supply-side planning network. A similar approach is adopted for in the present study to assess both GHG and local emission mitigation strategies. This modal was used to determine the differences in incremental cost while adopting GHG mitigation strategies and local pollution control strategies. The potential of each strategy in controlling the non-target pollutants – carbon dioxide (CO₂) and total suspended particulates (TSP) for local and global strategies, respectively- is assessed by running the optimization model for different levels of mitigation targets.

3.1 Incremental Cost Analysis

Total cost of transportation was determined without putting any emission constraints, which is considered as BASE case. Total cost of transportation was determined for all emission mitigation strategies and BASE case as well by running the optimization model. Total emission of various pollutants was also determined under each strategy. Incremental cost of different levels of emission mitigation efforts both global and local is determined in terms of the difference in total transportation cost under the respective scenario. Incremental benefits are presented in terms of emission mitigation of both target and non-target pollutants. Incremental costs and benefits of global and local strategies are compared to identify effective strategies for urban transportation in Mumbai.

3.2 Transportation Planning for Mumbai

Potential alternative choices need to be identified and assessed for energy saving, emission mitigation potential and economic viability in order to feed into the optimization model. In the present planning exercise for Mumbai, all modes of transport (bus, car, 3-wheelers and 2-wheelers) are selected and the alternative options in the respective modes are chosen as candidate options for the optimal transport planning for a period of 20 years (1998-2020). Selection of these alternatives is based on their energy saving potential (ESP), emission

reduction potential (ERP) and economic performance (IGIDR, 2002). Based on a major research study by IGIDR (IGIDR, 2002) the following alternative options are chosen for the case of Mumbai⁴.

Alternative option 1: Buses run on Compressed Natural Gas (CNG)

Alternative option 2: Cars run on Compressed Natural Gas (CNG)

Alternative option 3: Replacement of 2-Stroke 2-Wheelers by 4-Stroke 2-Wheelers
(motorbikes)

Alternative option 4: Three Wheelers running on Compressed Natural Gas (CNG)

Alternative option 5: Battery operated (BOV) 3-Wheelers

Adoption of cleaner fuels is a dominant trend in urban transportation among the cities in Asia and CNG leads the list of cleaner fuels. CNG is particularly good alternative to control emissions from the in-use vehicles. Though other alternative fuels like LPG, Ethanol and Methanol are tried, they could not be as successful as CNG (Yedla, 2005). As cars and buses dominate the Mumbai traffic, it would be logical to consider buses and cars running on cleaner fuels. Shifting from two-stroke two-wheelers to four-stroke two-wheelers is a recent trend observed in Indian cities. For the large metro system in place, three-wheelers are the prominent feeder service in Mumbai (Ramanathan, 1999; TERI, 1997). With these circumstantial facts supporting the above mentioned criteria of energy saving, emission reduction and economic viability, the above listed five alternative options have been considered for the case of Mumbai to improve the transportation and control pollution.

3.3 Comparative analysis of emission mitigation strategies

The comparative analysis of the strategic approaches to the local emission mitigation (LEMS) against the GHG mitigation strategies (GEMS) is done in two steps. In the first step, transportation planning for the Mumbai transport system was done with restrictions on CO₂ emissions. Levels of CO₂ mitigation targets tried are 5%, 10%, 15% and 20% of the overall CO₂ emissions over the planning period. Under each CO₂ mitigations target the vehicular mix and the emission of other pollutants is monitored. In the next step, the transportation planning

⁴ A major research project carried out by the authors at the Indira Gandhi Institute of Development Research (IGIDR), Mumbai, India is one of such efforts in identifying the potential of various alternatives in urban transportation in controlling GHG and other harmful emissions. Details on the energy saving, emission mitigation potential and economic performance of these selected alternatives vis-à-vis other alternatives can be obtained from IGIDR, 2002.

was done with restrictions on total suspended particulate matter with different levels of emission mitigation at 5%, 10%, 15% and 20% of the overall TSP. In each step, while constraints are declared for one pollutant, the other pollutants under consideration are not controlled. Other parameters analyzed in all these three steps apart from the target pollutant include CO₂, sulphur dioxide (SO₂), NO_x, TSP and hydrocarbons (HC).

4. Results and Discussion

Cost of transportation was determined for all the cases of ‘no emission control’, ‘GHG mitigation strategies’ and ‘local emission control strategies’. Table 1 presents the total cost of transportation under all conditions of mitigation targets and different mitigation strategies. Total cost of transportation under both the strategies (GEMS and LEMS) is very close to each other. This could mean that, irrespective of the strategic approach adopted, the cost of transportation remains closely comparable.

Table 1: Total cost of transportation under different emission reduction targets and different mitigation strategies

Emission reduction target	Total cost of transportation in Billion USD	
	CO ₂ Mitigation Strategy	TSP Mitigation Strategy
0	4.854	4.869
5	4.862	4.882
10	4.876	4.897
15	4.891	4.920
20	4.908	5.027

4.1 Incremental costs

Incremental costs towards the emission mitigation efforts are calculated with “no efforts” as the base case. Table 2 presents the incremental costs for GEMS as well as LEMS. As clearly mentioned in the earlier sections, only the costs involved in augmenting the vehicular fleet is considered for the calculation of the incremental costs.

Table 2: Incremental costs calculated for global mitigation strategies and local emission mitigation strategies over the planning period (1998-2020)

Emission reduction target	Incremental cost (million USD)	
	GHG Mitigation Strategies	Local Emission Mitigation Strategies
5	8	13
10	22	28
15	37	51
20	54	158

While GHG mitigation strategies showed uniform rise in incremental costs over the range of mitigation efforts, local emission control strategies showed sharp rise in incremental costs at a higher emission targets. This behavior can be observed clearly from Figure 1.

Though the efforts under GHG mitigation strategies are more cost effective compared to that of local emission mitigation strategies, from the figure it can be inferred that up to 15% reduction target, both strategies (GEMS and LEMS) would show similar economic performance. The following sections examine the incremental benefits under these two strategic approaches in order to determine the best approach to the urban transportation in Mumbai.

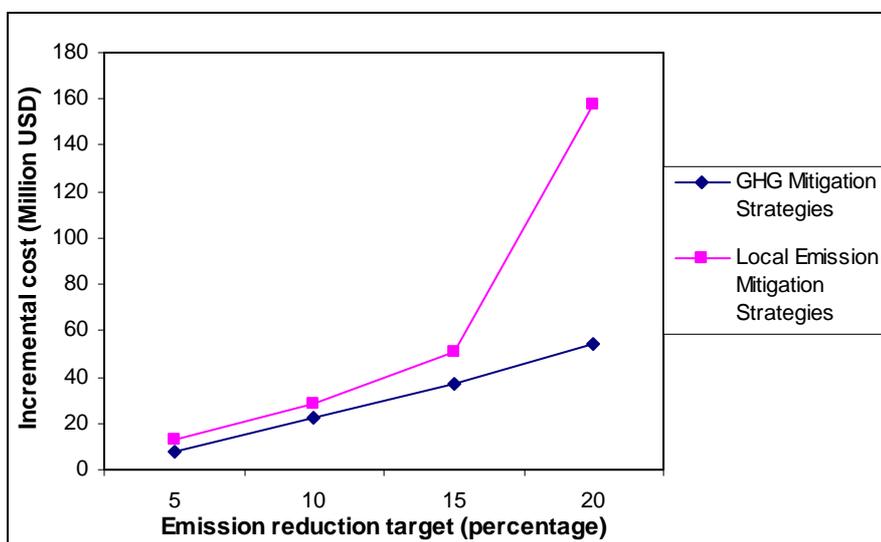


Figure 1: Trends of Incremental Cost for GHG mitigation strategies and local emission mitigation strategies

4.2 Incremental benefits

4.2.1 The case of “no reduction target”

In the base case scenario where no emission reduction is targeted, the optimization model chose CNG cars over CNG three-wheelers and CNG buses. It is observed that gasoline cars continue to occupy a major share of vehicular stock. Battery operated vehicles were selected in the beginning of the planning period (2005). CNG and gasoline cars replaced diesel cars. However, the share of diesel buses increases ignoring the CNG options completely, which could be due to the huge difference in capital cost of CNG and diesel buses. Under “no mitigation targets”, the annual emissions are expected to increase over the planning horizon

with intermittent control of their intensity. Under this scenario, over the planning horizon NO_x emissions are expected to increase by 5.5 times where as CO_2 and SO_x emissions increase by 4.4 and 4 times, respectively. TSP and HC are expected to increase by 3.3 times. This trend of emissions could be attributed to the increased share of CNG vehicles. Increased CNG usage would marginally increase the CO_2 emissions. However, this may results in decreased TSP and HC emissions. The persistence of diesel buses could lead to the increased emission of SO_x .

4.2.2 Incremental benefits

Incremental benefits of both the GHG mitigation strategies (GEMS) and local emission control strategies (LEMS) are determined in terms of direct benefits and indirect/co-benefits. Carbon dioxide reduction achieved under GEMS is considered a direct incremental benefit while the reduction of local pollutants namely suspended particulate matter, sulfur dioxide, oxides of nitrogen and hydrocarbons is considered as an indirect incremental benefit or co-benefit. Similarly reduction in carbon dioxide emission under LEMS is considered a co-benefit. Figure 2 to Figure 6 shows the incremental benefits both direct and indirect under the two strategic approaches considered viz. GEMS and LEMS.

The direct incremental benefit under GEMS is the reduction in carbon dioxide emissions. While the direct benefits are substantial under GEMS, the incremental benefits (co-benefits) in terms of CO_2 reduction under LEMS are comparable ranging from 45 to 73% of direct benefits under GEMS. It is interesting to observe that the co-benefits of both GEMS and LEMS in terms of TSP reduction and CO_2 reduction respectively are comparable with co-benefits of GEMS in terms of TSP reduction ranging from 43 to 76%. Figure 2 and Figure 3 presents these trends.

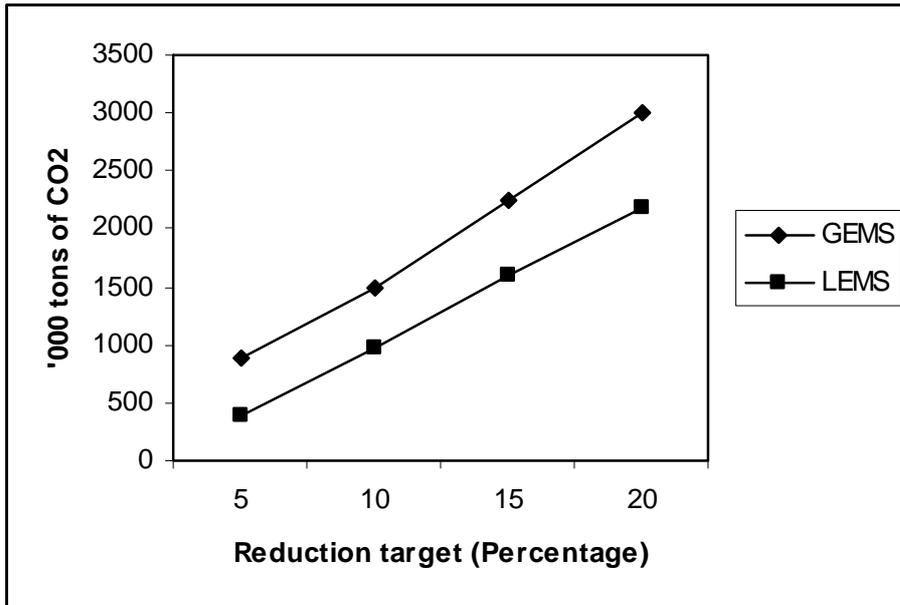


Figure 2: Incremental benefits in terms of CO₂ reduction under GEMS and LEMS

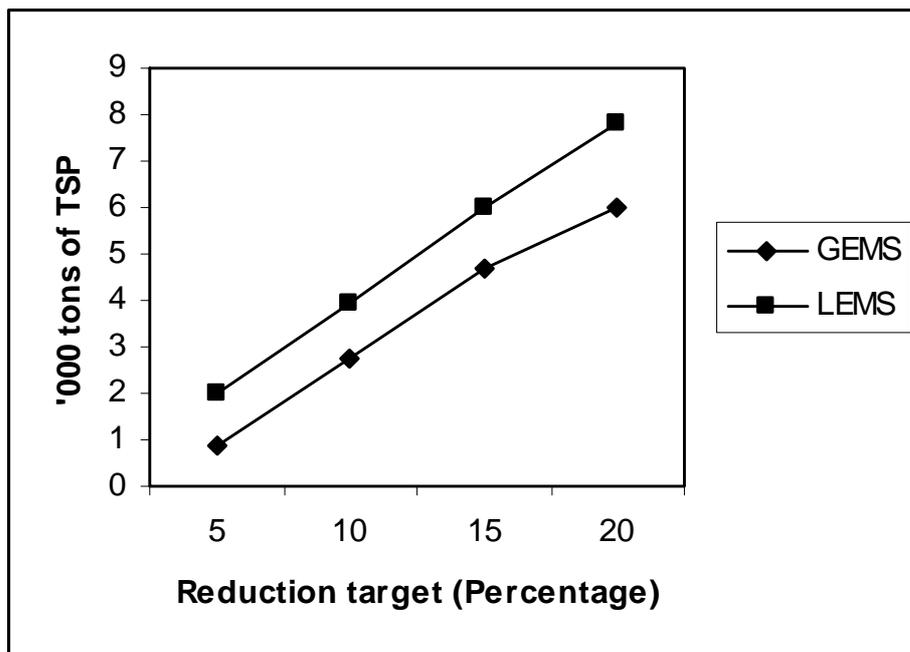


Figure 3: Incremental benefits in terms of TSP reduction under GEMS and LEMS

Increasing CO₂ mitigation targets have resulted in more penetration of alternative and cleaner transportation options (CNG, BOV, four-stroke vehicles). Battery operated three-wheelers (BOV) have dominated the number of three-wheelers added over the planning horizon at all levels of CO₂ mitigation targets. Under GHG reduction targets gasoline cars are expected to increase leaving the diesel cars least preferred. The stock of CNG cars did not change much with a certain level of technology penetration assumed at the beginning of the

planning period. The induction of CNG technology in buses is observed during the later part of planning horizon (2005 onwards).

Pereira et al (1997) found that transport sector in Venezuela is more effective in controlling CO₂ emissions and switching to larger capacity vehicles and conversion of gasoline vehicles to natural gas vehicles are considered more effective. It was also noticed in the literature that even when the natural gas or other alternative fuels are considered for CO₂ mitigation the options were chosen at a later time. Azar et al (2003), in their attempt to assess fuel choices in urban transportation sector in Sweden under stringent global carbon constraints by using a global energy systems model (GET 1.0) they found that despite the stringent CO₂ constraints oil-based fuels remain dominant in the transportation sector over the next 50 years. These observations from the literature complement the results of the present study.

Unlike the previous case of GEMS, TSP mitigation resulted in more shift towards the CNG technology and battery operated vehicles. The vehicular mix also suggests that diesel cars and buses are least preferred with no addition of them to the existing fleet of vehicles for the entire planning period. Unlike the case of CO₂ emission mitigation strategies, CNG three-wheelers are selected in LEMS though it is at a high level of mitigation targets (20% mitigation target). A similar trend is observed with CNG buses with increased share towards the later part of the time period. This is in spite of the higher capital investments required for CNG buses.

Reduction of SO_x, NO_x and HC are considered as indirect incremental benefits (co-benefits) under GEMS as well as LEMS. Figure 4 presents the trends of incremental benefits in terms of SO_x under both GEMS and LEMS. Under GEMS gasoline vehicles are predominant without much reduction in diesel vehicles. Where as in the case of LEMS the optimization model predominantly reduced the number of diesel vehicles. With the diesel vehicles contributing most of SO_x, LEMS performed much better compared to GEMS in controlling SO_x.

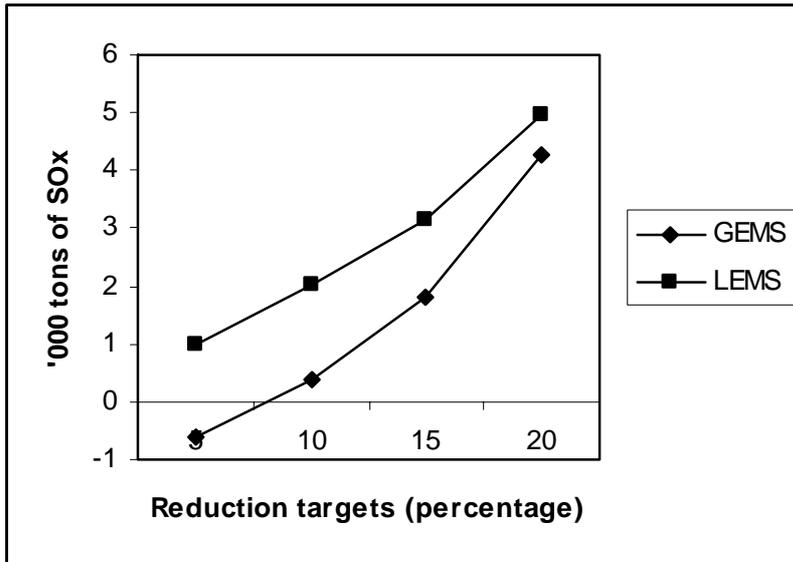


Figure 4: Incremental benefits in terms of SOx reduction under GEMS and LEMS

GHG mitigation strategies are expected to favour four-stroke engines and battery operated vehicles apart from gasoline vehicles. Whereas the model for the case of LEMS is expected to choose more of CNG vehicles along with gasoline vehicles ignoring the expensive battery operated vehicles. This result in higher benefits of NOx reduction under GEMS compared to that of LEMS. Figure 5 depicts these trends of incremental benefits in terms of reduction in oxides of nitrogen.

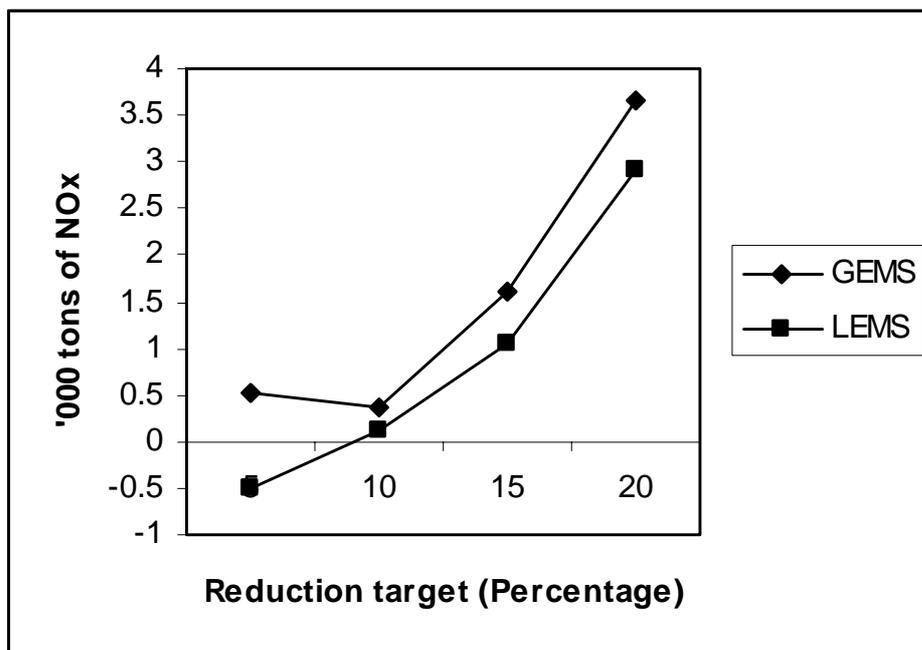


Figure 5 Incremental benefits in terms of NOx reduction under GEMS and LEMS

Both GEMS and LEMS show very similar benefits in terms of reduction in hydrocarbon emissions with LEMS performing slightly better compared to GEMS (Figure 6). It is interesting note that almost all benefits have their patterns changing at fifteen percent reduction targets.

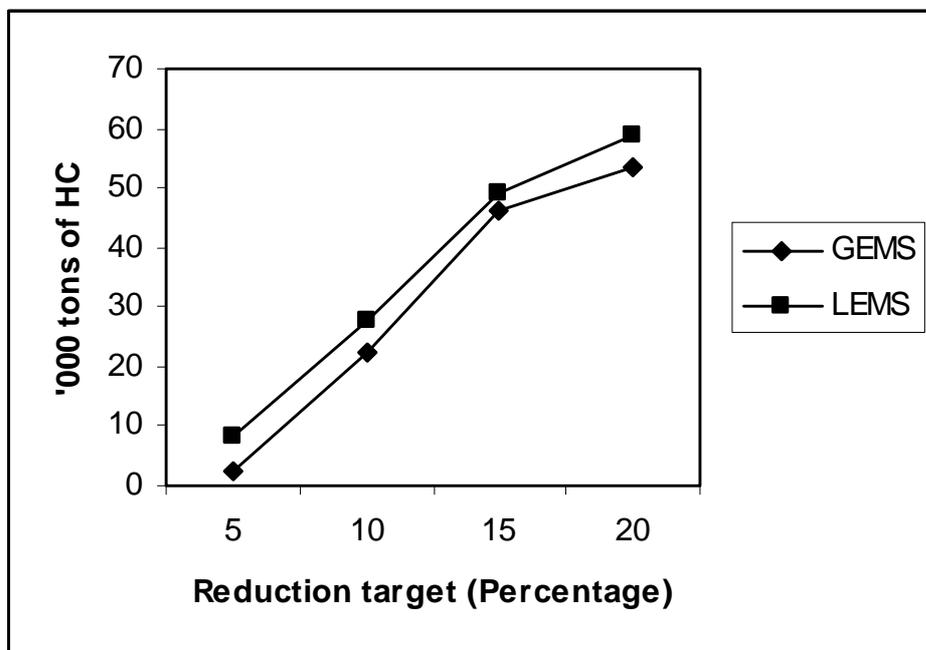


Figure 6: Incremental benefits in terms of HC reduction under GEMS and LEMS

While GHG mitigation strategies (GEMS) showed better indirect incremental benefits in terms of NO_x reduction, local emission control strategies (LEMS) resulted in better indirect incremental benefits in terms of SO_x and HC. Co-benefits of GEMS and LEMS in terms of TSP reduction and CO₂ reduction respectively are comparable with very marginal difference. While LEMS showed slightly higher incremental (co-benefits) benefits over GEMS, GEMS resulted in lesser incremental cost, though the difference is very marginal.

The dynamics of pollutant reduction is well explained by the cost per reduction of every ton of pollutant. It was reported by Yedla et al., (2005) that with a CO₂ mitigation strategy in urban transportation planning, cost per every ton of CO₂ reduction was in the range of 9.68 – 18 US\$. Local emission control strategies showed higher marginal abatement cost (MAC) for CO₂ mitigation (as non-target pollutant) with 31 – 72 US\$ for TSP mitigation targets of 5% – 20%. However at a moderate level of mitigation targets, MAC for carbon dioxide reduction under TSP and CO₂ mitigation strategies was found to be close. The difference between MAC values under different strategies is less between the mitigation target levels of 5%-15%. This demonstrates the potential of local pollution mitigation strategies (LEMS) in handling

the global emission mitigation. Therefore, employing local pollutant mitigation strategy in transportation planning would also cater for the needs of the GHG mitigation, which is a key factor in attracting international funding agencies to invest in transport infrastructure development in developing countries. By employing the local pollutant emission mitigation strategies (LEMS) in urban transportation planning it would be possible to handle both local and global pollutants with equal consensus from local policy makers and environmental activist and global actors.

Similar trends were observed in the case of Delhi transportation planning (IGIDR, 2002). However the intensity of emissions mitigation and economic performances vary from that of Mumbai, which could be attributed to the characteristic differences in the transport systems of Delhi and Mumbai.

5. Conclusions

This study examines various strategies to be followed in long term urban transportation planning and designing policies by adopting multiple constrained linear optimization model and incremental cost analysis. Global emission control strategies showed a slightly better incremental cost (lesser cost) compared to that of local emission control strategies (LEMS) in urban transportation of Mumbai over a period of twenty year (1998-2020). Adopting carbon dioxide mitigation strategies while planning for transportation system would cost less compared to that of local control strategies. Local strategies showed incremental costs very close and comparable to that GHG mitigation strategy. However, it was found that this observation is valid only up to 15% reduction target beyond which LEMS becomes increasingly expensive.

The analysis revealed that GHG mitigation strategies (GEMS) and local emission control strategies (LEMS) result in considerable indirect incremental benefits in terms of reduction in non-target pollutants like CO₂/TSP, SO_x, NO_x and HC. While GEMS showed better benefits in terms of NO_x, LEMS dominated with the benefits in terms of SO_x and HC. This makes LEMS a more effective strategy in terms of emission reduction. This presents a basis for the argument that the transportation projects can continue to look at local pollution mitigation approach and still derive effective GHG mitigation credits.

With more reduction of non-target pollutants (both local and global), competitive economic performance and preference from the local policy makers and civil societies, LEMS seems to be more effective than GEMS for long term transportation planning. Therefore, it would be better if the development projects in urban transportation planning and management consider the TSP mitigation strategy rather than the CO₂ or GHG mitigation strategy to achieve the same level of effect both locally and globally.

However, performance of these strategies depends on the choice of alternative transportation options, which in turn depends on the socio-economic and transportation characteristics of the city. Thus before generalizing the observations made in this study it is essential to validate the results for cities with varying characteristics. In such efforts the model has been applied to Delhi transport system, which is distinctly different from Mumbai transport system. Similar trends were observed for Delhi, though with varying intensities.

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