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India's Economic Growth and Environmental Sustainability

What Are the Tradeoffs?

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Abstract

One of the key environmental problems facing India is that of particle pollution from the combustion of fossil fuels. This has serious health consequences and with the rapid growth in the economy these impacts are increasing. At the same time, economic growth is an imperative and policy makers are concerned about the possibility that pollution reduction measures could reduce growth significantly.

This paper addresses the tradeoffs involved in controlling local pollutants such as particles. Using an established Computable General Equilibrium model, it evaluates the impacts of a tax on coal or on emissions of particles such that these instruments result in emission levels that are respectively 10 percent and 30 percent lower than they otherwise would be in 2030.

The main findings are as follows: (i) A 10 percent particulate emission reduction results in a lower gross domestic product but the size of the reduction is modest; (ii) losses in gross domestic proudct from the tax are partly offset by the health gains from lower particle emissions; (iii) the taxes reduce emissions of carbon dioxide by about 590 million tons in 2030 in the case of the 10 percent reduction and 830 million tons in the case of the 30 percent reduction; and (iv) taken together, the carbon dioxide reduction and the health benefits are greater than the loss of gross domestic product in both cases.

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India's Economic Growth and Environmental Sustainability: What Are the Tradeoffs?

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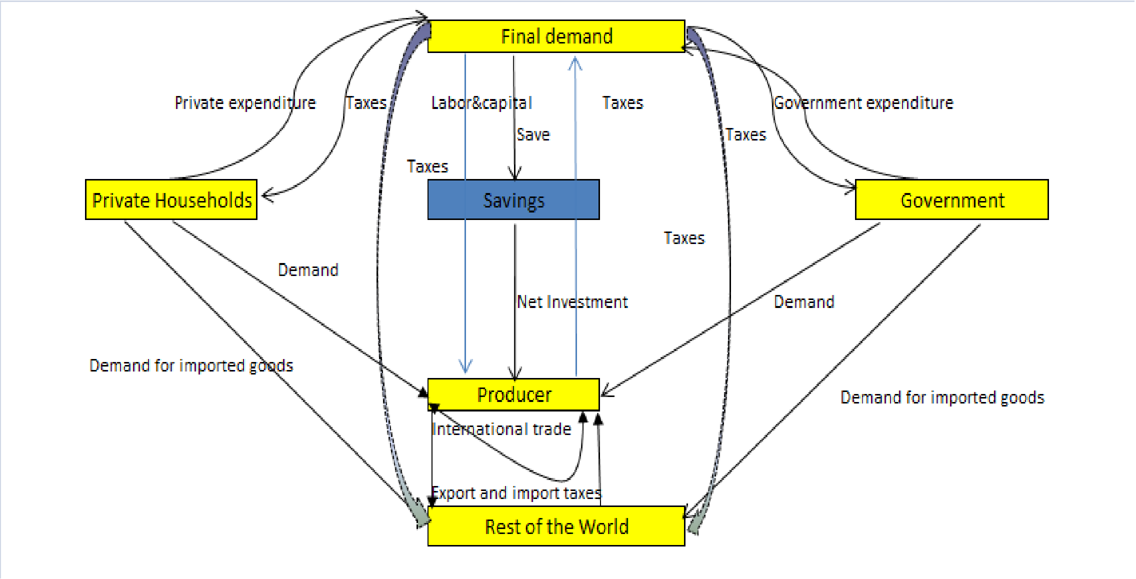
Introduction

1. This report analyzes some of the key tradeoffs between economic growth and environmental sustainability for India. The tool used for this analysis is a Computable General Equilibrium (CGE) model.[3] CGE models are powerful tools for tracing how changes in one sector are propagated through the rest of the economy, affecting dependent sectors, patterns of trade, income and consumption and the fiscal and international financing needed for macroeconomic stability and growth goals (see Figure 1).

Figure 1: Description of CGE Model



2. CGE models are also widely used to analyze the aggregate welfare and distributional impacts of policies whose effects may be transmitted through multiple markets. They can also be deployment to analyze the effects of specific instruments or a combination of instruments. Examples of their application may be found in areas as diverse as fiscal reform and development planning (see, e.g., Perry et al 2001; Gunning and Keyzer 1995), international trade (Shields and Francois 1994; Martin and Winters 1996; Harrison et al 1997), and, increasingly, environmental regulation (Weyant 1999; Bovenberg and Goulder 1996; Goulder 2002) (see Box 1).

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[3] CGE models are simulations that combine the abstract general equilibrium structure formalized by Arrow and Debreu with realistic economic data to solve numerically for the levels of supply, demand and prices that support equilibrium across a specified set of markets. A CGE model consists of a set of equations representing the behavior of all major sectors in an economy. These describe inter-sectoral linkages and the pattern of income and expenditure in the economy.

Box 1: CGE Models and Environmental Policy

Policies aimed at significantly reducing environmental problems such as global warming, acid rain, deforestation, waste disposal or any degradation air, water, or soil quality may imply costs in terms of lower growth of GDP, a reduction in international competitiveness or in employment. The implied change in relative prices will induce general equilibrium effects throughout the economy. For this reason, it is useful to evaluate the effects of environmental policy measures within the framework of a CGE model. Although partial equilibrium models make it possible to estimate the costs of environmental policy measures, taking substitution processes in production and consumption as well as market clearing conditions into account, CGE models additionally allow for adjustments in all sectors, enabling us to consider the interactions between the intermediate input market and markets for other commodities or intermediate inputs, and thereby complete the link between factor incomes and consumer expenditure.

Since the first environmental CGE models appeared (Forsund and Storm, 1988; Dufournaud et al., 1988), the literature has included applications in many major areas, such as: (a) models used to evaluate the effects of trade policies or international trade agreements on the environment (Lucas et al., 1992; Grossman and Krueger, 1993; Madrid-Aris, 1998; Yang, 2001; Beghin et al., 2002) and for diverse applications in the area of the Global Trade Analysis Project (Hertel, 1997); (b) models to evaluate climate change, which are usually focused on the stabilization of CO2, NOx and SOx emissions (Bergman, 1991; Jorgenson and Wilcoxen, 1993; Edwards et al., 2001); (c) models focused on energy issues, which usually apply energy taxation or pricing to evaluate the impacts that changes in the price of energy can have on pollution or costs control (Pigott et al., 1992); (d) natural resource allocation or management models, whose objective is usually the efficient interregional or inter-sectoral allocation of multi-use natural resources—for example, allocation of water resources among agriculture, mining, industry, tourism, human consumption and ecological watersheds (Robinson and Gelhar, 1995; Ianchovichina et al., 2001); and (e) models focused on evaluating the economic impacts of environmental instruments, or of specific environmental regulations, such as the Clean Air Act in the USA (Jorgenson and Wilcoxen, 1990; Hazilla and Koop, 1990).

The CGE modeling in India with environmental links has mainly focused on reduction of carbon emissions and its implications for economic growth (Murthy, Panda and Parikh, 2000; Ohja 2005, 2008).

Source: Conrad (2002)

3. The CGE model used here is based on a framework developed and maintained by the Global Trade Analysis Project (GTAP) network[4]. GTAP model is built on a global trade database and reflects, among other indicators, India's performance in terms of export growth, which has increased dramatically during the last decade. With India emerging as a major producer and exporter of goods including pollution intensive commodities, the use of such a model to assess the environmental impacts of the country's development path was considered appropriate. The main environmental variable that has been included in the model is emissions of particulate matter of less than ten microns (PM10) as well as particles of sulfates and nitrates). These emissions are recognized among the most important in terms of their health effects. The standard GTAP model has been expanded to include emissions from all the key sectors, including PM10 and other small particles

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[4] https://www.gtap.agecon.purdue.edu/ GTAP (1997), T. Hertel Ed., Global Trade Analysis Modeling and Applications, NY, USA.

emissions originating from fuel use and production activities. A detailed description of the model, assumptions and corresponding equations is given in Annex 1.

4. This is the first time that a CGE model for India has looked at the trade-offs between economic growth and "local" pollution mitigation. [5] The open economy model incorporates links among 57 sectors — various sectors within agriculture, manufacturing and services — of the Indian economy as well as links between the economic output of these sectors and air pollution emissions, principally PM10 and emissions of SO2 and NOx which give rise to health effects. Other CGE models for India have so far included only 11 to 36 sectors and have not tracked emissions such as PM10.

5. The model's database developed by the GTAP network[6] (GTAP database version 8 for 2007) includes data from the India's National Accounts. This was complemented with statistics on urban pollutants (from national statistical sources) and macro-economic variables (i.e. growth rate projections and total factor productivity (TFP) from the literature). Specifically, the model was extended by several external inputs, such as demographics, labor productivity and labor supply, and corrected for environmental health impacts, sectoral coefficients for PM10 emissions.

Methodology

6. In terms of the methodology, first, an economic growth scenario was developed, reflecting the most likely path that the Indian economy could follow from 2010 through 2030. This path represents the "economic baseline". The GTAP model was calibrated to reproduce actual GDP growth rates in the country during 2007-2010 and growth projections in line with World Economic Outlook projections.[7] While the recent IMF survey of the Indian economy suggests a robust 7-8 percent growth in the next few years in spite of a global economic slowdown, it will be necessary, according to the IMF, to focus on reinvigorating the structural agenda, rather than relying on monetary and fiscal stimulus to ensure sustainable growth. Measures to facilitate infrastructure investment, reform the financial sector and labor markets, and address agricultural productivity and skills mismatches stand out. Also according to IMF, reorienting expenditure toward social areas is vital to make growth more inclusive (which, in turn, would boost growth).[8]

7. Second, an "environmental baseline" was constructed according to our estimations of PM10 and other small particles.[9] Third, a health module was developed outside

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[5] Another CGE model that looks at the carbon impacts of different growth paths for India is Ojha, 2005, 2008. His model is much smaller (11 sectors) and does not look at local pollutants such as PM10.

[6] The standard version of the model represents the world economy in the form of 57 sectors/economic units trading with each other for 113 countries/regions. In this study, India is disaggregated from the rest of the regions and from the other South Asian countries.

[7] IMF (2011). World Economic Outlook: Slowing Growth, Rising Risks, September 2011.

[8] IMF (2012). India: 2012 Article IV Consultation-Staff Report.

[9] From the literature, the contribution to the costs of environmental degradation traditionally include not only PM10 and poor water supply and sanitation, but also groundwater depletion and soil degradation, which play a significant role in agriculture. These are not included in this study due to data and modeling constraints.

the CGE to estimate the health impacts expected to occur during the same period: the potential mortality and morbidity effects of such small particles.[10] The pollution impact on health is characterized by mortality and morbidity figures for three different pollution scenarios ("upper", "central" and "lower").[11] These reflect the uncertainties about the magnitude of the impacts of PM10 and other small particles.

8. The main analysis carried out was to evaluate the economic and environmental impacts of a 10 percent reduction or a 30 percent reduction in PM10 and other small particle emissions relative to what they would be in 2030 under a Business As Usual scenario. To achieve these targets, two different types of policy instruments in addition to an increase in autonomous energy efficiency and investment in clean energy were considered:

   (a) a tax on coal alone; and
   (b) a tax on PM10 and other small particles, translated into a tax on the fuels that generate PM10,[12] namely coal and oil.

   In each case, the model was run to look at the effects of the taxes on conventional GDP, and their impacts on particulate emissions. The health damages and the welfare impacts of the tradeoffs are dealt with outside of the model.

9. The application of tax policies in the model should not be construed as an endorsement of these specific policy approaches. Tax policies are an analytically convenient way to represent a broader class of policies that use economic incentives to change behavior, including an emissions trading system. However, our approach can less readily be interpreted as showing the impacts of more prescriptive emission control policies, such as specific technology standards, which generally are costlier – sometimes much more so – than incentive-based policies. On the other hand, the CGE approach has limitations in its ability to fully reflect the potential for "low hanging fruit," notably improvements in thermal and end-use energy efficiency that can yield reduced emissions as a co-benefit (i.e between CO2 and PM10). This point plays an important part in our analysis, as described below.[13]

10. In terms of environmental impacts the model was expanded to estimate PM10 emissions and generation of sulfates and nitrates of similar diameter up to 2030

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[10] The Cost of Environmental Degradation study which complements this study (Strukova et. al. 2011) finds that the health effects from particulate matter represent a loss of 1.7% of GDP –higher than any other type of environmental impact..

[11] Recognizing the general uncertainty regarding the estimates, upper, central and lower bound estimates are provided to indicate the ranges within which the actual health effects are likely to fall (Ostro, 1994). This is standard in environmental health literature.

[12] The tax on PM10 also applies to secondary particles. Relatively generic coefficients are used to translate between fuel use and emissions, as distinct from more detailed and site-specific emissions coefficients – that is beyond the scope of the current model.

[13] In this study we also conducted an extensive research on cost and benefits of CO2 mitigation and converted them to PM10 mitigation equivalents when needed. Our assumptions/results are aligned with the literature on critical parameters such as GDP elasticities of CO2 mitigation, historical autonomous energy efficiency increase in India etc.

based on fuel use and production. These pollutants are the most important of all air pollutants in terms of their health impacts and are associated with significant additional mortality and morbidity to the population, including the labor force (see Box 2). In this study, morbidity was quantified by estimating the days lost due to reduced activities and increased hospital admissions due to respiratory illnesses. Each of these impacts was quantified based on epidemiological studies (more details are in Annex 1). Based on the CGE model estimation of emissions, the increase in PM10 and other small particle concentrations was estimated using the concept of uniform rollback[14]. Under this assumption, health impacts can be linked directly to levels of emissions; the analysis does not include a characterization of how emissions affect air quality (pollutant concentration), the physical measure one would typically see in the health literature to estimate changes in illness and risk of premature death.

11. The morbidity and premature mortality impacts of PM concentrations were measured in monetary terms as follows. For morbidity, an estimate was made of losses in productivity and costs of treatment for illness. For premature mortality the impacts were valued in terms of both loss of future productivity (where appropriate) and the welfare loss associated with early death (see Annex I, section VII for details).

12. It is often the case that if an environmental policy such as a tax induces technical change, for example by triggering emission or resource-saving technical change, it reduces the cost of achieving a given abatement or resource conservation target. For example, emission air pollutants can be reduced cost-effectively by fuel substitution (non-energy for energy or within-energy inputs), and by efficiency improvements in power generation and use. Most CGE models, however, assume no difference in the **pattern** of technical change between the base case and the policy case, which often leads to an upward bias in the cost estimate of policy. Other common approaches to technical change are the use of capital vintages involving different technologies or the modeling of autonomous energy efficiency improvements. An attempt is therefore made in the CGE model to capture these technological shifts over time by altering the elasticity of substitution between capital and energy and by altering levels and types of investments and corresponding emission coefficients (in line with the existing bottom up analyses for India). These are described in detail in the methodology section.

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[14] The concept of "uniform rollback" states that the percentage change in pollutant emissions can be assumed to be equal to the percentage change in pollutant concentration. This assumption invariably involves a simplification of how emissions affect air quality; how much of a simplification depends on specific circumstances.

Box 2: Particulate Emissions in India

Particulate matter is by far the most problematic air pollutant on a national scale, with annual average concentrations of Suspended Particulate Matter (SPM) exceeding the National Ambient Air Quality Standards (NAAQS) in most cities (CPCB, 2006; MoEF 2009). India's national average of 206.7µm/m3 of Suspended Particulate Matter (SPM) in 2007 was well above the old NAAQS of 140 µg / m3 for residential areas. Most Indian cities exceed, sometimes dramatically, the current NAAQS of 60µm / m3 for Respirable Suspended Particulate Matter (RSPM). Average annual concentration of RSPM in Delhi for example is about 120 µg / m3, as against a residential National Ambient Air Quality Standard of 60 µg / m3 and World Health Organization (WHO) guidelines of 20 µg / m3 (Central Pollution Control Board (CPCB), 2006; Word Health Organization (WHO), 2008). Five of six cities covered in a recent report exceeded the standard in all years 2000-2006 (CPCB, 2011). By contrast, sulfur dioxide (SO2) and nitrogen oxides (NOX) are less of a problem in India. Most cities are below the NAAQS for these pollutants.

The figures refer to both SPM and RSPM. SPM is a broader category referring to all suspended particulate matter of less than 100 micrometers in diameter. Research on the health effects of particulate matter indicates that the smaller particles in RSPM are more dangerous for health because they penetrate more deeply into the lungs (US Environmental Protection Agency (USEPA), 2008). In India, RSPM is defined as fine particles less than 10 µm (PM10). Other countries refer to this pollutant as PM10 and may also measure PM2.5, i.e. smaller particles of less than 2.5 µm in diameter.

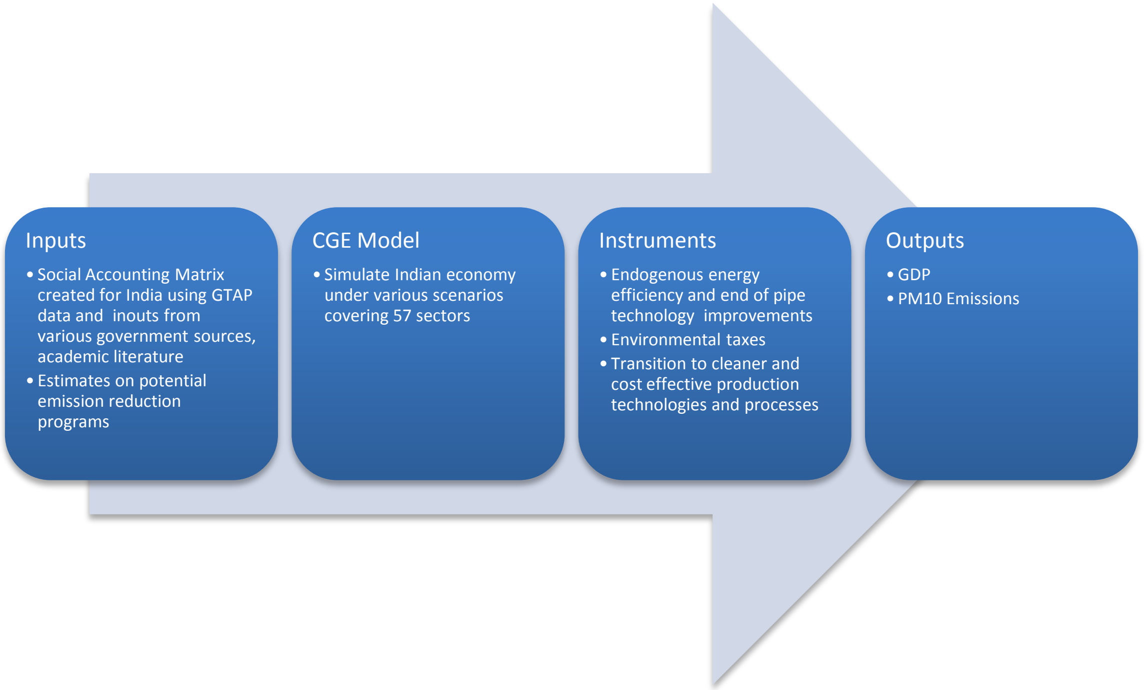
Indian standards recognize the danger of air pollution. In November 2009, the Ministry of Environment and Forests (MoEF) announced new NAAQS (CPCB, 2009). Compared to the previous version from 1994, the revised NAAQS brought six new pollutants under regulation (including introducing a standard for PM2.5), tightened the acceptable ambient concentration for other pollutants, and eliminated the distinction between industrial and residential areas. As a result, many urban areas—which may have been out of compliance even with the older norms—must significantly cut emissions to move towards the more stringent, uniform standards now in place. The shift from regulation of ambient SPM to RSPM in the new NAAQS in particular is significant in directing the focus of regulation to those pollutants that matter for human health. India's MOEF has launched a pilot emissions trading scheme in three states to improve air quality and help the states meet the new NAAQS.

Source: Greenstone and others (2012)

Scenarios

13. As noted above the model was run for the Business as Usual Scenario, plus six scenarios reflecting a menu of instruments that look at the impacts of reducing PM10 and other particles through different tax instruments (see Figure 2). Details of the different scenarios are given in Table 1.

Figure 2: How the CGE Model Works



Inputs
- Social Accounting Matrix created for India using GTAP data and inouts from various government sources, academic literature
- Estimates on potential emission reduction programs

CGE Model
- Simulate Indian economy under various scenarios covering 57 sectors

Instruments
- Endogenous energy efficiency and end of pipe technology improvements
- Environmental taxes
- Transition to cleaner and cost effective production technologies and processes

Outputs
- GDP
- PM10 Emissions

Two types of taxes are modeled:

Domestic fuel tax (*to*) is added to the producer price (*ps*) for coal, oil, natural gas and refined oil to obtain the market price (*pm*):

$$\mathrm{pm(i,r,t) = to(i,r,t) + ps(i,r,t)} \quad (1)\ \text{eq. 1}$$

$$\mathrm{to(i,r,t)} > 0$$

$$\mathrm{ps(i,r,t)\colon producer\ price\ for\ commodity\ i\ in\ region\ r\ in\ year\ t}$$
$$\mathrm{to(i,r,t)\colon tax\ on\ domestic\ fuel\ \ in\ region\ r\ in\ year\ t}$$
$$\mathrm{pm(i,r,t)\colon market\ price\ of\ commodity\ i\ in\ region\ r\ in\ year\ t}$$

The tax rate increases at a decreasing growth rate starting from 2012. Tax rates (to) used in different scenarios are displayed in Table 4.

$$\mathrm{to(i,r,t) = to(i,r,t-1)} * \Delta\mathrm{to(i,r,t)} \quad \text{(eq. 2)}$$

Imported fuel tax (*tm*) is applied to the import price (*pms*) of coal, oil, natural gas and refined oil. $\Delta\mathrm{to} > 1\ decresing\ over\ time$

$$\mathrm{pms(i,r,s,t) = tm(i,r,t) + tms(i,r,s,t) + pcif(i,r,s,t)} \text{ (eq. 3)}$$

$\mathrm{pms(i,r,s,t)}$: import price of commodity i by region r from region s in year t
$\mathrm{tms(i,r,s,t)}$: add valorem tariff on commodity i in region r imported from region s in year t
$\mathrm{tm(i,r,t)}$: tax on import of i from r in year t
$\mathrm{pcif(i,r,s,t)}$: border price of commodity i in region r imported from regions s in year t

$$\mathrm{tm(i,r,t) = tm(i,r,t-1)} * \Delta\mathrm{tm(i,r,t)} \text{ (eq. 4)}$$

$$\Delta\mathrm{tm(i,r,t)} > 1, decreasing\ over\ time$$

The tax rate on imported fuel also increases linearly at a constant rate starting from 2012. Tax rates used in different scenarios are given in Table 4.

Business as Usual (BAU) GDP Growth Scenario

14. The (BAU) GDP growth scenario refers to a purely economic baseline and is based on past economic performance for 2007–10 and on IMF projections of GDP for 2011–2015, with associated projections up to 2030 derived from projections for population and TFP. The model then calculates the required investments to achieve the projected growth, along with the demands for different types of fuel. Domestic prices for fuel as well as other goods are determined so that demand and supply are equated. Some emission reduction (and therefore decline in PM intensity of GDP) happens under BAU due to autonomous technological change built into the model.[15] This is partly driven by the macro-economic structural shift away from the agriculture sector towards knowledge-based industries, greater and easier access to global knowledge, technology and capital, and the growth impetus provided by the commercial and services sectors. In addition the shift also reflects the recent policy initiatives to reduce the sulfur content of diesel in the transport sector, the use of compressed natural gas for public transport, emissions limiting performance standards for passenger vehicles, and stricter enforcement of existing environmental laws.[16]

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[15] Autonomous energy efficiency (kg CO2 emitted per unit of GDP in 2000$) improved by 1% per year between 1980-2008 (WDI) and our BAU reproduces the same trend.

[16] New substitution elasticity between capital and energy was introduced into the standard GTAP model to capture this effect. This is based on the notion that technical progress is entirely embodied in the design and operating characteristics of new capital plant and equipment. For example, the energy saving effects of embodied technical progress depends critically on the rate at which new investment goods diffuse into the economy. By introducing substitution between capital and energy in the model, we mitigate CO2 emissions by 20% (India would have emitted emit 3246 mtons in 2030 but with the substitution only emits 2631mtons under BAU).

Table 1: CGE Model — Scenarios

Scenarios	Instruments	Assumptions	Results
BAU GDP Growth		Economic growth of approximately 7 % p.a.	Some PM emission reduction because of increase in autonomous energy efficiency of supply and end-use technologies (driven by current policies).
Green Growth	Using a tax on coal only. Tax applied to both domestic and imported coal.	Tax induced shift to a greener fuel mix and annual energy efficiency gains over and above the historic trend. Limited investment availability and turnover of capital stock.	A 10 percent reduction in PM10 and other small particles in 2030 over and above reductions achieved under BAU
	Using a tax on PM10. Tax applied to coal and oil in relation to the emissions of PM10 and other small particles		
Green Growth Plus	Using a tax on coal only. Tax applied to both domestic and imported coal.	Tax induced shift leading to significant improvement in coal technologies along with change in plant vintages over time. Higher investment availability and faster turnover of capital stock.	A 30 percent reduction in PM10 and other small particles in 2030 over and above reductions achieved under BAU
	Using a tax on PM10. Tax applied to coal and oil in relation to the emissions of PM10 and other small particles.		

Green Growth scenario

15. The Green Growth Scenario targets a reduction in PM10 and other small emissions by 10 percent more that what could be achieved relative to BAU in 2030. The Green Growth Scenario is thus a modified version of the BAU GDP Growth Scenario, where a tax instrument is used to achieve a targeted emissions reduction. This is modeled through a tax on coal or through a tax on PM10.[17] A tax thus

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[17] Although most countries use technical standards to curb air pollutants, modeling the effect of market-based instruments is useful because they favor allocation through relative prices. This is consistent with India's recent approach to use market based instruments to deal with air pollution. The Government of India introduced on July 1, 2010 a nationwide coal tax of 50 rupees per metric ton ($1.07/t) of coal both produced and imported into India. The tax raised 25 billion rupees ($535 million) for the financial year 2010–2011. Many consider this coal tax is a step towards helping India meet its voluntary target to reduce the amount of carbon dioxide released per unit of gross domestic product by 25% from 2005 levels by 2020. Further, India's federal cabinet on April 12, 2012 approved a proposal to change the method used to calculate the royalty that coal miners pay to state governments, imposing a flat 14% tax based on prices.

designed on polluting inputs will raise the unit cost of production and, responding to the rise in unit cost of production, [18] the producer will reduce the output or substitute it with a more eco-friendly input. Either of these actions will reduce pollution. It is thus anticipated that the tax in the model will encourage a shift to a greener fuel mix and annual energy efficiency gains over and above the historic trend. In the case of a tax on PM10 for instance we consider a modest tax as a way of reducing particle emissions per unit of coal used. For further reductions in PM the tax has to induce a shift out of coal to cleaner fuel. The scenario outline is summarized in Table 1.

Green Growth Plus Scenario

16. The Green Growth Plus Scenario incorporates a more aggressive target of a 30 percent reduction in PM10 and other small particles in the air in 2030 over what could be achieved under the BAU. Here again, targeted small particles emissions reduction is attained through a tax on coal or through a tax on PM10.

17. One important difference between the Green Growth and Green Growth Plus scenarios is that the latter assumes that, as the economy matures, the market realizes the economic benefits of cleaner and more efficient production. Gradually the environmental command-and-control 'push' policies in the initial periods are replaced in the medium to long run by market-driven pull policies to achieve cleaner and more efficient production. For example, the performance of coal technologies improves over time, reflected in their rising plant load factor, and newer plant vintages, with more of the older, less efficient plants getting replaced and in the increased penetration of advanced coal technologies like super-critical pulverized coal and integrated gasification combined cycle which will become competitive over time. While recognizing the limitations of incorporating all these technologies within the CGE framework, they have been modeled through broad alterations in investments and emission coefficients. The idea is that the latest vintage, added to aggregate capital stock, embodies innovation and technological improvement with no additional cost to the producer.[19]

18. The CGE model used in this analysis was limited in terms of formulating different policy scenarios because the current dataset included only five types of energy sources-- coal, crude oil, refined oil and coal products, natural gas and electricity. Based on data availability, the model and study can be expanded in the future to include other energy sources, such as renewable energy and carbon sequestration measures.

Calibrating the Model for the BAU GDP Growth Scenario

19. Estimates of growth in population and labor force were based on projections made by national / international sources (e.g. the National Council for Applied Economic Research (NCAER), UN and World Bank). Medium projections were used for measuring population growth in 2007-2030 using UN demographic data. The annual

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[18] Environmental taxes are corrective measures for dealing with the environmental "externality" first studied by Pigou (1932). A Pigouvian approach sets taxes equal to the marginal damage caused to the environment by the production process thereby "internalizing" the full social marginal costs.

[19] A more formal representation of this can be found in Conrad and Henseler-Under (1986).

TFP growth (which picks up the exogenous factors that influence growth in an economy) was assumed to be 2 percent a year. This is somewhat conservative but not out of line with previous studies for India. The NCAER CGE model assumes TFP growth of 3% p.a., as do the Energy and Research Institute (TERI) MOEF Model and the IRADE AA Model. However the same studies cite others that assume figures of between 1 and 3 percent. Given this range an assumed value of 2 percent seems reasonable.

20. The assumed annual growth rate in real GDP from 2010 to 2030 is estimated at 6.7 percent. The economic growth (measured as an index) rises from 100 in 2010 to 367 in 2030. This is the Conventional GDP Growth (BAU) scenario estimate (as per NCAER and recent IMF projections) without correcting for implication of any new policy changes to deal with pollution..

21. The standard GTAP model's structure has been modified to allow substitution between capital and energy (by increasing the elasticity of substitution from 0 to 0.5, as in the GTAP-E model). This modified version of the model is close to the energy version of the GTAP model (called GTAP-E) but does not comprise a nested structure in the energy block (which would require more data than was available).

Method for estimating PM10 emissions

22. The demands for different kinds of energy and the outputs of the different sectors were converted to PM10 emissions using corresponding emission coefficients (α(i,j) and *Bi*, respectively).[20] The Conventional GDP Growth scenario (BAU) generated PM10 emission estimates for 2010–2030 from fuel use and production activities as described in equation (1) below:

$$E = \sum_i \sum_j \alpha_{ij} C_{i,j} + \sum_i \beta_i XP_i$$

(Eq. 5)

E = PM10 emissions

$C_{i,j}$ = Demand for fuel products j in Sector i

i = Sector (firm, household, government)

j = Energy (coal, crude oil, refined oil and coal products, natural gas, and electricity).

$\alpha_{i,j}$ = Emission coefficient associated with the consumption of one unit of energy product j by the Sector i

XP_i = Production activity and process of sector i

β_i = Emission coefficient associated with one unit of output in sector i.

23. Both the consumer demand for energy products ($C_{i,j}$) and sectoral economic activity (XP_i) up to 2030 were estimated by the CGE model.

24. First, PM10 emission coefficients are taken from the Garbaccio et al. (2000) study for China. This is presently the only source for these coefficients being mapped

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[20] Emission coefficients vary through time to reflect technological change, modernization of power plants, improved energy efficiency and India's emission abatement levels (on the basis of 1% annual increase on average in BAU reported in WDI statistics).

across sectors to the CGE model based on the GTAP database.. The Institute for Applied System Analysis (IIASA) reports PM10 and other secondary emissions for India, which corresponded to almost to 8.7 million tons in 2010. The emission coefficients based on Garbaccio et al. (2000) were updated to reproduce the aggregate PM10 and other small particles level for India in 2005 and then extrapolated following the growth assumptions in BAU.

25. Table 3 in Annex 1 represents the relative shares of PM10 emissions by sector and energy ($\alpha_{i,j}$).

26. Emissions from productive activities and the respective coefficients (β_i) were calculated as follows:
    - First, the shares of production activities and process (XP) and energy use (C) related emissions in total emissions (E) were calculated as per the Garbaccio et al. (2000) study.
    - Second, sector-specific emission coefficients in Garbaccio et al. (2000) were re-adjusted according to the GTAP classification in proportion to the sector's contribution to overall PM10 emissions and overall emission estimates from the IIASA model.

27. On the basis of equation (1) and the CGE simulations, the increase in PM10 emissions and other particulate emissions over time was calculated as a function of the demand for each type of energy by sectors (Ci,j), and the economic expansion of production activities (XPi).

28. Second, the emissions coefficients α_{ij} and β_i are modified over time to account for the improvements in the emission-capturing technologies, ; through (a) a shift to cleaner coal (imported coal has lower emissions per unit of energy than domestic coal and its share in the total amount of coal used in India is rising); and (b) other measures such as coal washing. These reductions in emissions are partly driven by administrative measures, and partly by trade factors and such improvements are included in the BAU. The rates of decline in unit emission are for these reasons taken from micro studies (see Cropper et al, 2012). Further reductions in the coefficients may be achieved through a tax on PM10 and similar emissions. Such reductions in the coefficients reflect the impact of further pollution control measures that will be introduced as a result of the tax.[21]

29. The energy demand in value (US$) for four fuel types — coal, crude oil, oil and coal products, and natural gas — were obtained for 2010–2030 using the CGE model. This was converted into volume in terms of Thousand Tons of Oil Equivalent (TTOE) using appropriate factors.

Main Results

PM10 and other particle emissions

30. Fossil fuel use, the primary cause of pollution, is expected to decrease under BAU due to a declining share of coal in the overall energy demand (although coal would still dominate in 2030); to greater emissions capture; and to the shift to cleaner coal. Demand for refined oil products and electricity, however, will still increase considerably. As a result, the share of emissions from productive activities in total

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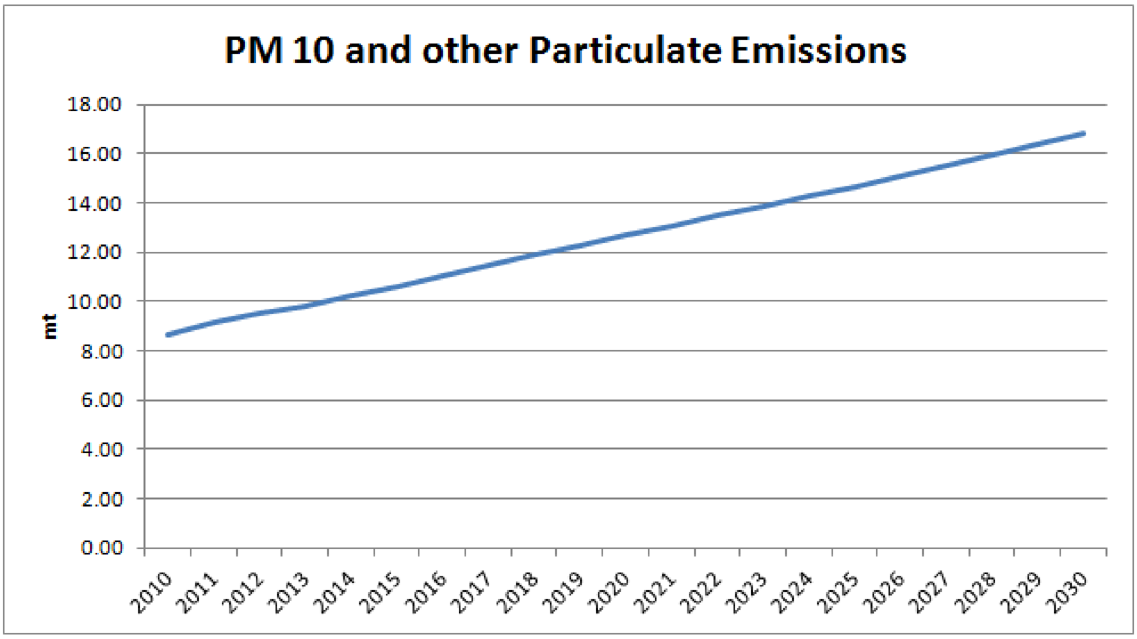
[21] The PM10/CO2 elasticity varies across scenarios, the average is found to be 1.62 which means that 1 unit of CO2 abatement will bring 1.62 unit of PM10 abatement.

PM10 emissions is expected to double along with the impacts of the fast-increasing economic activities, such as manufacturing and construction, and transportation. The total PM10 emissions under BAU are estimated to go up from 8.7 million tons in 2010 to 16.8 million tons in 2030, an annual rate of increase of 1.9 percent against an annual GDP increase of 6.7 percent (Figure 3). Emission will grow more slowly than GDP because of the exogenous factors noted above.

Figure 3: Total PM10 and Similar emissions (BAU GDP Growth scenario) (in million tons)



Conventional GDP Growth scenario vs. Green Growth Scenarios

31. Recall that the Green Growth Scenarios seeks to constrain particulate emissions through a menu of instruments that translate into 10 percent or 30 percent less than emissions under the BAU scenario. They do this by imposing different fuel or emission taxes, as already described, along with other *assumed* reductions in emissions resulting from low-cost measures especially in the Green Growth plus scenario which are encouraged by tax policies that operate outside the scope of the model. The combined effect of the two drivers – the tax measures, and the other low-hanging fruit measures –results in reduction in emissions of PM and CO2. Table 2 shows the following results:

Table 2: Comparing the Base Case (BAU) with a 10% and 30% Reduction in PM

	2010	2030	Percentage Increase p.a.	GDP loss % wrt BAU	% reduction in CO2 wrt BAU
BAU					
GDP US$Bn. 2010	3,763	13,820	6.89		
CO2: Mn. Tons	1,563	2,770	1.77		
PM10: Mn. Tons	8.68	16.81	1.94		
10% Reduction Via a PM tax					20%
GDP US$Bn. 2010	3,763	13,774	6.87	0.33	
CO2: Mn. Tons	1,563	2,180	0.79		
PM10: Mn. Tons	8.68	15.12	1.03		
10% Reduction Via a Coal Tax					10%
GDP US$Bn. 2010	3,763	13,751	6.86	0.5	
CO2: Mn. Tons	1,563	2,499	0.9		
PM10: Mn. Tons	8.68	15.24	1.03		
30% Reduction Via PM Tax					60%
GDP US$Bn. 2010	3,763	13,723	6.85	0.7	
CO2: Mn. Tons	1,563	1,108	0.4		
PM10: Mn. Tons	8.68	11.86	1.02		
30% Reduction Via Coal Tax					30%
GDP US$Bn. 2010	3,763	13,672	6.83	1.07	
CO2: Mn. Tons	1,563	1,939	0.7		
PM10: Mn. Tons	8.68	11.84	1.02		

The results in summary are:

i. With the different tax regimes for a 10 percent particulate emission reduction we have a lower GDP but the size of the reduction is modest. With a PM10 tax conventional GDP is about US$46 billion lower in 2030, representing a loss in growth of 0.3 percent with respect to BAU. The impact on GDP is greatest if we seek to achieve the PM target via a coal tax.

ii. For a 30 percent particulate emission reduction the conventional GDP is about US$97 billion lower in 2030 representing a loss of 0.7 percent. The scenario suggests that even a substantial reduction in emissions can be achieved without compromising much on GDP growth rates if supported by adequate least cost policy measures. Again the coal tax performs worse with a GDP loss of 1.07 percent.

iii. It should also be noted that the Green Growth Plus scenario assumes, in addition to the taxes, some increase in investment towards cleaner technologies. Such investments are associated with an increase in pollution control techniques, modernization of the existing capital and/or use of less polluting capital over time with very low additional cost to the producer (see Box 3). These outside-the-model emission declines are assumed to be stimulated by the new investments, but themselves having minimal economic costs--play a crucial role in the analysis of the environment-growth tradeoffs for this scenario. They account for almost two-thirds of the PM10 reductions (20 out of 30percent) in the Green Growth Plus Scenario. If we do not include these minimal-cost emissions savings from outside the model, there would be bigger negative GDP impacts indicated by adjustments of inputs and outputs in the model. We would, however, argue that the stronger tax regime will result in enterprises looking for to realize benefit from these low-cost mitigation measures.[22]

iv. On the welfare side, health damages from PM are significantly reduced in the 30 percent reduction case when compared to a 10 percent reduction (Table 3). Savings range from U$24 billion from reduced health damages in the case of a 10 percent reduction (lower estimate) to US$105 billion in the case of a 30 percent reduction (upper estimate scenario). The central estimates are in US$34-$67 billion range which more or less offsets the GDP loss from the introduction of the tax. The introduction of tax regimes lowers GDP in all scenarios but this can be at least partially offset by the benefits of lower health damages.

v. The different tax regimes provide an important co-benefit in terms of substantial reduction in CO2 emissions. We find the PM tax makes the bigger reduction in these emissions than the coal tax. Our calculations show that even with a value per ton of CO2 of just US$10 the reduction in CO2 for the 10 percent PM reduction case is worth US$59 billion which is little more than the loss of GDP. For the 30 percent reduction case the reduction is worth US$83 billion, slightly less than the loss of GDP. In addition we can take account of the savings in PM10 damages too which gives an overall net gain through this route (see Table 3).

vi. Also, Given our assumptions on economy and environmental targets in 2030, the model gave us the percent of tax we have to apply on coal (first scenario) and coal/oil (second scenario) (see Table IV). We shocked the energy in BAU by these tax rates to reach our PM10 reduction targets.

vii. In terms of sector prices, we find that the energy-intensive sectors will be the most impacted in 2030 under the various tax regimes. While the electricity, petroleum, chemical and minerals sectors will be impacted the most from a PM tax, metal products (e.g. iron and steel) will be most affected from a coal tax.

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[22] As a result of tax policies private firms are expected to invest in clean technologies: either financed by FDI or through domestic investments. This investment may even generate new activity sectors if environment friendly technologies are domestically produced. According to the model estimations these new investments will generate a value added equivalent of 0.8-1.2% of GDP in different scenarios that we simulated.

Box 3: Technologies for Control of PM10 and CO2 from Power Plants in India

Control of particulate emissions from power plants has been a concern in India for many years now, especially because of the high ash content of Indian coal which is the primary fuel for the overwhelming majority of thermal power plants. Over the last two decades, various studies have been carried out to establish effective ways of dealing with these emissions over time (Lookman and Rubin (1998), Kumar and Rao (2002), TERI (2003), Murthy et.al. (2006), Sengupta (2007), Cropper et. al. (2012)).

Coal beneficiation is the process of removal of the contaminants and the lower grade coal to achieve a product quality which is suitable to the application of the end user - either as an energy source or as a chemical agent or feedstock.

A common term for this process is coal "washing" or "cleaning". According to Zamuda and Sharpe (2007), Indian coals are of poor quality and often contain 30-50% ash when shipped to power stations. In addition, over time the calorific value and the ash content of thermal coals in India have deteriorated as the better quality coal reserves have been depleted and surface mining and mechanization expanded. This poses significant challenges. Transporting large amounts of ash-forming minerals wastes energy and creates shortages of rail cars and port facilities. Coal washing reduces the ash content of coal, improves its heating value and also removes small amounts of other substances, such as sulfur and hazardous air pollutants. The benefits of using washed coal, inter alia, include reductions in particulate and sulfur emissions, reductions in flyash disposal costs and reductions in the cost of transporting coal, per unit of heat input. Use of washed coal may also reduce plant maintenance costs and increase plant availability.

Installing a washery for coal would entail an expenditure of around INR 400 million for a 3 MTPA plant. According to Zamuda and Sharpe (2007) for a typical 500 MW plant, the use of washed coal with ash reduced from 38% to 30% could result in a 2% reduction in the cost of electricity generation with savings averaging INR 0.035 per kWh of generated power, once various benefits to plant operation and reduced emissions are accounted for. Lookman and Rubin (1998) had previously analyzed 174 plants across India and found that coal cleaning could result in savings in the range of of USD75-150 million and USD15-25 million for existing plants by 2002 in terms of 1996 dollars. More recently, Cropper et. al. have, using updated figures from India's Central Electricity Authority for a particular plant in Rihand, estimated that levelized cost of electricity generation increases from INR 1.206 to INR 1.405 but did not take into account any of the other benefits that Zamuda and Sharpe quantified.

Table 3: Health Damage Estimates for Alternative Scenarios

	2010	2030	2030	2030
Morbidity (US$Bn.)		**BAU**	**10% PM Reduction**	**30% PM Reduction**
Lower	32.38	230.46	206.94	160.96
Central	46.12	328.37	294.84	229.28
Upper	72.39	515.24	462.64	359.83
Mortality (US$Bn.)				
Lower	9.31	14.02	13.56	12.47
Central	14.87	22.36	21.63	19.90
Upper	20.39	30.65	29.65	27.29

Total (US$Bn.)				
Lower	41.70	244.49	220.50	173.43
Central	60.99	350.73	316.48	249.18
Upper	92.78	545.90	492.29	387.11
Saving (US$Bn.) from Reduced Health Damages				
Lower			23.99	47.07
Central			34.25	67.30
Upper			53.60	105.18

Table 4: Different Taxes (%) for a 10% Reduction in PM Emissions by 2030 -- derived from the CGE simulations

Tax Regime	Applied to	2014	2030
Coal Tax	Coal	14.0%	38.5%
PM Tax	Coal, Oil	3.4%	16.2%

Conclusions

33. The study shows that policy interventions such as environmental taxes are likely to yield positive net environmental benefits for India. The CGE analysis also shows that addressing "public bads" via selected policy instruments need not translate into large losses on GDP growth. The environmental cost model developed in this study can thus be used to evaluate the benefits of similar pollution-control policies and assist in designing and selecting appropriate targeted intervention policies (such as a SO_2 tax, a CO_2 tax, or emission trading schemes). Once the impact on ambient air quality of a policy to reduce particulate emissions is estimated, the tools used to calculate the health damages associated with particulate emissions can also be used to compute the welfare impacts of reducing them. The monetized value of the health benefits associated with each measure can be calculated, using the techniques developed in this study, and compared with the costs.

36. The comparisons made between the BAU scenario and the Green Growth scenarios reveal that a low carbon, resource-efficient, greening of the economy should be possible at a very low cost in terms of GDP growth. This would make the Green Growth scenarios attractive compared to the Conventional GDP Growth scenario. A more aggressive low carbon strategy (Green Growth Plus) comes at a slightly higher price tag for the economy while delivering higher benefits. The extent to which GDP growth would be impacted under more severe cuts on polluting emissions has to be determined by further study using the CGE model. On the other hand, the modest GDP impacts indicated in this study depend on the availability of minimal-cost mitigation options (energy efficiency improvements, embodied technological improvements, improved daily operating practices of boilers). With fewer such options, the GDP cost of hitting the 10 percent and 30 percent targets would be

higher – potentially considerably higher. In evaluating the environment-growth tradeoffs, accordingly, a judgment must be made about the size and availability of such “low hanging fruit” and appropriate incentives.

37. Both Green Growth scenarios have other important benefits. Most significantly they reduce CO2 emissions, which have an important value. If we take that value at even a modest US$10 per ton, reflecting what might be gained in revenues from participation in emerging carbon abatement markets, India could realize an additional benefit of around US$59 billion (with a PM10 tax). Global carbon models estimate that these emissions could be worth much more—US$50-120—by 2030. The green growth scenarios have other environmental benefits we have not included, especially in the areas of natural capital [elaborated in the companion paper, “Valuation of Biodiversity and Ecosystem Services.”]. Finally the Green Growth scenarios produce benefits for all: i.e. they have distributional advantage over the conventional scenario.[23]

38. The findings and conclusions of this study and the use of the CGE model should also be considered in the context of various assumptions/limitations.

    - Only particulate emissions were analyzed; other local environmental issues were not considered.
    - The baseline PM10 and other particulate emissions used in the CGE model were obtained from the IIASA literature on India and were not based on actual measurements.
    - The CGE model did not separate health services from overall public services as an economic sector. The expected expansion of health services to address the increasing environmental health issues was not separately covered.[24]
    - The CGE model has a medium- to long-term structure and therefore could not cover short-term fluctuations, e.g. oil price volatility.
    - Both production sectors (57) that cover agriculture, manufacturing, services, and households were represented as prototypes; thus the distributional environmental health impacts on different economic strata and geographic locations were not taken into account.

39. The study shows that the CGE model could be used as a tool for policy making. Being a general equilibrium open economy model, its strengths lie in the representation of inter-sectoral linkages both within and outside the country. At an economy-wide level, the CGE model makes it possible to determine whether growth objectives are compatible with the environmental objectives. The management of pollutants at the sectoral level can also be used to determine the abatement costs across the sectors. Distributional implications (winners vs. losers) among the sectors could also be analyzed.

40. Further work using the CGE model after correcting for environmental health impacts would be useful in policy making. The present approach has the flexibility to incorporate multiple scenarios, e.g. the various scenarios in Parikh (2009) to

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[23] Improving air quality is a public good. Even if poor air quality affects all equally, an improvement has a bigger proportional benefit to the poor. And there is evidence that the poor are more affected by air pollution.

[24] Health services are in the same category as education and defense: public services. They are separated from other services provided by the private sector such as trade, transport etc

determine the implications on GDP, which could be further corrected for environmental health impacts. The CGE approach described in this study was fairly detailed, with the 57 sectors tailored to India-specific parameters. The study recommends the use of this approach for the following possible scenarios:

- Including more energy sources so that it explicitly accounts for more renewable and nuclear energy.
- Considering higher levels of de-carbonization and carbon capture and storage (CCS) as targets to be modeled and evaluated against the Conventional GDP Growth scenario.
- Examining different instruments (beyond the ones examined here) to achieve the shift from the Conventional GDP Growth scenario to an environmentally sustainable scenario.

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I. The economic growth baseline: GTAP-India 2030 model

Definitions; *Computable* refers to numerically solvable models. *General* refers to an economy-wide approach. *Equilibrium* is satisfied at multiple levels between (i) demand and supply of factor of production, commodities, and services, (ii) consumers' demands and their budget constraints (*expenses* equal *revenues*), and (iii) macro-economic balance[25] [GDP = C + G + I + (X-M)].

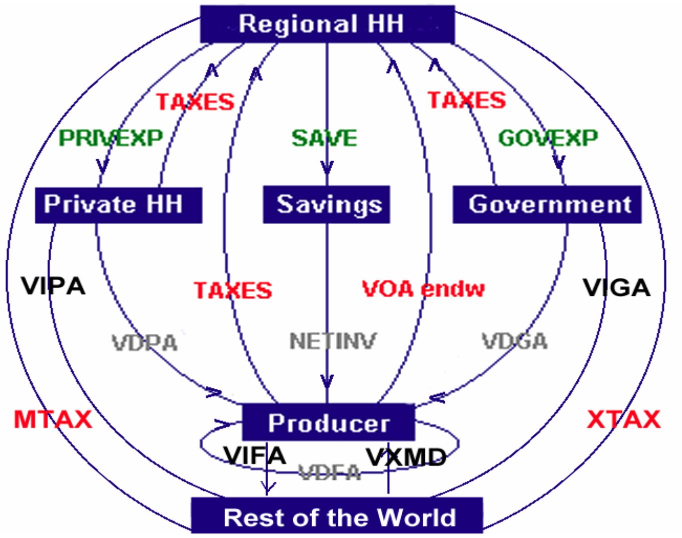
The GTAP model, like most of the standard CGE models, comprises non-linear behavioral equations and macro-economic accounting links (linear relations describing the break-even points in different markets).

The model is solved under GEMPACK (General Equilibrium Model Package) which uses a Euler algorithm; 3-4-5 step extrapolation method.

The Indian economy is modeled as an open economy composed of 57 firms, one representative household, and the government. Five factors of production exist; skilled labor, unskilled labor, capital, land, and natural resources.

Commodities/services, capital and labor are mobile across sectors and countries (international migration is not specified in the current version). The model represents the circular flow of goods and services in the economy and (i) permits flexibility in economic agents' behaviors, (ii) captures substitution/complementarity relations across demand for goods and services, and (iii) calculates price changes resulting from changing demand and supply conditions.

Figure 1: Circular flows in GTAP-CGE model



Adapted from http://www.unescap.org/tid/artnet/mtg/cb3_d3s2.pdf

Within a top-down structure; domestic gross output is an aggregate of domestic sales and exports obtained through a constant elasticity of transformation (CET) function.

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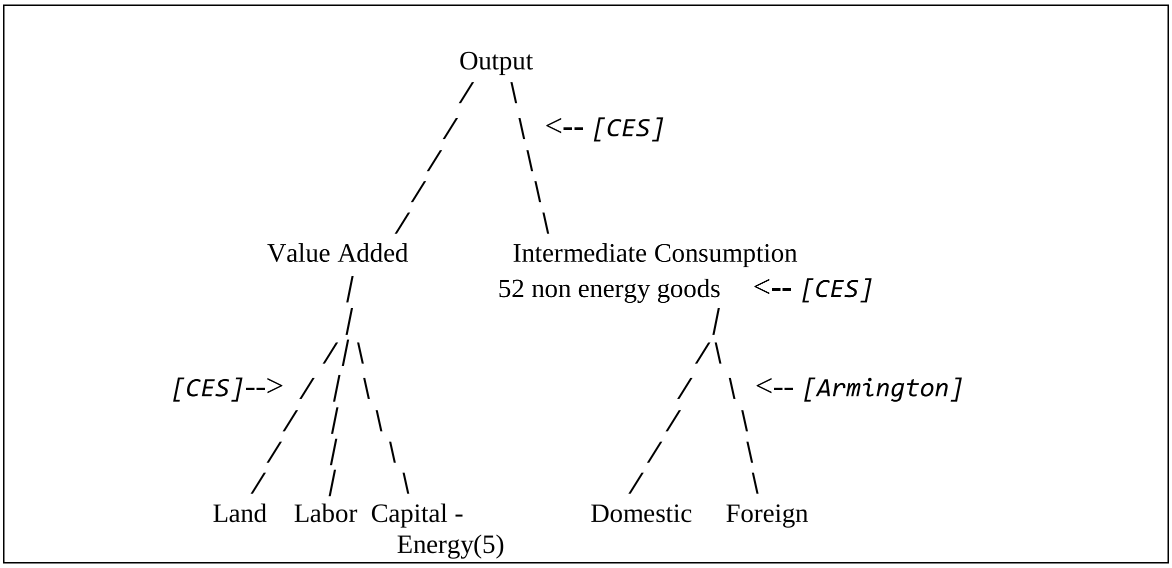
[25] Stock changes are not taken into account.

The production structure is specified in the form of nested constant elasticity of substitution (CES) functions that use labor (skilled and unskilled), capital, land and natural resources as inputs (Figure 2).

Figure 2: Modified production structure of the GTAP-CGE model used in this study



Intermediate consumption includes 5 energy products; (coal, crude oil, petroleum products, natural gas, and electricity) and 52 non energy goods. All intermediate goods are differentiated according to their origin as domestic and imported products. Imports by the countries of origin follow an Armington specification (1969).

Regional utility per capita is defined at the regional level, within a Cobb-Douglas function by private consumption, government consumption, and savings.

The demand for final goods is defined at the regional level by (i) household consumption through a constant-difference-elasticity (CDE) [26] demand specification which is a non-homothetic demand system; and (ii) public sector using a Cobb-Douglas aggregation composed of market commodities and government spending where both are specified as a fixed share of income.

Households' and firms' savings as well as taxes finance investment and government expenses. The price of utility from private consumption depends on the level of private consumption expenditure.

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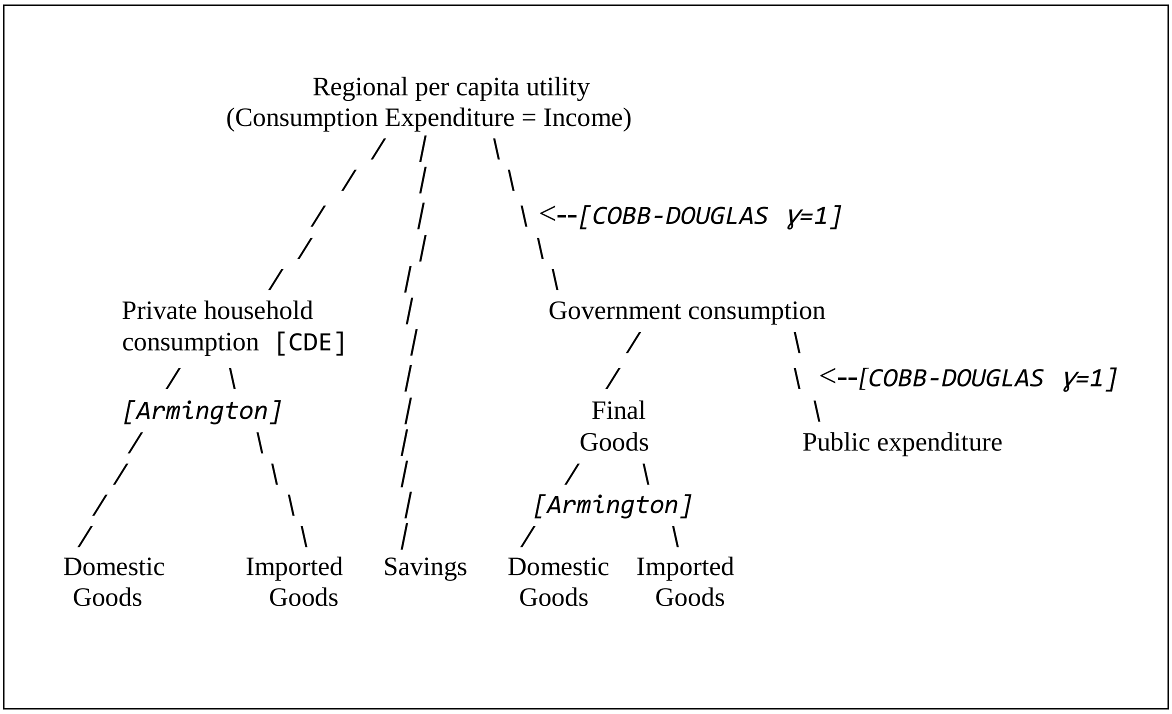
[26] Elasticities of substitution between pairs of commodities can differ and income elasticities may be different than one.

Figure 3: Consumption module in GTAP-CGE model



The GTAP-India 2030 model is used to develop an economic baseline which represents the most likely path of development of the Indian economy until 2030. Population/labor force, capital inflows and productivity growth are the drivers of the economic growth, no economic policy or pollution control measures are specified.

The economic baseline is developed by applying shocks to the initial equilibrium conditions that represent the Indian economy and its linkages with the Rest of the World in 2007.

In order to represent the most likely growth path, the model is solved for successive years using statistical projections on population, labor supply and TFP, 2 percent per year following the literature). A new equilibrium: i.e. new prices and demand/supply conditions are determined for each year.

II. The PM10 emission baseline

Fossil fuels are the major source of many local and regional air pollutants including the suspended particulate matter (SPM) and PM10 emissions. Other sources of particulate matter include physical processes of grinding, crushing and abrasion of surfaces. Mining and agricultural activities are also known to contribute larger sized particulate matter to the environment. In this exercise, the PM10 emissions, which cover the inhalable size fraction of SPM are estimated in two steps--as input and output related emissions.

The construction of the environmental baseline captures the influence of the economic growth drivers on India's pollution SPM/PM10 levels. The emission estimates are introduced into the CGE model to calculate the economy-wide impacts of emission reduction policies in the last section.

Equation 1 summarizes the PM10 estimation method: (*E*) emissions comprise input and output related pollutants. The former refers to fuel combustion related particulate emissions; therefore it is estimated on the basis of different categories of agents' demands for fuel (*C*). The second types of pollutants are emitted during the production processes (*XP*) of different sectors.

$$E = \sum_i \sum_j \alpha_{i,j} C_{i,j} + \sum_i \beta_i XP_i$$

Eq. (1)

E = PM10 emissions
$C_{i,j}$ = Demand for energy products j
i = institution (firm, household, government)
j = energy good (coal, crude oil, natural gas, electricity, refined oil).
$\alpha_{i,j}$ = emission coefficient associated with the consumption of one unit of energy product j by the institution i
XP_i = Output of firm i
β_i = emission coefficient associated with one unit of output in sector i.

Most of the CO2 emissions from fuel combustion are directly correlated to the level of carbon intensive activities, such as electricity generation, production of chemicals and basic metal products, and consumption of transport fuels; these refer to direct production-based emissions.

This study borrows inputs from previous studies on India. More specifically, PM10 estimations developed by the International Institute for Applied System Analysis' (IIASA) GAINS model are used as the initial pollution level in our model. Accordingly, we assumed that the PM10 emission level corresponded to 7 million tons in 2005.

Based on the sectoral breakdown displayed in Annex Table 1, we calculated the shares of PM10 emissions from fuel use in the GTAP model. Approximately 3/4 of PM10 emissions are caused by fuel consumption (5 million out of 7 million tons).

Annex Table 2 shows that 93 percent of the energy consumption at the origin of the PM10 emissions was domestically produced in 2005. Carbon intensive consumption accounts for 63 percent of the pollution.

PM10 emissions' estimations linked to production process follow the method in Garbaccio et al. (2000) study for China. They are assumed to represent a certain percentage of the total PM10 emissions. The corresponding coefficient is borrowed from the estimations developed by IIASA using the GAINS model. In 2005 output related PM10 emission represents approximately 26 percent of the total PM10 level[27].

Annex Table 1: PM10 estimations per fuel use (GAINS model simulations - www.iiasa.ac.at)

	1990	**1995**	**2000**	**2005**
PM10 (Thousand tons)	5,702	6,731	7,059	7,032
Brown coal/lignite, grade 1	283	411	360	305
Hard coal, grade 2	1,485	2,023	2,049	2,041
Derived coal (coke, briquettes)	5	4	3	2
Biomass fuels	...	1	0	1
Agricultural residuals - direct use	608	696	802	764
Biogas	0	0	0	0
Dung	814	773	732	590
Fuelwood direct	938	1,020	1,097	1,228
Heavy fuel oil	6	7	8	9
Medium distillates (diesel, light fuel oil)	98	132	180	139
Gasoline and other light fractions of oil (includes kerosene)	83	117	162	67
Liquefied petroleum gas	1	1	2	3
Natural gas (incl. other gases)	0	0	0	0
Non exhaust PM emissions - road abrasion	3	3	4	3
Non exhaust PM emissions - brake wear	1	2	2	1
Non exhaust PM emissions - tyre wear	3	4	5	3
No fuel use	*1,373*	*1,536*	*1,651*	*1,876*

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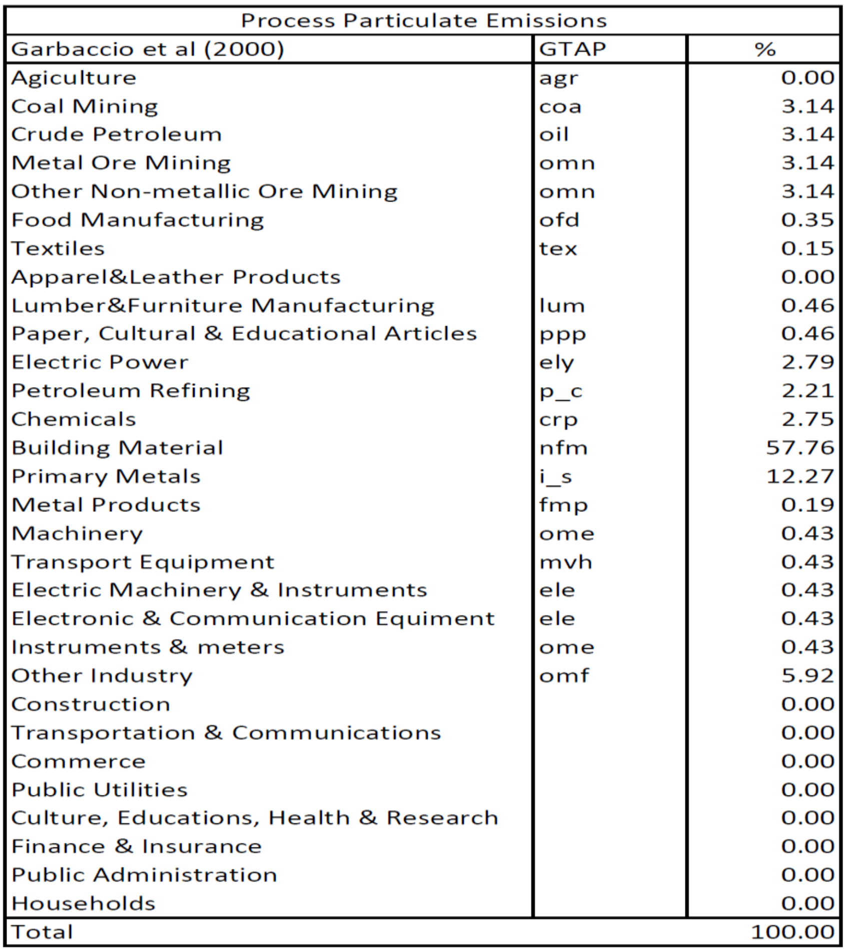
[27] See Table 3b in Garbaccio et al (2000) study for a list of activities at the origin of PM10 emissions (i.e construction). However, there is no construction sector in the GTAP model, hence the emissions coefficient from the Garbaccio et al (2000) are adjusted: "building material", "primary metals", "metal products" and "construction" sectors have been aggregated into one sector.

Annex Table 2: PM10 emissions per fuel use and origin in GTAP-India 2030 model[28]

2005	PM10 by fuel		
	Domestic	Imported	Total
Coal	3,070,247	216,773	3,287,020
Crude Oil	233	16	250
Natural Gas	259,912	145	260,057
Refined oil& coal products	1,475,492	128,605	1,604,098
Electricity	0	0	0
Total	4,805,884	345,540	5,151,424

Annex Table 3: GTAP mapping of process based emission coefficients



Process Particulate Emissions		
Garbaccio et al (2000)	GTAP	%
Agiculture	agr	0.00
Coal Mining	coa	3.14
Crude Petroleum	oil	3.14
Metal Ore Mining	omn	3.14
Other Non-metallic Ore Mining	omn	3.14
Food Manufacturing	ofd	0.35
Textiles	tex	0.15
Apparel&Leather Products		0.00
Lumber&Furniture Manufacturing	lum	0.46
Paper, Cultural & Educational Articles	ppp	0.46
Electric Power	ely	2.79
Petroleum Refining	p_c	2.21
Chemicals	crp	2.75
Building Material	nfm	57.76
Primary Metals	i_s	12.27
Metal Products	fmp	0.19
Machinery	ome	0.43
Transport Equipment	mvh	0.43
Electric Machinery & Instruments	ele	0.43
Electronic & Communication Equiment	ele	0.43
Instruments & meters	ome	0.43
Other Industry	omf	5.92
Construction		0.00
Transportation & Communications		0.00
Commerce		0.00
Public Utilities		0.00
Culture, Educations, Health & Research		0.00
Finance & Insurance		0.00
Public Administration		0.00
Households		0.00
Total		100.00

Currently, India’s major cities have severe air pollution problems, with average ambient concentrations of pollutants far in excess of WHO guidelines and/or Indian ambient standards. These problems are expected to increase with the rise of PM10 pollutants and their adverse effects on human health, which is detailed in the next section.

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[28] Adapted from Table 1

III. Sectoral Sources of Particulate Emissions

Agriculture related
Paddy or rice; wheat; cereal grains and others; vegetables, fruit, nuts; oil seeds; sugar cane, sugar beet; plant-based fibers; crops and others; bovine cattle, sheep and goats; animal products and others; raw milk; wool, silk-worm cocoons; forestry; fishing.

Energy related
Coal mining; crude oil; natural gas extraction; refined oil products; petroleum; coal products; and electricity.

Energy intensive industries
Minerals and others; chemical, rubber, plastic prod; mineral products and others; ferrous metals; metals and others.

Other industries and services
Bovine cattle, sheep and goat; meat products; vegetable oils and fats; dairy products; processed rice; sugar; food products and others and others; beverages and tobacco products; textiles; wearing apparel; leather products; wood products; paper products, publishing; metal products; motor vehicles and parts; transport equipment and others; electronic equipment; machinery and equipment and others; manufactures and others; water; construction; manufacturing and distribution of natural gas; trade; transport and others; water transport; air transport; communication; financial services and others; insurance; business services and others; recreational and other service; public administration and defense, education; ownership of dwellings.

IV. Assumptions of BAU

The following tables give the key exogenous assumptions that were used in the model.

Annex Table 4: Assumptions of BAU (Conventional GDP Growth)

(in % terms)

Years	Population Growth	Labor Force Growth	TFP Change	GDP growth
2010	1.01	1.01	2.00	10.08
2011	1.01	1.01	2.00	7.84
2012	1.01	1.01	2.00	7.51
2013	1.01	1.01	2.00	8.11
2014	1.01	1.01	2.00	8.17
2015	1.01	1.01	2.00	8.14
2016	1.01	1.01	2.00	8.16
2017	1.01	1.01	2.00	7.60
2018	1.01	1.01	2.00	7.23
2019	1.01	1.01	2.00	6.77
2020	1.01	1.01	2.00	6.58
2021	1.01	1.01	2.00	6.43
2022	1.01	1.01	2.00	6.24
2023	1.01	1.01	2.00	6.13
2024	1.01	1.01	2.00	5.95

2025	1.01	1.01	2.00	5.84
2026	1.01	1.01	2.00	5.77
2027	1.01	1.01	2.00	5.63
2028	1.01	1.01	2.00	5.57
2029	1.01	1.01	2.00	5.47
2030	1.01	1.01	2.00	5.37

V. PM10 emission coefficients linked to fuel use by sector (tons per million local currency)

Sectors (Garbaccio et al., 2000)	Coal	Oil	Natural Gas
Agriculture	42,560	160	27
Coal Mining	38,182	143	24
Crude Petroleum	38,182	143	24
Metal Ore Mining	38,182	143	24
Other Non-metallic Ore Mining	38,182	143	24
Food Manufacturing	32,983	124	21
Textiles	18,505	69	12
Apparel, Leather Products	7,678	29	5
Lumber, Furniture Manufacturing	25,629	949	27
Paper, Cultural & Educational Articles	25,629	949	27
Electric Power	32,642	544	0
Petroleum Refining	7,235	723	12
Chemicals	17,898	1,790	30
Building Material	13,454	1,345	22
Primary Metals	6,379	638	11
Metal Products	8,814	33	6
Machinery	11,970	45	7
Transport Equipment	11,970	45	7
Electric Machinery & Instruments	11,970	45	7
Electronic & Communication Equipment	11,970	45	7
Instruments & meters	11,970	45	7
Other Industry	46,872	176	29
Construction	42,560	160	27
Transportation & Communications	42,560	5,320	27
Commerce	42,560	160	27
Public Utilities	42,560	160	27
Culture, Educations, Health & Research	42,560	160	27
Finance & Insurance	42,560	160	27
Public Administration	42,560	160	27
Households	21,280	426	27

VI. Sector process-linked contributions to PM10 emissions

Sectors (Garbaccio et al., 2000)	%	GTAP Abbrev.
Agriculture	0.00	
Coal Mining	3.14	Coa
Crude Petroleum	3.14	Oil
Metal Ore Mining	3.14	Omn
Other Non-metallic Ore Mining	3.14	Omn
Food Manufacturing	0.35	Ofd
Textiles	0.15	Tex
Apparel, Leather Products	0.00	
Lumber, Furniture Manufacturing	0.46	Lum
Paper, Cultural & Educational Articles	0.46	Ppp
Electric Power	2.79	Ely
Petroleum Refining	2.21	p_c
Chemicals	2.75	Crp
Building Materials	57.76	Nfm
Primary Metals	12.27	Nfm
Metal Products	0.19	Fmp
Machinery	0.43	Ome
Transport Equipment	0.43	Mvh, otn
Electric Machinery & Instruments	0.43	Ele
Electronic & Communication Equipment	0.43	Ele
Instruments & meters	0.43	Ome
Other Industry	5.92	Omf
Construction	0.00	
Transportation & Communications	0.00	
Commerce	0.00	
Public Utilities	0.00	
Culture, Educations, Health & Research	0.00	
Finance & Insurance	0.00	
Public Administration	0.00	
Households	0.00	
Total	100	

Note: Mapping with the GTAP classification done by the study team

VII . The health impact simulations

Particulate matter can be defined as a mixture of liquid and solid particles and chemicals that vary in size and spatially. The smaller the size of the particle, the easier it is for it to enter the human respiratory system and even the bloodstream in some cases. The existing literature on the health effects of particulate matter show that particles measuring less than 10 microns penetrate the lungs more easily than the larger sized particles. In particular, PM10 has an impact on the respiratory diseases. The most widely known adverse health impact of PM10 is premature mortality. Long-term exposure to PM10 can impact mortality and morbidity levels. Levels of particulate matter are often much higher in developing countries as compared to those in developed countries. Ostro (1994) coefficients are used to calculate PM10 health effects.

Since PM10 causes premature death, one of the implications of high PM10 levels in the country would be a decrease in the available labor force. With a large population the effect on mortality rates and on the labor force are calculated using estimates from the Jakarta study (Ostro, 1994). The health damages calculated outside of the CGE model produced central, upper and lower estimates for the coefficients of change in mortality. All three figures have been used to calculate a range of results in the CGE simulations.

As for the PM10 emissions, the projections from the CGE results have been used to calculate the PM10 concentrations for India. The base year concentration level of 97.58$\mu g/m^3$ is the average concentration level of the pollutant across all cities in India (calculated using Central Pollution Control Board of India data). The concept of uniform rollback was used to calculate the concentrations for the subsequent years. Uniform rollback states that the percent change in pollutant emissions on an annual basis will equal to the percent change in pollutant concentrations on an annual basis. Therefore, using the base year average for PM10 for the year 2010, projections can be made for PM10 concentrations using the percent change in PM10 emissions from the CGE model.

The dose response coefficients are from the Ostro study on Jakarta (Ostro, 1994). Such an epidemiological study has not been carried out for India Jakarta is the next best study as its data provide more plausible health estimates than data from industrialized nations. For the purpose of this study, we calculate the impact of premature mortality on India's labor force which would likely have the highest and are the most impacted. Literature suggests that in general children and people above the age of 65 are most vulnerable to respiratory diseases from particulate matter In the case of India, however, the labor force will have maximum exposure to PM10 since they have maximum outdoor exposure.

The dose response coefficient for premature mortality has a central value and upper and lower bounds for the 95 percent confidence interval. The numbers in the table below give the percentage increase in mortality from the baseline per one microgram per normal cubic meter of concentration. All three coefficients have been used to project a range of the mortality effects along with the central estimates.

The total labor force numbers and projections have been obtained from the CGE model results. These numbers are used to calculate the effected labor force numbers. Exposure to PM10 will reduce the labor force as a result of premature mortality. These numbers will be used to project an economic growth path taking into account the reduced labor force.

Dose Response Coefficients

Dose Response Coefficient	**Value**
Upper	0.008272
Central	0.006015
Lower	0.003758

Source: Pope et al. 1995

Health Impacts and Monetary Losses

The health damage estimates from PM10 were calculated for three health-related endpoints:

i. Premature Mortality from PM10
ii. Morbidity from PM10 - Reduced Activity Days (RAD)
iii. Morbidity from PM10 - Respiratory Hospital Admissions (RHA)

Premature Mortality

The log linear method has been used to estimate premature mortality, as outlined in the WHO, 2004 paper. To estimate premature mortality, we use PM2.5 concentrations, which have been converted from PM10 using a conversion factor of 0.65. In order to calculate mortality, the relative risk (RR) is calculated based on the observed PM concentrations as shown in equation (1) below. Using the RR, the attributable factor (AF) is calculated as shown in equation (2) below. Premature mortality is estimated using equation (3) for all cities.

$$\text{Relative Risk (RR)} = [(X+1)/(X_0+1)]^{\beta} \qquad (1)$$

Where:

X = Observed PM Concentration
X_0 = Background PM Concentration (taken as 5μg/m^3, as per WHO guidelines (WHO, 2004))
β = Concentration-Response Coefficient

$$AF = (RR-1)/RR \qquad (2)$$

Where,
AF = Attributable Factor

$$\text{Mortality} = AF \times POP \times CMR \qquad (3)$$

Where,
POP: City Population exposed to PM2.5
CMR: Urban Crude Mortality Rate

PM2.5 is known to cause premature mortality and the crude mortality rate (CMR) is required for its estimation. The CMR estimation was specifically done for urban areas (Registrar General of India, SRS Bulletin, 2009). The CMR figure is higher at the national level than at the urban level, since the national CMR also includes deaths in rural areas. To obtain accurate results, urban CMR figures were used for mortality calculations. CMR projections were made following the trends in the past years since there is no other source for the CMR.

The dose–response coefficient for premature mortality as a result of exposure to PM2.5 was taken from Pope et al. (2002). Premature mortality estimates for the selected cities for all years were made using central estimates and the 95 percent confidence intervals for premature mortality.

The monetary value of premature mortality from PM2.5 was estimated using the standard Value of Statistical Life (VSL) method. VSL was estimated for premature deaths across the mega cities, million-plus cities and the metropolitan cities from 2010 to 2030. This study used an average VSL value based on estimates from four India-specific studies. The values were as follows:

- Shanmugam (1999) using a WTP (Willingness to Pay)approach: Rs 18,932,020 (2010 prices): approximately US$ 420,712
- Simon, et al. (1999) using WTP approach: Rs 16,197,563 (2010 prices): approximately US$ 142,608–US$ 359,946
- Madheswaran, S. (2007): Rs 16,939,353 (2010 prices): US$ 376,430
- Bussolo & Connor (2001) Human Capital Approach: Rs 19,109,280 (2010 prices): approximately US$ 424,651
- The average exchange rate for 2010 was US$ 1 = Rs 45.

The average VSL estimate from these four abovementioned studies is US$ 404,422. This value will increase over time in line with the growth rate for income per capita as projected in the CGE model.

Reduced Activity Days (RADs)

The equation for calculating RAD due to PM10 exposure was as follows:

$RAD = \gamma \text{ x } POP \text{ x } PM10$

RAD: Reduced Activity Days from PM10 for a given year for each city
γ: RAD Dose Response Coefficient for PM10 (WHO, 2004)
POP: City Population exposed to PM10
PM10: PM10 Concentration in each city

The WHO 2004 study estimated the dose–response coefficient for RAD arising from PM10 concentrations. The RAD coefficient was calculated based on epidemiological studies. The coefficient was used to determine RAD in each city until 2030. Reduced activity in a day would lead to a loss in income. The average income per capita per day in urban areas was used as the basis to determine the total loss. This income per capita per day increased in line with the projections for per capita GDP from the CGE model.

Respiratory Hospital Admissions (RHA)

The equation for calculating the respiratory hospital admissions from exposure to PM10 is as follows:

$RHA = \xi \text{ x } POP \text{ x } PM10$

RHA: Respiratory Hospital Admissions from PM10 for a given year for each city
ξ: RHA Dose Response Coefficient for PM10 (WHO, 2004)
POP: City Population
PM10: PM10 Concentration in each City

The WHO 2004 study estimates the dose–response coefficient for RHA arising from PM10 concentrations. Each RHA involved an eight-day hospital stay, with incurred medical expenses and loss of income. The hospital costs were estimated at US$ 30 per day, based on WHO figures for India. The income per capita per day in urban areas was used as the basis to determine the total loss. Both the income per capita per day and hospital costs increased in line with the projections for per capita GDP from the CGE model.