Aligning Energy use, Air Quality and Climate Change through Sustainable Development: A Case Study of Delhi

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ABSTRACT: High consumption of fossil fuels, increased greenhouse gas emissions and deterioration of local air quality have resulted from rapid industrialization and urbanization in India in the last decade. India has taken many initiatives to address these problems such as new automobile fuel policies, energy efficiency measures, promotion of renewable energy use, relocation of highly polluting industries, enforcing use of low emission fuels like CNG for public transport in large cities, and introducing metro rail networks in megacities. This paper highlights results of adopted policies in Delhi showing relationships between air quality and climate change and having sustainable development as the driving force with focus on environmental and social dimensions.

KEYWORDS
Air quality, Climate Change, Energy efficiency, mitigation policies, renewable energy, CNG, environmental and social development.

Alineando uso energético, calidad del aire y cambio climático vía desarrollo sostenible: El caso de Delhi en India

RESUMEN. La rápida industrialización y urbanización en India en la última década ha resultado en un alto consumo de combustibles fósiles, incremento en la emisión de gases de invernadero y deterioro de la calidad del aire. India ha emprendido varias iniciativas para resolver estos problemas como son nuevas políticas de combustibles de automóviles, medidas de uso eficiente de la energía, promoción del uso de recursos renovables, relocalización de industrias altamente contaminantes, uso de combustibles bajos en emisiones como el CNG en ciudades grandes, e introducción de redes de metro-ferrocarriles en mega-ciudades. El presente artículo resume los resultados de políticas adoptadas en Delhi que muestran los nexos entre calidad del aire y cambio climático teniendo como fuerza impulsora el desarrollo sostenible con énfasis en las dimensiones ambientales y sociales.

PALABRAS CLAVE
Calidad del aire, Cambio Climático, Eficiencia energética, políticas de mitigación, recursos renovables, CNG, desarrollo ambiental y social.

INTRODUCTION

During the last two decades, rapid industrialization coupled with urbanization in India and also in many developing countries has resulted in the emergence of industrial centers without corresponding growth in civic amenities and pollution control mechanisms. Concentration of industrial centers, consuming population and large vehicular fleets in cities has led to high consumption of fossil fuels – resulting in increased greenhouse gas emissions and deterioration in local air quality.

The number of cities over one million population has increased from 22 to 28 in India during 1990-2005. During the same period, the Indian gross domestic product (GDP) has grown by 148%, commercial energy supply by 118%, CO_2 emissions by 100%, NO_X by 90%, SO_2 emissions by 69%, and particulates by -5% [1], [2] [3]. It may be noted that local pollutant emissions (SO_2, particulates and NO_X) have grown much slowly than CO_2 emissions, as local pollution control has assumed policy prominence. The Government of India has targeted above 130% GDP growth during 2002-2012 (average annual growth rate of 8.1% for 2002-07, and 9.3% beyond), implying a rapid growth in CO_2 emissions, accompanied by a lower but reasonable growth in SO_2 and NOx emissions.

Development is a complex process and has its own possibilities and constraints in a large developing country like India with over a billion people and a multi-party democracy. India has taken substantial policy initiatives over the last 10-years to address the interlinked concerns of energy use, local air quality and climate change. These include a new automobile fuel policy with tightened emission norms, energy efficiency measures, renewable energy promotion, relocating polluting industries away from urban centers, commissioning all public transport on low emission fuels such as compressed natural gas (CNG) in 7 large Indian cities, and initiating metro rail networks in mega cities. In the present paper we discuss the various links and disjoints in energy use, air quality and climate change and how sustainable development could enhance their alignment.

NEXUS BETWEEN AIR QUALITY AND CLIMATE CHANGE

Air quality is usually dependent upon the concentration of local pollutant traces in the air. Some of the important pollutants are sulfur dioxide (SO_2), nitrogen oxides (NO_X), suspended particulate matter (SPM) of different sizes, lead, carbon monoxide (CO), non-methane volatile organic compounds (NMVOC), and tropospheric ozone. Fossil fuel combustion is the main source of these pollutants. Fossil fuel combustion is also the main source of greenhouse gas emissions accounting for more than 90% CO_2 emissions [3]. The local air quality in large urban centers is more determined by transport sector, while large point sources (LPS) emissions play a more prominent role in GHG emissions.

The global and local emissions have varied sectoral and fuel-based dominance, as well as regional distribution patterns in India. Coal consumption in power sector dominates CO_2 and SO_2 emissions, while power and road transport equally contribute to NO_X emissions. Rice cultivation and livestock related emissions from the agriculture sector dominate CH_4 emissions, while synthetic fertilizer use in the same sector is the major source of N_2O emissions. PFC emissions are dominated by C_2F_6 and CF_4 emissions from aluminium production. The majority of HFC emissions are contributed by HFC-23, a by-product during the production of HCFC-22 that is widely used in refrigeration industry. CO emissions have dominance from biomass burning. Particulate emissions are dominated by biomass burning (residential sector), road transport and coal combustion in large plants. These varied emission patterns provide interesting policy links and disjoints, such as - which and where mitigation flexibility for the Kyoto gases, exploring co-benefits of CO_2 and SO_2 mitigation, and technology and development pathway dependence of emissions.

An analysis of emissions from LPS in India indicates that there is a strong nexus between local air quality and GHG emissions presently [4]. There are mitigation opportunities such as fuel switching, energy efficiency, low or no-carbon technology penetration that address both these concerns simultaneously. However there may also be separate policy options for addressing both these concerns individually, such as low sulfur diesel, FGD, ESP, that would de-link local and global emissions in future. National policy priorities and cost differentials would determine which of these routes are adopted.

LINKING DEVELOPMENT, AIR QUALITY AND CLIMATE CHANGE: CNG CONVERSION IN DELHI

Global climate change policies in terms of GHG emission reductions in urban transportation can facilitate that local ancillary benefits are gained in terms of reduced local air pollution. A number of international and country studies have estimated these benefits and have concluded that in many developing countries local air pollution reduction benefits are large compared with mitigation costs. These benefits might even be greater than previously assessed if the climate change benefits such as reduced GHG emissions are also taken into consideration. Most measures that reduce PM_{10} pollutants such as cleaner road transport fuels and vehicles, stricter monitoring of power plant emissions, energy efficiency improvements, also reduce CO_2 emissions. A case of policy driven fuel switch from diesel to compressed natural gas (CNG) for all public transport in Delhi is presented to highlight this nexus.

Delhi, the national capital of India, has an area of 1483 square kilometers and over 13 million people. Population growth has been extraordinary, increasing from 1.7 million in 1951 to over 13 million in 2000 and is expected to reach 220 million in 2021 (Delhi Statistical Handbook). The urban structure is polynucleated with widespread distribution of industries, commercial and residential areas.

The characteristic feature of the transport system is the pre-dominance of private vehicles, which comprise about 90% of the total vehicles in Delhi, but cater to around 40% of the total traffic load. On the other hand, buses cater to around 55% of the total traffic load, but constitute only 1.2 % of the total vehicles in Delhi (the remaining 5% of the traffic is catered by cycle rickshaws and cycles) [5].

Source	1970-71	1980-81	1990-91	2000-01 (projected)
Industrial	56	40	29	20
Vehicular	23	42	63	72
Domestic	21	18	8	8

Table 1. Sources of air pollution in Delhi (in per cent)
(Source: White Paper on Pollution in Delhi with an Action Plan, 1997).

This pattern of development has resulted in vehicular emissions being increasingly responsible for the deteriorating air quality in Delhi (table 1). Diesel, gasoline and compressed natural gas (CNG) are the main autofuels used in Delhi currently. Personal transport like two-wheelers run on gasoline and the public/ commercial transport like buses, three-wheelers, taxis, light and heavy-duty vehicles used to run on diesel till 2002. Majority of personal cars still run on diesel since it is 35% cheaper than gasoline. The mileages are almost the same for diesel and gasoline cars.

In 1998, the Supreme Court of India passed orders that gave a time frame for implementing measures to control vehicular pollution in the National Capital Region, including Delhi. The orders included, among others, the following:

• Replacement of all pre-1990 autos and taxis with new vehicles using clean fuels by March 31, 2000.

• Financial incentives for replacement of all post-1990 autos and taxis with new vehicles on clean fuels by March 31, 2001.

• No buses more than eight years old to ply except on CNG or other clean fuels, by March 31, 2000.

• Entire city bus fleet (Delhi Transport Corporation owned and private) to be steadily converted to single fuel mode on CNG by March 31, 2001.

• Gas Authority of India Ltd. to expand its CNG dispensing capacity from nine stations to 80 by March 31, 2001.

These orders have been since implemented and have resulted in reducing local and GHG pollution loads in Delhi, while simultaneously making the city transport more sustainable. If we analyze the public policies to mitigate various types of emissions in Delhi over the last decade, we find that the following energy sector related policies have been implemented:

• Introduction of low sulfur diesel (from 1% max to 0.25% max sulfur by volume) during 1996-1998.

• 1160 industries closed or relocated during 1997-1999 including hot mix plants, arc induction furnaces, brick kilns.

• Supply of only premix petrol in all petrol filling stations to two stroke engine vehicles; ban on supply of loose 2T oils since 1998.

• Phasing out/ban on old commercial/transport vehicles (>15 yrs) since 1998.

• Introduction of Euro I equivalent fuel emission norms for all private non-commercial road vehicles from 2000, and Euro II from 2005.

• Introduction of low sulfur gasoline (from 0.2% max to 0.05% max sulfur by volume) during 2000.

• Buses more than 8 years phased out or to ply on compressed natural gas (CNG) since 2000.

• The three coal based power plants to switch over to beneficiated coal.

• Introduction of very low sulfur diesel (from 0.25% max to 0.05% max sulfur by volume) during 2001.

• Phasing out of old (and thus inefficient) 3-wheelers since 2001.

• Gradual reduction in aggregate technical and commercial (AT&C) losses for electricity distribution in Delhi since 2002.

• Conversion of all diesel-driven public road transport to CNG completed during 2000-2003.

• Gradual introduction of metro rail transport in some congested areas since 2002.

• Gradual replacement of traffic lights at major intersection with flyovers, including the entire Ring Road since 2001.

• Providing timer indicators at traffic intersections to encourage engine turn-offs for longer waiting periods.

A closer look at these policies highlights sustainable development of Delhi as the driving force, with more focus on the environmental and social dimensions of development. In the short term, some measures did cause economic hardships to many individuals such as sunk investments and sudden need to upgrade their technology stocks. However from a longer and broader perspective, the citizens of Delhi have benefited from these measures. The results of these policies on annual emissions of PM_{10}, SO_2 and CO_2 during 1990-2005 are provided in figures 2-4, while figure 1 provides the energy consumption trend in Delhi over 1990-2005. The total registered road vehicle population in Delhi has risen to over 5 million in 2005 from a mere 1.8 million in 1990. Out of this, 2-wheelers (scooters and motorcycles and mopeds) account for the highest share at 64%, followed by cars and jeeps at around 30%, 3-wheelers 2% and buses around 1%. The emissions have been reigned in to some extent even when energy consumption is rising. SO_2 emissions in 2005 are much lower than those in previous years. PM_{10} emissions have also declined since 2000[1]. CO_2 emissions are rising but their growth rates have reduced during 1995-2005 (figure 5).

1 Liquefied petroleum gas (LPG) is the dominant fuel used in 68% households, kerosene in 24% and solid fuels (mainly biomass) only in 7% (http://des.delhigovt.nic.in/Publications/HB2004/hb2004I.pdf on 13 June 2006). Therefore indoor air pollution may not be that large a pollution source in Delhi.

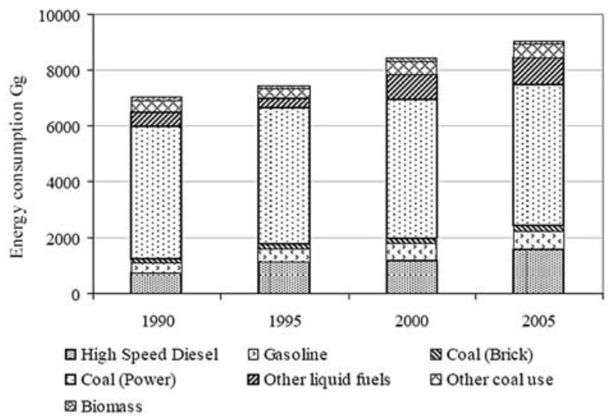

Figure 1. Energy consumption trends in Delhi, Gg per year.

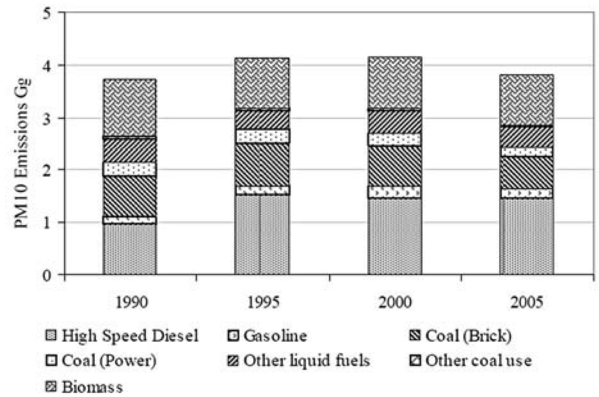

Figure 2. Source specific PM10 emission trend for Delhi, Gg per year.

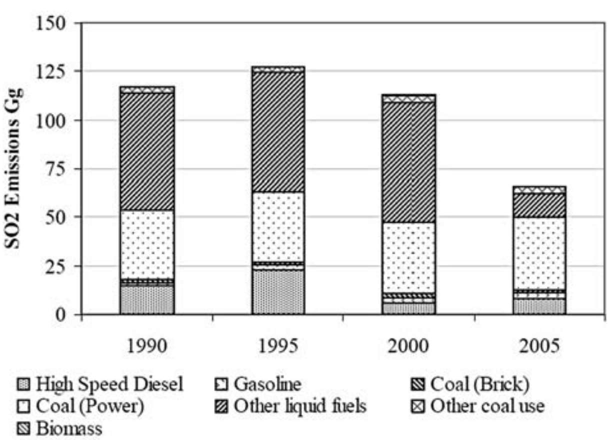

Figure 3. Source specific SO2 emission trend for Delhi, Gg per year.

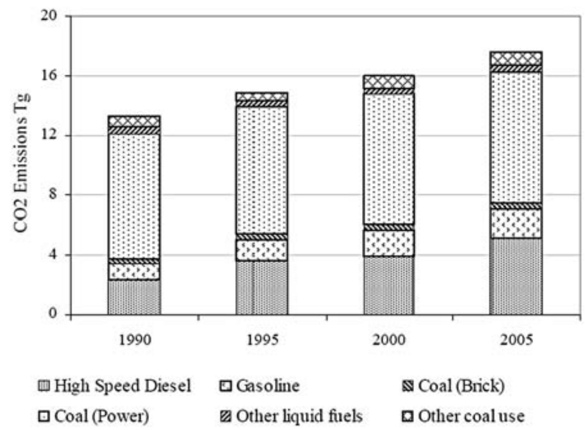

Figure 4. Source specific CO2 emission trend for Delhi, Tg per year.

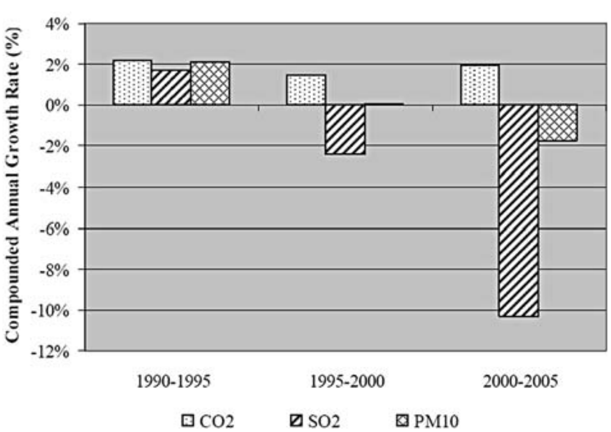

Figure 5. Compounded annual growth rate of emissions in Delhi.

THE DELHI EXPERIMENT AND DEVELOPMENT AND CLIMATE CHANGE LINKAGES

There are several positive spillovers of the CNG experience in Delhi. While there could be debate on the choice of CNG as a solution to air pollution, there is no doubt that the entire transition process heightened the awareness of the common public about the negative externalities of air pollution, especially the adverse health impacts, and the need to find solutions. This is an important step towards sustainable development process in a developing country, where other socio-economic goals have higher priority, often at the cost of the environment.

The use of CNG has improved the air quality in Delhi, especially in terms of reduction of the suspended particulate matter. At the same time, it has also led to reduction in CO_2 emissions since the carbon content of CNG is lower than that in diesel, the fuel that it has replaced. This amply demonstrates use of a single technical solution to solving air quality and climate change concerns simultaneously.

Moreover, the CNG experience has also expedited the process of adopting other measures for improving the transport system in Delhi, which would have considerable environmental benefits. The most important of these measures is the development of the Metro system in Delhi. This system is being developed to improve the public transport in Delhi as also to reduce the traffic congestions, especially at traffic intersections. This would have positive environmental benefits, especially due to the reduction in emissions from the idling vehicles at the intersections, and also have developmental benefits, like reduced health problems as well as reduction in wastage of resources. For instance, a study by the Petroleum Conservation Research Association estimated in 1998 that Delhi wastes $300,000 in fuel daily just through vehicles idling at traffic lights. These issues could be addressed to a large extent through the Metro system. And, this process has been expedited due to public demand for cleaner Delhi air, with all institutions feeling the need to address the problem. The CNG experience and low sulfur diesel provided the immediate solutions that would be strengthened by the Delhi Metro in the long-term.

Similarly, the CNG infrastructure development in the national capital and seven other large Indian cities has been substantial and it would be appropriate to conclude that India has leapfrogged in this process of technological adoption and diffusion by at least a few years.

The Delhi experience highlights aligning the common mitigation opportunities for improving local air quality and climate change mitigation through sustainable development. Policy optimization, under simultaneous constraints on carbon and SO_2, shows diverse results depending on the assumptions about the future carbon price [6]. Under high carbon prices, in the range higher than $40 per ton of carbon in the year 2010, there is significant substitution of coal by natural gas in industry and power sectors, although little substitution occurs for the oil use in transport sector. Thus, significant mitigation of SO_2 happens under high carbon price future, although urban hotspots of high SO_2 concentrations persist. Thus, a separate SO_2 mitigation policy for urban air quality is still needed. Under low carbon prices, carbon mitigation is only marginal and so is the mitigation of associated SO_2 emissions. Besides, low carbon price does not induce significant fuel or technology substitutions, which is the main source of SO_2 mitigation under high carbon price regime. Thus, policy optimization under simultaneous carbon and SO_2 constraints still indicates separate policy regimes for dealing with local and greenhouse gas mitigation.

FRAMEWORK FOR AIR QUALITY IMPROVEMENT AND CLIMATE CHANGE MITIGATION

Our analysis shows that while emissions from India are growing, their growth rates are declining since 2000 [3]. The contributing factors to these declining growth rates for CO_2 emission include improving performance of coal-based power plants, policies pushing more energy efficient automobiles, targeted energy efficiency measures by large producers of energy intensive commodities like the Steel Authority of India that produces nearly two thirds of Indian steel, and changeover to dry cement production process by increasingly consolidating Indian cement industry. N_2O emission growth rate is declining marginally as synthetic fertilizer use is becoming more efficient. In agriculture, agriculture extension services promoted by the Government for educating and helping farmers for more efficient and effective utilization of input resources have contributed to reducing emissions of methane and N_2O per unit of production.

The policies mandating successive reduction in sulfur content of petroleum products have been a key contributor to reduced SO_2 emissions over past five years, while the relative reduction in TSP emission is mainly due to enforcement of the use of electro-static precipitator (ESP) in power plants and industries using coal, and efficiency measures in industries. The reduction in growth rate of carbon monoxide emission is more gradual since cleaner technology and fuels are penetrating relatively slowly in rural cooking where a vast population still continues to use inefficient biomass stoves with below 10% combustion efficiency. This is a vital area for technology strategy for three reasons: a) the energy use via these technologies represent nearly a quarter of total energy use in India, b) the indoor air pollution (mainly particulate and carbon mono-oxide) caused by these technologies is a major cause of health damage among the low income population, c) from market perspective these technologies offer a sizable "no regret" potential. The technology policies during past two decades to harness these "low hanging fruits" have met with myriad barriers but should however be pursued with fresh institutional initiatives.

Another important insight is the differential growth rates for GHG and local air pollutant emissions. The former, especially the dominant CO_2 emissions, are growing faster than the latter. The driving forces of emission growths are also inherently different. While formal public initiatives are being increasingly instituted to mitigate local pollution, the GHG emission intensity is improved mainly due to enhanced competition in the wake of economic reforms such as energy efficiency measures by companies. The expectations of higher activity levels in the coming years, namely more power generation, increased industrial outputs and more private transport, imply that GHG emissions would continue to rise in absolute terms, though the emissions intensity of the economy would continue to improve. Table 2 provides an overall framework in the Indian context to align air quality improvements and climate change mitigation through sustainable development policies.

CONCLUSIONS

The paper has highlighted the strong nexus between energy use, air quality, development and climate change. Energy efficient and environmentally cleaner technologies, cleaner fuels and institutional measures offer solutions to these concerns. However before embarking on a new technology that addresses a particular source of air pollution, it is essential to verify that

PARAMETERS	LARGE POINT SOURCES OF EMISSION	MANY, SMALL BUT CONCENTRATED SOURCES	MANY, SMALL AND DISPERSED SOURCES
Sectors	Energy, industry, land fill	Urban transport and households	Agriculture, rural households
Main emissions	CO_2, SO_2, SPM, CH_4	CO_2, SO_2, SPM, NO_X	CO_2, CH_4, N_2O
Policies	Emission targets, Taxes, Technology Push	Technology/ Fuel standards, Technology Push, Clean fuel	Clean substitutes, Improved cultivar, low CH4 rice / cattle feed
Measures	Emission rights, accounting, clean technologies	Efficient engine, low sulfur fuel, catalytic converter, monitoring and enforcement	Local institutions, user education/ training, information program, market development
Key Institutions	Government, Industry Associations	Government, vehicle manufacturers, consumers	Agriculture universities, Agriculture extension services, Government
Implementation Strategy	Standards, permits, emission accounting, monitoring, correction	Standards, monitoring, enabling environment, manage lobbying	RD&D projects, communication, distribution network

Table 2. Framework for aligning air quality improvement and climate change mitigation.

emissions from that source indeed contribute a sizeable portion of the ambient pollutant concentration.

Putting the infrastructure in place is a pre-requisite for the successful implementation of policies to align development, air quality and climate change, be it Euro IV norms for all vehicles, Metro rail, CNG, ultra-low-sulfur diesel, or coal washeries. This would include the production facilities, supply and distribution networks, regulatory and administrative mechanisms, training and awareness of the users and mechanics for proper use, maintenance and repair. This was a major point of controversy in the CNG issue.

It is also crucial that a longer-term analysis of the cost-effectiveness of the different technologies is carried out before adopting a specific technology. For instance, it has been argued that advances in diesel engines and diesel engine emission control devices that use clean diesel fuel formulations might enable buses in developing countries to reduce emissions. Over the next five to ten years, the comparative advantage of CNG buses in terms of environmental impact may be reduced by advanced diesel after-treatment technology. When particulate traps and catalytic NO_x reduction (either by lean NO_x catalysts, NO_x absorbers) will be introduced in the US and in Europe, diesel buses may be more or less considered as comparably clean. However, the necessary prerequisite would be the availability of high-quality diesel fuel with extremely low sulfur content (http://www.cai-infopool.org/bus_cng-vs-diesel.htm). On the other hand, future CNG engine technology has the potential to reduce the energy consumption penalty and cost differential as compared to the ultra-low-sulfur diesel fuel. For instance, the basic disadvantage in energy consumption, resulting from the fact that CNG bus engines are equipped with spark ignition and have therefore lower compression ratios than diesel engines, can be compensated, to some extent, by direct-injection technology, which is currently under development. Therefore, understanding these dynamics of technological changes and the new technologies that are in the pipeline is crucial before choosing a specific technology to prevent a technology lock-in. In this context, the use of models has assumed immense significance, since they help to do a cost-effective study of different technologies under alternate scenarios.

Our analysis is a pointer to the future emission pathways for India wherein energy consumption, local air pollutant and GHG emissions, although connected, may not move in synchronization and therefore would require alignment through well crafted development and environment strategies.

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