GAINS ASIA

SCENARIOS FOR COST-EFFECTIVE CONTROL OF AIR POLLUTION AND GREENHOUSE GASES IN INDIA

Pallav Purohit, Markus Amann, Ritu Mathur, Ila Gupta, Sakshi Marwah, Vishal Verma, Imrich Bertok, Jens Borken, Adam Chambers, Janusz Cofala, Chris Heyes, Lena Hoglund, Zbigniew Klimont, Peter Rafaj, Robert Sandler, Wolfgang Schöpp, Geza Toth, Fabian Wagner, Wilfried Winiwarter

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The GAINS-Asia model integrates a number of established economic and environmental models developed by international experts at the following institutions:

IIASA
International Institute for Applied Systems Analysis
Laxenburg, Austria

ERI
Energy Research Institute
Beijing, China

TERI
The Energy and Resources Institute
Delhi, India

JRC-IES
Institute for Environment and Sustainability of the Joint Research Centre of the European Union
Ispra, Italy

UBERN
The University of Bern
Bern, Switzerland

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Further information:

GAINS
International Institute for
Applied Systems Analysis (IIASA)
Schlossplatz 1
A-2361 Laxenburg
Austria

Tel: +43 2236 807
Email: rainsinfo@iiasa.ac.at
Web: http://gains.iiasa.ac.at

Executive Summary

There is growing recognition that a comprehensive and combined analysis of air pollution and climate change could reveal important synergies of emission control measures. Insight into the multiple benefits of measures could make emission controls economically more viable, both in industrialized and developing countries. However, while scientific understanding on many individual aspects of air pollution and climate change has considerably increased in the last years, little attention has been paid to a holistic analysis of the interactions between both problems.

The Greenhouse gas – Air pollution Interactions and Synergies (GAINS) model has been developed as a tool to identify emission control strategies that maximize synergies between the control of local air quality and the mitigation of greenhouse emissions. GAINS investigates how specific mitigation measures simultaneously influence different pollutants that threaten human health via the exposure of fine particles and ground-level ozone, damage natural vegetation and crops, contribute to climate change.

In recent years the GAINS model has been implemented for India in collaboration between the International Institute for Applied Systems Analysis (IIASA) and The Energy and Resources Institute (TERI). This report presents a first analysis conducted with the GAINS model that highlights how strategies to control local air quality could be designed in such a way that co-benefits on greenhouse gas mitigation could be maximized. The main qualitative findings of this study are summarized below; however, robust quantitative conclusions for India will require validation of the input data that have been collected in this initial study.

Current economic growth will counteract ongoing efforts to improve air quality problems in India unless pollution control laws are significantly upgraded.

Current and future economic growth in India will counteract ongoing efforts to improve air quality through controls of particulate matter emissions from large stationary sources and nitrogen oxide (NO_x) emissions from vehicles. In a scenario of rapid economic growth and increasing reliance of power generation on imported coal (without appropriate pollution control technologies being adopted), SO_2 emissions could increase five-fold over the next two decades in India. Further, if there are no regulations for controlling emissions of NO_x from large stationary sources, there could be a three-fold increase in India's NO_x emissions between 2005 and 2030 despite the tight emission control legislation that has been recently imposed on mobile sources. Without further air pollution control policies or major fuel and technological changes, negative impacts on human health and vegetation that are currently felt across India may not substantially improve in the coming decades. For instance, the GAINS model estimates that present exposure to fine particulate matter (PM2.5) is shortening life expectancy of the Indian population by approximately 25 (13-34) months, and it would double in a business-as-usual case for the next two decades. Emissions of greenhouse gases that contribute to global climate change would increase by a factor of three between 2005 and 2030.

Advanced emission control technologies are available to maintain acceptable levels of air quality despite the pressure from growing economic activities.

Yet, advanced emission control technologies are available to maintain acceptable levels of air quality despite the pressure from growing economic activities. Full application of advanced technical end-of-pipe emission control measures in India (e.g., flue gas desulfurization or catalysts for power plants) could lead to substantial improvements in air quality. Based on a preliminary analysis using the GAINS-Asia model, it is estimated that in 2030 by applying such advanced emission control technology to all large sources in India negative health impacts could be reduced by half compared to the business-as-usual case. However, such an undifferentiated across-the-board approach would impose significant burden on the economy, involving an additional expense of 0.80% of GDP.

A cost-effective strategy can reduce costs for air pollution control by up to 50% compared to conventional approaches.

The GAINS model can identify cost-effective portfolios of emission control measures that achieve improvements in environmental impacts at least costs. A cost-effective emission control strategy developed with the GAINS optimization tool, which selectively allocates specific reduction measures across economic sectors, pollutants and regions, indicates that equal air quality improvements till 2030 could be achieved at only 50% of the costs of a conventional across-the-board approach. An integral element of such an air pollution control strategy will be measures to eliminate indoor pollution from the combustion of solid fuels. The preliminary analysis also indicates that such an investment could also reduce ozone precursor emissions and thereby crop losses by around 40% and have far ranging positive impacts on the environment.

A smart mix of measures that includes actions to reduce energy consumption can further cut air pollution control costs, and achieve lower greenhouse gas emissions.

Well-designed air pollution control strategies can also reduce emissions of greenhouse gases. For achieving given targets on ambient air quality, the cost of air pollution can be further reduced by adopting certain low carbon measures. A GAINS scenario demonstrates that a strategy employing certain climate-friendly measures, e.g., energy efficiency improvements, fuel substitution, co-generation of heat and power, integrated coal gasification combined cycle (IGCC) plants, etc., would reduce air pollution at lower costs than a conventional approach that relies on technical end-of-pipe emission control measures. At the same time greenhouse gas emissions would be lower.

For policymakers, industry, NGOs and researchers wishing for more information and to conduct independent analyses, the GAINS-Asia model and documentation is freely available online at http://gains.iiasa.ac.at.

About the authors

This report is the result of cooperation between scientists at the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria and The Energy and Resources Institute (TERI) in New Delhi, India.

At IIASA, the work was carried out by team of IIASA's Atmospheric Pollution and Economic Development programme, led by Markus Amann. Team members include Imrich Bertok, Jens Borken, Janusz Cofala, Chris Heyes, Lena Hoglund, Zbigniew Klimont, Pallav Purohit, Peter Rafaj, Wolfgang Schöpp, Geza Toth, Fabian Wagner and Wilfried Winiwarter.

The team at TERI was led by Ritu Mathur. Team members included Ms Ila Gupta, Ms Sakshi Marwah, Mr Vishal Verma.

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1 Introduction

After decades with moderate economic growth in India of typically 5% per year, economic reforms have boosted annual growth rates of GDP (at constant prices) after 2002 to 8-9 percent per year (Planning Commission, 2006a). Thereby, India has embarked on a growth track that resembles the dynamic path of China after 1992. In order to achieve its development goals, the Indian government aims to maintain the economic growth rate above 8 percent per year in the next two decades (Planning Commission, 2006b; TERI, 2006), which would increase per-capita income by a factor of five, and total GDP by a factor of seven up to 2030 as compared to the base year 2005, given that population is likely to grow to 1.5 billion people. While other estimates such as those of the IEA consider a lower GDP growth of around 6.3% for India (IEA, 2007) during this period, these studies also indicate the challenge of achieving the desired growth in a sustainable manner.

Rapid increase in energy and infrastructure requirements is imminent for a country like India – but brings with it the formidable challenge of providing appropriate infrastructure and securing the supply of inputs such as energy without compromising the sustainability of natural resources, the local environment and the living conditions of the population. The challenge of advancing human wellbeing through continued economic development while providing acceptable levels of air quality to the citizens and assuring sustainable conditions to vegetation and ecosystems is further compounded by the concerns about greenhouse gas (GHG) emissions. Given the multitude of challenges facing the policy makers, it is important to examine the synergies between measures to combat air pollution and GHG mitigation.

For a number of historic reasons, response strategies to air pollution and climate change are often addressed by different policy institutions. However, there is growing recognition that a comprehensive and combined analysis of air pollution and climate change could reveal important synergies of emission control measures (Swart *et al.*, 2004; Ramanathan and Carmichael, 2008), which could be of high policy relevance. Insight into the multiple benefits of control measures could make emission controls economically more viable, both in industrialized and developing countries. While scientific understanding on many individual aspects of air pollution and climate change has considerably increased in the last years, little attention has been paid to a holistic analysis of the interactions between both problems (Barker *et al.*, 2007).

The Greenhouse gas – Air pollution Interactions and Synergies (GAINS) model has been developed as a tool to identify emission control strategies that achieve given targets on air quality and greenhouse gas emissions at least costs. GAINS considers measures for the full range of precursor emissions that cause negative effects on human health via the exposure of fine particles and ground-level ozone, damage to vegetation via excess deposition of acidifying and eutrophying compounds, as well as the six greenhouse gases considered in the Kyoto protocol. In addition, it also considers how specific mitigation measures simultaneously influence different pollutants. Thereby, the GAINS framework allows for a comprehensive and combined analysis of air pollution and climate change mitigation strategies, which reveals important synergies and trade-offs between these policy areas. This state-of-the-art interdisciplinary model builds on a scientific tool that has already helped European governments slash air pollution across the continent without compromising economic development (Hordijk and Amann, 2007).

Under the EU Sixth Framework Programme on Research (FP6), an international team of research institutions has implemented the GAINS model for India and China. The research team, headed by the International Institute for Applied Systems Analysis (IIASA, Laxenburg, Austria), included the Chinese Energy Research Institute (ERI, Beijing, China), Tsinghua University (Beijing, China), The Energy and Resource Institute (TERI, Delhi, India), the Institute for Environment and Sustainability of the Joint Research Centre of the European Commission (IES-JRC, Ispra, Italy) and the University of Bern (Switzerland). The GAINS model with all databases is now freely accessible for interactive use at the Internet (http://gains.iiasa.ac.at).

This report presents a set of scenarios that explore cost-effective strategies for reducing health and vegetation impacts of poor air quality in India. As a starting point the report summarizes emissions and resulting air quality for the year 2005 as estimated by the GAINS model (Section 2). For the projection of the Indian government on economic development up to 2030, Section 3 outlines the likely development of emissions, air quality and health and vegetation impacts that would result from the full implementation of emission control measures that are currently laid down in current Indian legislation. Section 4 explores alternative emission control strategies for reducing air pollution impacts in the future. It examines the cost-effectiveness of (i) uniform application of advanced end-of-pipe emission control technologies to large emission sources, (ii) an optimized allocation of air pollution control measures that achieve the same environmental improvements at least cost, (iii) of air pollution control strategies that also include structural changes in the energy system, and (iv) energy strategies that aim at reducing greenhouse gas emissions in India. Conclusions are drawn in Section 5.

This report is the outcome of a collaborative effort of IIASA and TERI. Activity data and projections for energy, agriculture, mobile and process industries were provided by TERI. Most of these data and projections were taken from the study "National Energy Map for India: Technology Vision 2030" that has been carried out by TERI for the Office of the Principal Scientific Advisor to the Government of India in 2006 (TERI, 2006). Emissions characteristics and control strategies for India have been jointly developed by IIASA and TERI. IIASA developed the GAINS online model, the optimization module, and the emission control costs and impacts module.

This report aims at highlighting the scope for measures that maximize co-benefits between air pollution control and greenhouse gas mitigation in qualitative terms. A quantitative policy analysis, however, will require a more in-depth review of the input data that have been compiled by the project.

The methodology of the GAINS-Asia model is documented in detail in a companion report (Amann *et al.*, 2008a) that is available at http://gains.iiasa.ac.at. Policy scenarios for China are presented in a parallel report (Amann *et al.*, 2008b). The interactive GAINS-Asia model is freely accessible on the Internet at http://gains.iiasa.ac.at.

2 Emissions and air quality impacts in 2005

2.1.1 AN EMISSION INVENTORY FOR 2005

As a starting point for the analysis of future air quality impacts, the GAINS model employs and emission inventory that reflects sectoral emissions in the year 2005 for the 23 regions distinguished for this exercise. For the purposes of this study, Indian States were grouped into 23 regions. Most of the regions represent a single state, although some of the smaller states were grouped together.

Based on energy statistics and information on fuel quality and specific combustion characteristics, the GAINS model estimates that in 2005 India emitted 6.41 million tons of SO_2, 5.07 million tons of NO_x, 8.21 million tons of PM10 of which are 5.8 million in form of PM2.5, 6.64 million tons of NH_3 and 15.17 million tons of VOC into the atmosphere (Table 2.1).

Table 2.1: Estimates of emissions of air pollutants from anthropogenic sources in India in 2005, by sector (kilotons)

SECTOR	SO_2	NO_x	PM2.5	PM10	NH_3	VOC
COMBUSTION IN ENERGY AND TRANSFORMATION INDUSTRIES	3396	1546	275	600	0	44
NON-INDUSTRIAL COMBUSTION PLANTS	352	408	3107	3221	55	10266
COMBUSTION IN MANUFACTURING INDUSTRY	2208	759	1353	3016	1	22
PRODUCTION PROCESSES	189	44	81	191	37	2330
EXTRACTION AND DISTRIBUTION OF FOSSIL FUELS AND GEOTHERMAL ENERGY	0	0	3	26	0	103
SOLVENT AND OTHER PRODUCT USE	0	0	0	0	0	0
ROAD TRANSPORT	117	1273	219	237	4	1359
OTHER MOBILE SOURCES AND MACHINERY	124	1017	106	111	0	385
WASTE TREATMENT AND DISPOSAL	3	3	146	148	665	0
AGRICULTURE	17	16	513	660	5875	656
TOTAL	6406	5066	5803	8210	6638	15166

For SO_2, almost 87 percent of total emissions originated from power generation and industrial energy combustion. 44 percent of NO_x emissions are estimated to emerge from mobile sources (25 percent from road traffic), while industrial sources contributed 15 percent and the power sector 31 percent. The largest sources of fine particles (PM2.5) were domestic sector (54 percent) with its incomplete combustion of solid fuels, while the industrial sector as the next largest source of fine particles, emitted 23 percent of PM2.5. Solid fuel combustion in households was also responsible for 68 percent of the anthropogenic emissions of volatile organic compounds, while NH_3 emissions were predominantly released from agricultural activities (Figure 2.1).

Table 2.2: Estimates of Indian emissions of greenhouse gases from anthropogenic sources in 2005, by sector

SECTOR	CO_2 (Mt)	CH_4 (kt)	N_2O (kt)	All GHGs (Mt CO_2eq)
COMBUSTION IN ENERGY AND TRANSFORMATION INDUSTRIES	642	9	9	645
NON-INDUSTRIAL COMBUSTION PLANTS	103	1983	27	153
COMBUSTION IN MANUFACTURING INDUSTRY	357	7	3	358
PRODUCTION PROCESSES	24	1	4	26
EXTRACTION AND DISTRIBUTION OF FOSSIL FUELS AND GEOTHERMAL ENERGY	32	5570	0	149
SOLVENT AND OTHER PRODUCT USE	0	0	7	2
ROAD TRANSPORT	141	107	4	144
OTHER MOBILE SOURCES AND MACHINERY	70	58	2	72
WASTE TREATMENT AND DISPOSAL	3	3728	56	99
AGRICULTURE	0	14916	654	516
TOTAL	**1373**	**26378**	**766**	**2164**

In 2005, power generation accounted for almost 47 percent of anthropogenic CO_2 emissions in India, and industrial energy combustion another 26 percent. The largest shares of CH_4 emissions originated from agricultural (57 percent) and coal mining (21 percent) activities, while agriculture emitted 85 percent N_2O emissions (Table 2.2, Figure 2.2).

While there are significant uncertainties in all estimates of emission inventories, in particular for the conditions of developing countries, GAINS estimates compare well with the other available inventories from national and international sources. However, there are particular large uncertainties for pollutants for which very limited information is available for the specific conditions of India, such as for PM2.5, NH_3 and VOC. For calculating these emissions, the current GAINS analysis employs emission factors that have been determined for countries with similar conditions to arrive at a first estimate of the potential magnitude of emissions (Cofala and Syri, 1998a 1998b; Klimont et al. 2000, 2002; Klimont and Brink, 2004; Höglund-Isaksson and Mechler, 2005; Klaassen et al., 2005; Tohka, 2005; Winiwarter, 2005). As a consequence the real emission situation for specific emission sources in India may be very different. A more precise estimate will require measurements of emission factors, at least for the most relevant emission sources. Detailed comparisons of available emission inventories for India are provided in Annex I.

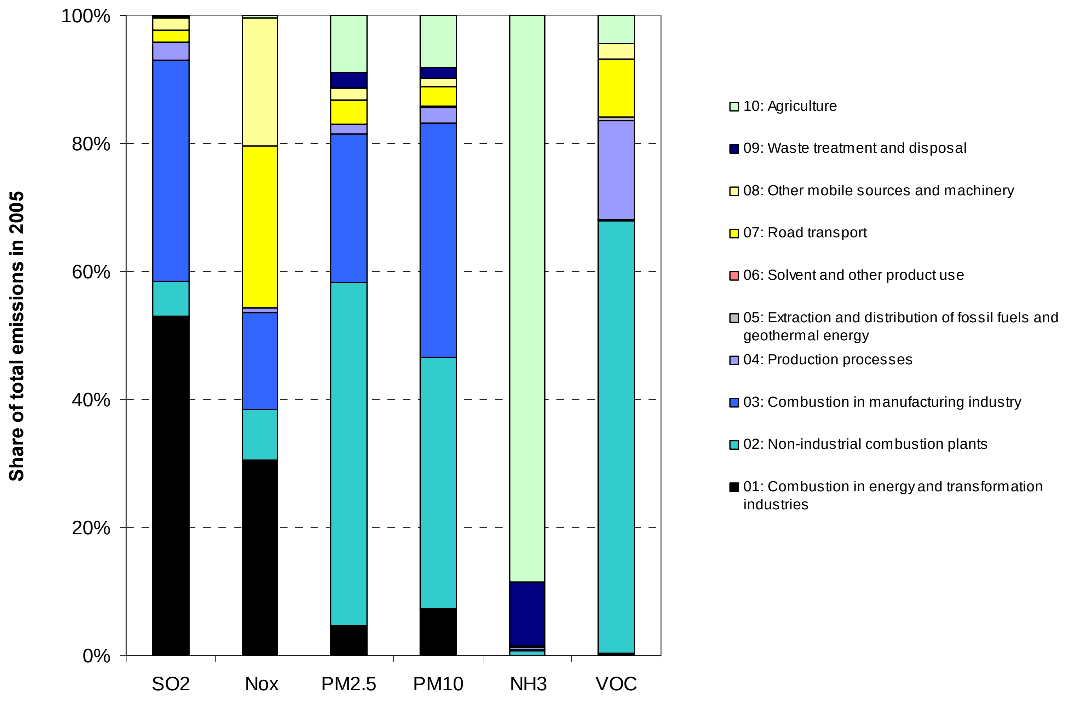

Figure 2.1: Contributions of source sectors to total anthropogenic emissions of air pollutants in India in 2005

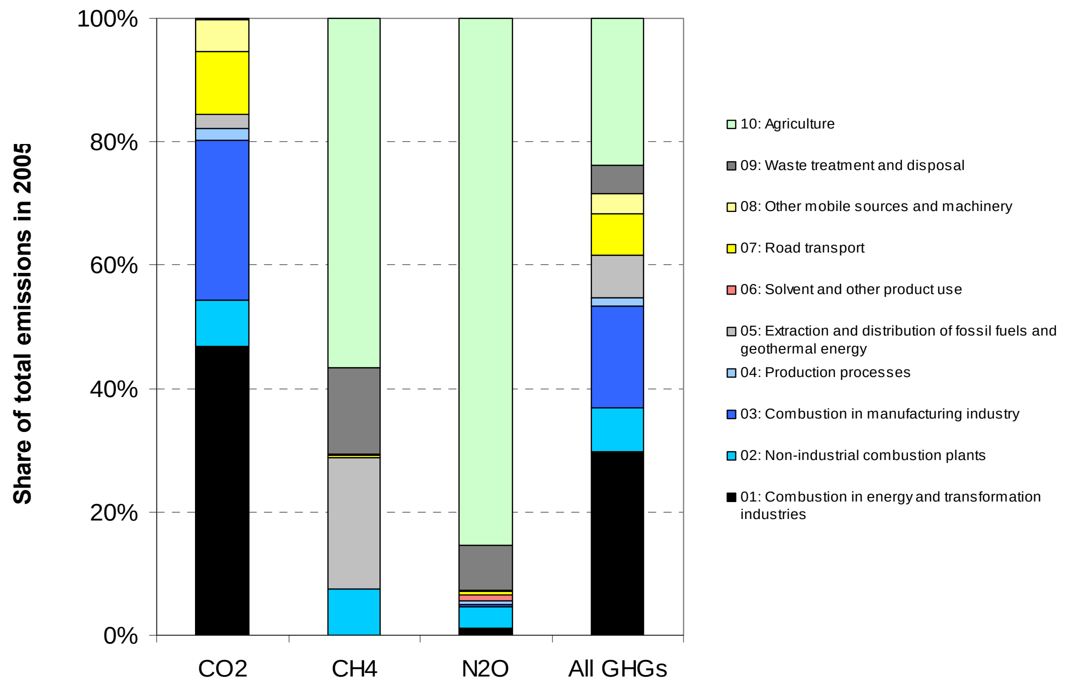

Figure 2.2: Contributions of source sectors to total anthropogenic emissions of greenhouse gases in India in 2005

Based on regional energy statistics and fuel characteristics, emissions are estimated for each of the 23 regions considered in this study (Table 2.3 and Table 2.4).

Table 2.3: Emissions of air pollutants in 2005 by GAINS regions in India (kilotons)

	SO_2	NO_x	PM2.5	PM10	NH_3	VOC[1)]
ANDHRA PRADESH	523	425	412	629	589	942
ASSAM	51	69	135	153	163	487
WEST BENGAL	487	377	434	562	446	1194
BIHAR	117	125	232	308	398	771
CHHATTISGARH	343	227	271	537	180	353
DELHI	54	109	28	37	15	207
NORTH EAST[2)]	89	112	181	321	72	363
GOA	17	20	6	10	4	23
GUJARAT	706	376	410	744	330	760
HARYANA	140	171	118	150	263	332
HIMACHAL PRADESH	44	43	50	68	47	134
JHARKHAND	175	118	194	312	146	379
KARNATAKA	217	201	303	362	331	916
KERALA	122	126	178	191	61	658
MAHARASHTRA[3)]	870	534	462	672	533	1058
MADHYA PRADESH	391	313	361	545	475	834
ORISSA	345	205	314	458	260	751
PUNJAB	173	172	132	176	302	320
RAJASTHAN	209	284	471	552	456	1372
TAMIL NADU	677	452	238	336	309	597
UTTARANCHAL	14	29	132	139	68	394
UTTAR PRADESH	636	547	675	875	1115	2090
JAMMU AND KASHMIR	9	32	65	74	75	232
TOTAL	6406	5066	5803	8210	6638	15166

Note: [1)] Energy-related emissions only

[2)] Excluding Assam

[3)] Including Dadra and Nagar Haveli and Daman and Diu (Other Union Territories are added with the neighbouring GAINS region/State)

Table 2.4: Emissions of greenhouse gases in 2005 by GAINS regions in India

	CO_2 (Mt)	CH_4 (kt)	N_2O (kt)	all GHGs (Mt CO_2eq)
ANDHRA PRADESH	126	2376	81	201
ASSAM	11	729	15	31
WEST BENGAL	109	1970	57	168
BIHAR	30	1388	44	73
CHHATTISGARH	81	1746	17	123
DELHI	24	85	2	26
NORTH EAST	31	357	7	41
GOA	3	17	0	4
GUJARAT	119	1039	34	151
HARYANA	29	618	30	52
HIMACHAL PRADESH	9	141	5	13
JHARKHAND	49	1641	14	88
KARNATAKA	48	942	47	82
KERALA	19	295	8	28
MAHARASHTRA	159	1826	67	218
MADHYA PRADESH	96	2007	44	152
ORISSA	73	1998	26	124
PUNJAB	37	916	38	67
RAJASTHAN	53	1330	51	97
TAMIL NADU	106	832	43	137
UTTARANCHAL	3	294	7	11
UTTAR PRADESH	154	3577	119	266
JAMMU AND KASHMIR	3	253	9	12
TOTAL	1373	26378	766	2164

As indicated in Figure 2.3, per-capita emissions for SO_2 and NO_x are significantly lower in India than in the United States, European Union and China; somewhat lower for NH_3 and VOC; but higher than the per-capita emissions of the European Union for PM2.5. Figure 2.4 indicates that when compared on a per-capita basis, estimates of all GHG emissions for India are much lower when compared with data for the United States of America, the European Union and China. It is important to examine the future growth in levels of air pollutants to examine which of these might have major implications for the region over time.

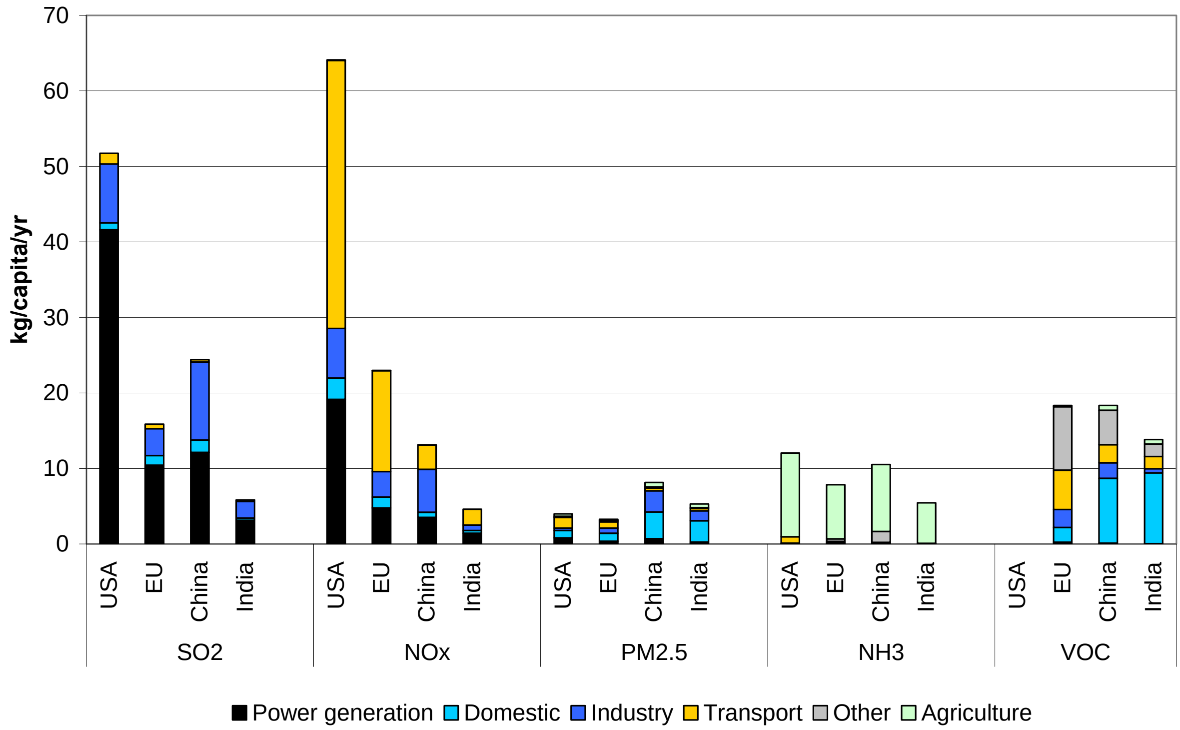

Figure 2.3: Per-capita emissions of air pollutants by sector in 2005

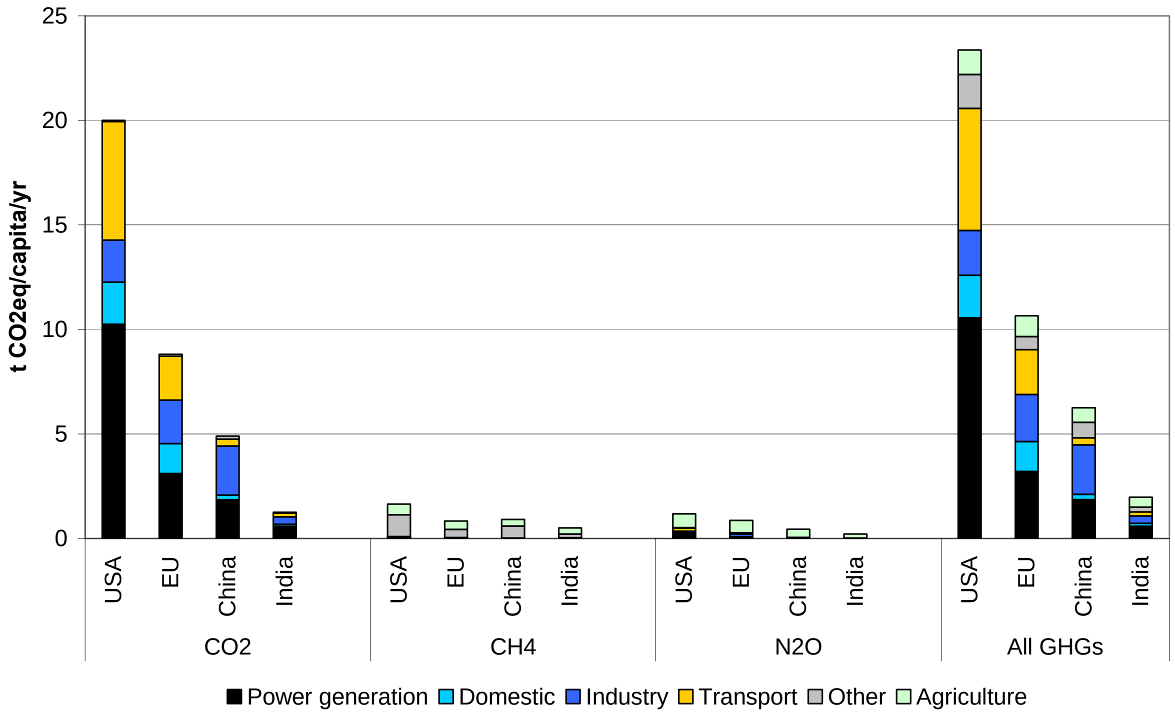

Figure 2.4: Per-capita emissions of greenhouse gases by sector in 2005

2.2 Air quality

For the emission inventory presented above the GAINS model estimates air quality and resulting impacts on human health and environment.

2.2.1 AMBIENT CONCENTRATIONS OF PM2.5

Based on the detailed spatial and sectoral GAINS emission inventory, GAINS computes fields of ambient concentrations of PM2.5 with the help of source-receptor relationships derived from the TM5 model (Krol et al., 2005). The model computed contributions from (i) primary particulate matter (PM2.5) released from anthropogenic sources, (ii) secondary inorganic aerosols formed from anthropogenic emissions of SO_2, NO_x and NH_3, and (iii) particulate matter from natural sources (soil dust, sea salt, biogenic sources).

In its standard mode the TM5 model calculates PM2.5 concentrations with a 1 x 1 degree spatial resolution. Ideally, though, a health impact assessment requires more spatially detailed information on population exposure in urban areas, where the majority of people live. In order to provide this extra detail, a special routine was developed to identify sub-grid differences in PM2.5 concentrations as a function of local emission densities and the spatial extensions of urban areas within a 1 x 1 degree grid cell. In this way, making use of the detailed data available from the CIESIN 2'5 x 2'5 population database, an "urban increment" in PM2.5 concentration could be estimated for the major population centres (http://www.ciesin.columbia.edu/; http://sedac.ciesin.columbia.edu/gpw/).

The health impact assessment in GAINS associates only anthropogenic sources with negative health impacts. Figure 2.5 displays annual mean concentrations of PM2.5 in ambient air computed for the emissions of 2005.

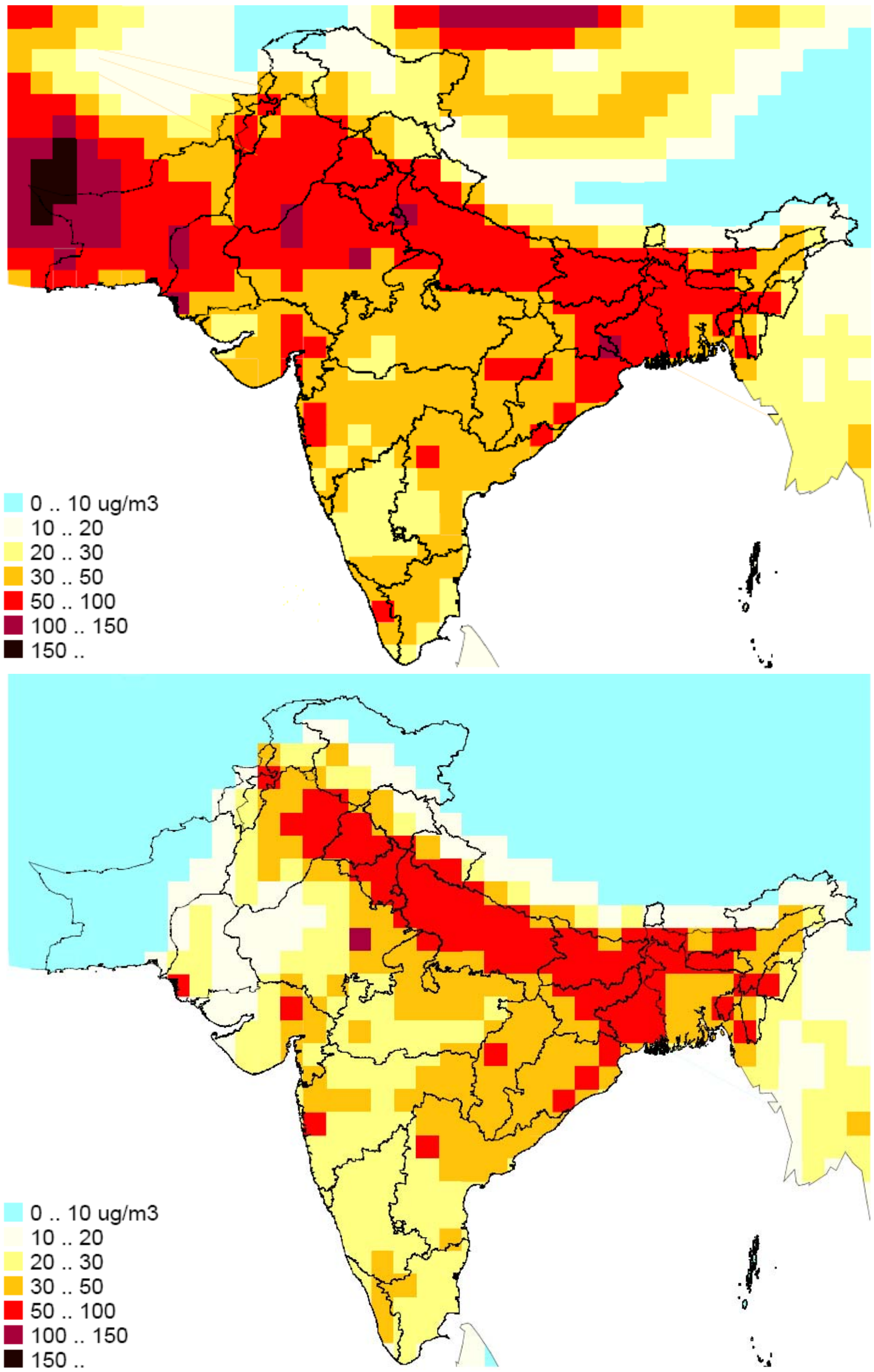

Figure 2.5: Ambient concentrations of PM2.5 computed for 2005. Top panel: all sources, bottom panel: PM2.5 only from anthropogenic emissions

The annual average PM2.5 concentrations estimated using GAINS were compared with measurements made in the following cities: Delhi (ESMAP, 2004), Mumbai (ESMAP, 2004; Kumar and Joseph, 2006), Kolkota (ESMAP, 2004), Chandigarh (ESMAP, 2004), Chennai (Kim Oanh *et al.*, 2006), Kanpur (Sharma and Maloo, 2005) and Lucknow (Barman *et al.*, 2008).

The model-measurement comparison is shown in Figure 2.6. The GAINS estimate for PM2.5 concentrations in urban background air includes the annual average anthropogenic $PM_{2.5}$ concentration for the relevant grid cell plus the calculated urban increment from local low level emission sources – if appropriate – plus an estimate of the fine fraction of the natural dust concentration (provided by the TM5 model).

As seen from Figure 2.6 there are only rather few monitoring points available for a validation of the GAINS transfer coefficients for India. In some cases multiple observations are available for the same grid cell (city) in the GAINS model, referring to different monitoring stations or different time periods. From the available data it can be concluded that the GAINS model tends to underestimate observed PM2.5 concentrations, although the general level of agreement can be considered as encouraging given the large uncertainties, especially in the quantification of PM2.5 from natural sources (biogenic, soil dust).

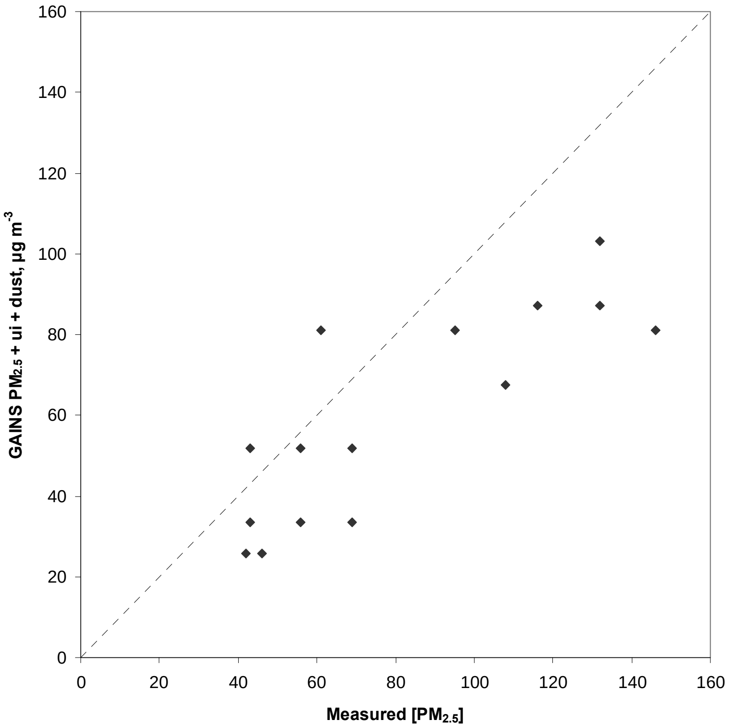

Figure 2.6: Comparison of GAINS estimates of $PM_{2.5}$ with available $PM_{2.5}$ measurements in Indian cities.

2.2.2 CONCENTRATIONS OF GROUND-LEVEL OZONE

GAINS also estimates concentrations of ground-level ozone (annual mean concentrations are shown in Figure 2.7) and assesses resulting impacts on human health and crops using different ozone exposure metrics. Annual mean concentrations of ozone are computed in a range between 40 and 50 ppb in most of central and southern India. Higher concentrations are estimated for the northern states.

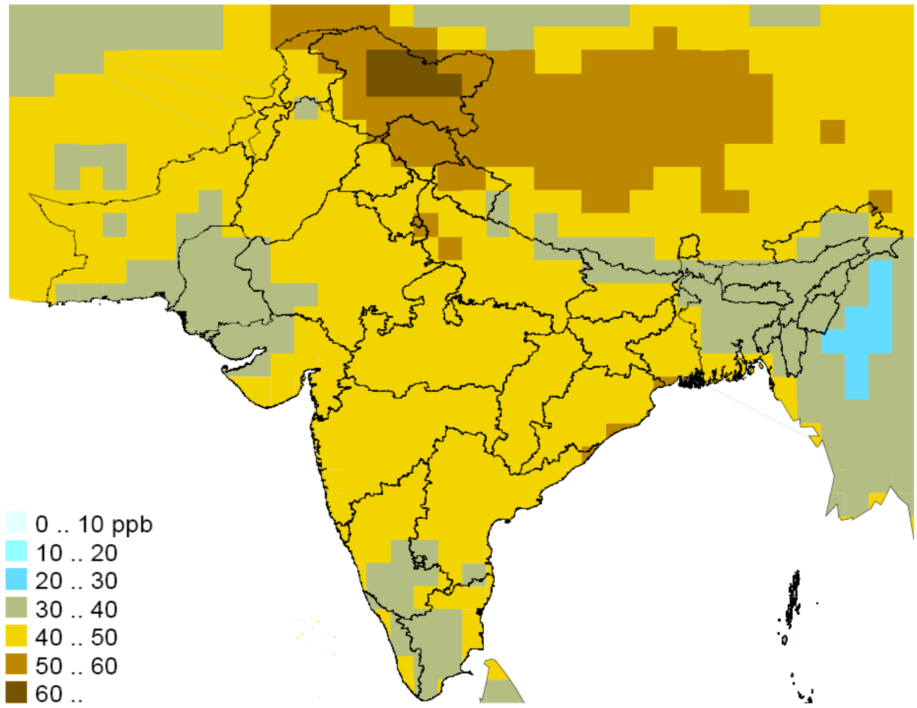

Figure 2.7: Rural annual mean concentrations of ozone, computed for the emissions of 2005. Note that in cities ozone will be lower due to titration with local NO_x emissions.

2.3 Air quality impacts

2.3.1 HEALTH IMPACTS FROM OUTDOOR POLLUTION

For the year 2005, GAINS estimates for the Indian population a loss in statistical life expectancy attributable to outdoor exposure of PM2.5 of 25 months (Table 2.5). Obviously, such a calculation is burdened with significant uncertainties, and sets of alternative assumptions result in a range from 13 to 34 months. It should be noted that the methodology adopted for GAINS associates only exposure to PM2.5 of anthropogenic origin with negative health effects, and does not; therefore, link particles from natural sources (soil dust, sea salt, vegetation, etc.) with reduced life expectancy. More details are provided in Amann *et al.*, 2008a.

Table 2.5: Loss in statistical life expectancy in India estimated for 2005 (months)

	Central estimate*	Lower estimate	Upper estimate	Central estimate without emissions from solid fuel combustion in households
ANDAMAN NICOBAR	4.2	2.1	5.8	3.9
ANDHRA PRADESH	17.6	8.9	24.4	13.6
ARUNACHAL PRADESH	11.3	5.7	15.7	8.1
ASSAM	26.3	13.3	36.6	16.4
BIHAR	29.0	14.6	40.2	19.2
CHANDIGARH	34.9	17.6	48.5	26.1
CHHATTISGARH	21.9	11.0	30.4	17.0
DADRA NAGAR HAVELI	15.0	7.5	20.8	12.6
DAMAN DIU	12.7	6.4	17.6	10.5
DELHI	54.1	27.3	75.0	40.7
GOA	10.8	5.4	15.0	9.1
GUJARAT	20.1	10.1	27.9	15.2
HARYANA	35.3	17.8	49.0	25.0
HIMACHAL PRADESH	18.8	9.5	26.1	14.1
JAMMU KASHMIR	19.7	9.9	27.4	12.4
JHARKHAND	32.1	16.2	44.6	20.3
KARNATAKA	13.1	6.6	18.2	10.0
KERALA	17.6	8.9	24.5	11.5
MADHYA_PRADESH	16.3	8.2	22.6	12.2
MAHARASHTRA	16.0	8.1	22.2	12.8
MANIPUR	31.0	15.6	43.0	19.5
MEGHALAYA	31.1	15.7	43.2	22.7
MIZORAM	23.1	11.7	32.1	17.2
NAGALAND	18.2	9.2	25.3	14.7
ORISSA	25.4	12.8	35.2	18.0
PONDICHERRY	11.0	5.5	15.2	9.2
PUNJAB	35.4	17.9	49.1	27.7
RAJASTHAN	18.4	9.3	25.6	11.8
SIKKIM	10.0	5.1	13.9	8.4
TAMIL NADU	13.7	6.9	19.0	11.3
TRIPURA	40.1	20.2	55.7	25.7
UTTAR PRADESH	34.3	17.3	47.6	22.4
UTTRANCHAL	30.7	15.5	42.6	14.1
WEST BENGAL	37.6	19.0	52.2	24.8
TOTAL	24.9	12.5	34.5	17.3

* In view of the inherent uncertainties GAINS assesses a range of outcomes based on different assumptions on relative risk factors and mortality rates (Amann *et al.*, 2008a). The mean value of this range is presented as the central estimate.

Since GAINS computes ambient concentration based on a detailed chemical transport model, it allocates contributions to ambient PM2.5 concentrations to their different origins, both from natural and anthropogenic sources. It has been pointed out above that combustion of solid fuels in households constitutes in India a major source of PM emissions. Analysis shows that about 44 percent of the health impacts from outdoor exposure to PM2.5 can be linked to emissions from the combustion of solid fuels in households (Figure 2.8). In addition to their outdoor health effects, serious health impacts through the exposure to indoor pollution are a matter of concern.

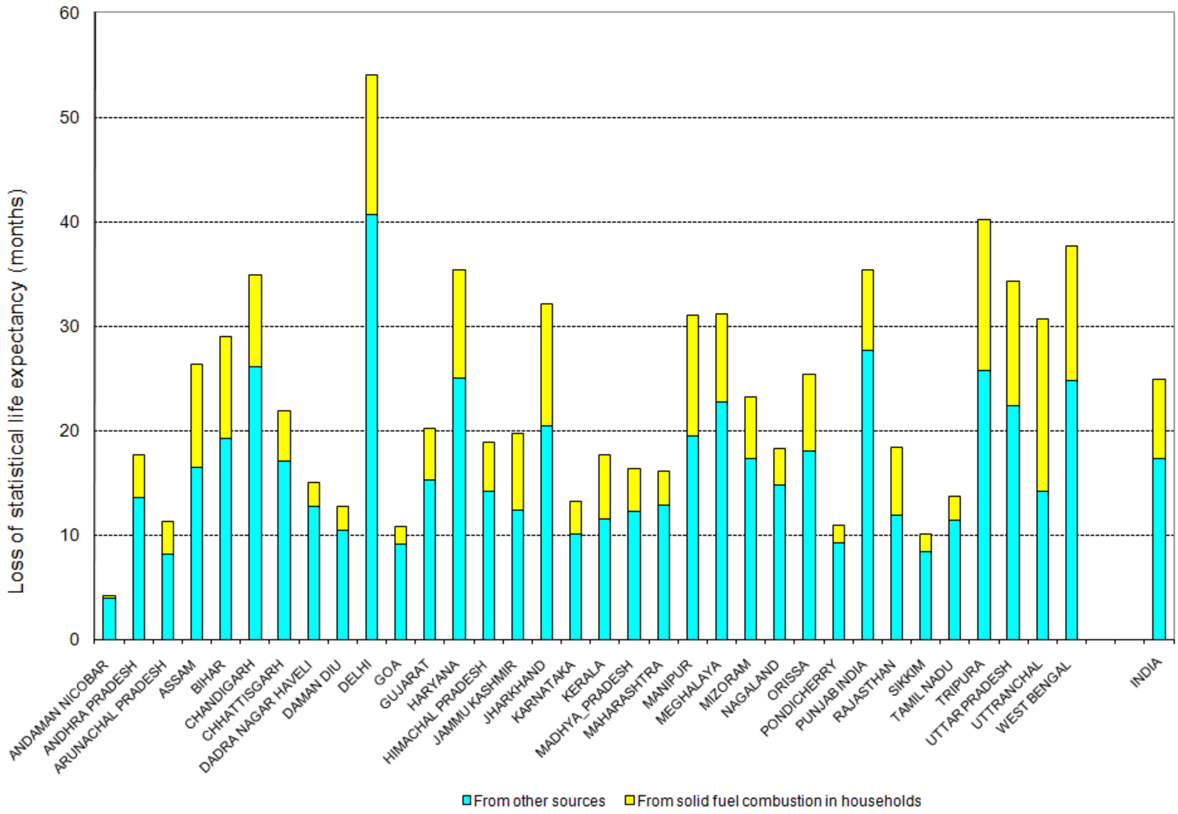

Figure 2.8: Loss in statistical life expectancy that can be attributed to the outdoor exposure to PM2.5 in India in 2005, central estimate.

2.3.2 HEALTH IMPACTS FROM INDOOR POLLUTION

The GAINS model estimates health impacts from indoor pollution resulting from solid fuel in households, following the methodology employed for the WHO Global Burden of Disease project (Smith *et al.*, 2004). In line with the WHO methodology, GAINS calculations compute disability adjusted life years as the metric for health impacts. In contrast to outdoor effects, which are quantified only for the population older than 30 years, estimates of health impacts from indoor pollution also relate to children. Estimates for the year 2005 are presented in Table 2.6.

Table 2.6: Disability adjusted life years (DALY) from indoor pollution, India 2005 (1000 DALYs/year)

		2005
ALRI FROM INDOOR BURNING OF BIOMASS	Children < 5 yrs	9200
COPD FROM INDOOR BURNING OF BIOMASS	Women>30 yrs	2107
LUNG CANCER (FROM EXPOSURE TO COAL SMOKE)	Women>30 yrs	5
COPD FROM INDOOR BURNING OF BIOMASS	Men>30 yrs	1508
LUNG CANCER (FROM EXPOSURE TO COAL SMOKE)	Men>30 yrs	9
TOTAL		12828

ALRI: Acute lower respiratory infections

COPD: Chronic obstructive pulmonary disease

2.3.3 CROP LOSSES FROM GROUND-LEVEL OZONE

In addition to health impacts, GAINS estimates for a number of economically important agricultural crops (wheat, corn, rice, and soybean) potential crop losses that are attributable to ground-level ozone. There are some areas in India for which current ozone levels are likely to cause considerable losses in agricultural productivity. As an example, Figure 2.9 shows the spatial distribution of potential crop losses for wheat, which reaches in some areas of northern India more than 20 percent.

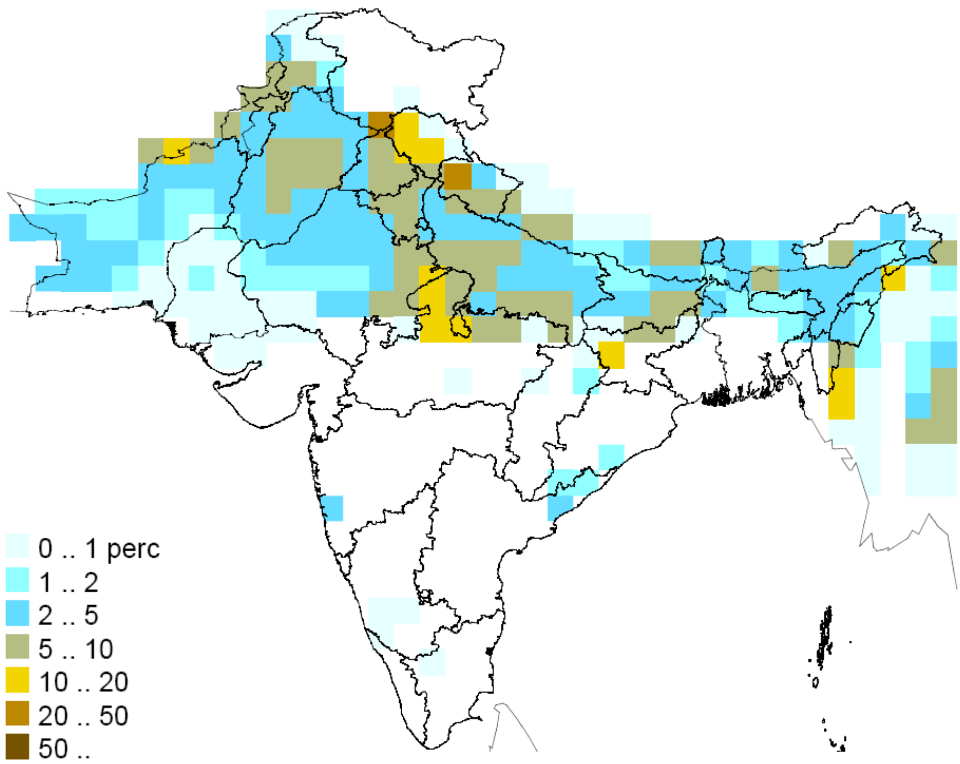

Figure 2.9: Potential losses in wheat yield due to ground-level ozone in 2005, %

3 The baseline projection up to 2030

3.1 Macro-economic development and energy consumption

As a reference for the analysis of alternative policy scenarios, this report adopts the assumptions of the "National Energy Map for India" that has been published by the Office of the Principal Scientific Advisor to the Government of India in 2006 (TERI, 2006) as its base case. Following the plans of the Government of India, GDP is assumed to grow by 8 to 10 percent/year in the Eleventh Five Year plan and then at an average rate of 10 percent/year in the 12th plan in order to double per-capita income by 2016-17 (Planning Commission, 2006a). These increases result from continued population growth (from 1.1 billion people in 2005 to 1.5 billion people in 2030) combined with enhanced economic development that will provide increased economic wealth to the Indian population (Figure 3.1, left panel).

As pointed out in the National Energy Map for India (TERI, 2006), such high economic growth will put heavy demand on the supply of energy. Under business-as-usual conditions, consumption of total primary energy is estimated to increase by a factor of 3.5 between 2005 and 2030, indicating a clear decoupling between economic and energy consumption as a consequence of mainly technological improvements in addition to the ongoing structural transformations in the Indian economy. As the growth in the transport sector will further deteriorate India's oil import dependency (from currently 70 percent to 90 percent in 2030), maximum utilization of indigenously available energy resources is seen as an important measure to safeguard energy security. Thus consumption of coal is projected to grow by a factor of six, mainly to fuel power generation (Table 3.1). Thereby, coal will remain the dominant source of primary energy in India. Similar growth rates are anticipated for renewable energy (e.g., hydropower and wind), but starting from a much lower level in 2005.

Table 3.1: Baseline projection of fuel consumption for India (PJ/yr)

	1990	2000	2005	2010	2020	2030
COAL	3879	6776	8788	11501	21603	45096
OIL	2606	4314	5538	6843	10726	16846
GAS	593	1294	1627	3107	7153	7873
RENEWABLES	1	9	13	34	41	105
HYDRO	260	291	306	774	1258	1693
NUCLEAR	58	166	165	518	1619	1619
BIOMASS	4810	5446	6484	6987	6950	6896
TOTAL	12207	18295	22922	29764	49351	80129

Energy demand from households will be strongly influenced by the expected increase in urbanization (for 2030, the share of urban population is anticipated to increase from currently 28 to 40 percent) and the general rise in economic wealth. For 2030, the baseline projection assumes that all of the currently 87 million rural and 43 million urban households with low income (i.e., with monthly per capita consumption expenditures below 775 rupees) will increase their incomes above this level. Nevertheless, consumption levels of fuel wood, dung and agricultural residuals in households (i.e., mainly for cooking purposes) are not expected to change significantly, as these remain sources of cheap energy (Figure 3.1, right panel).

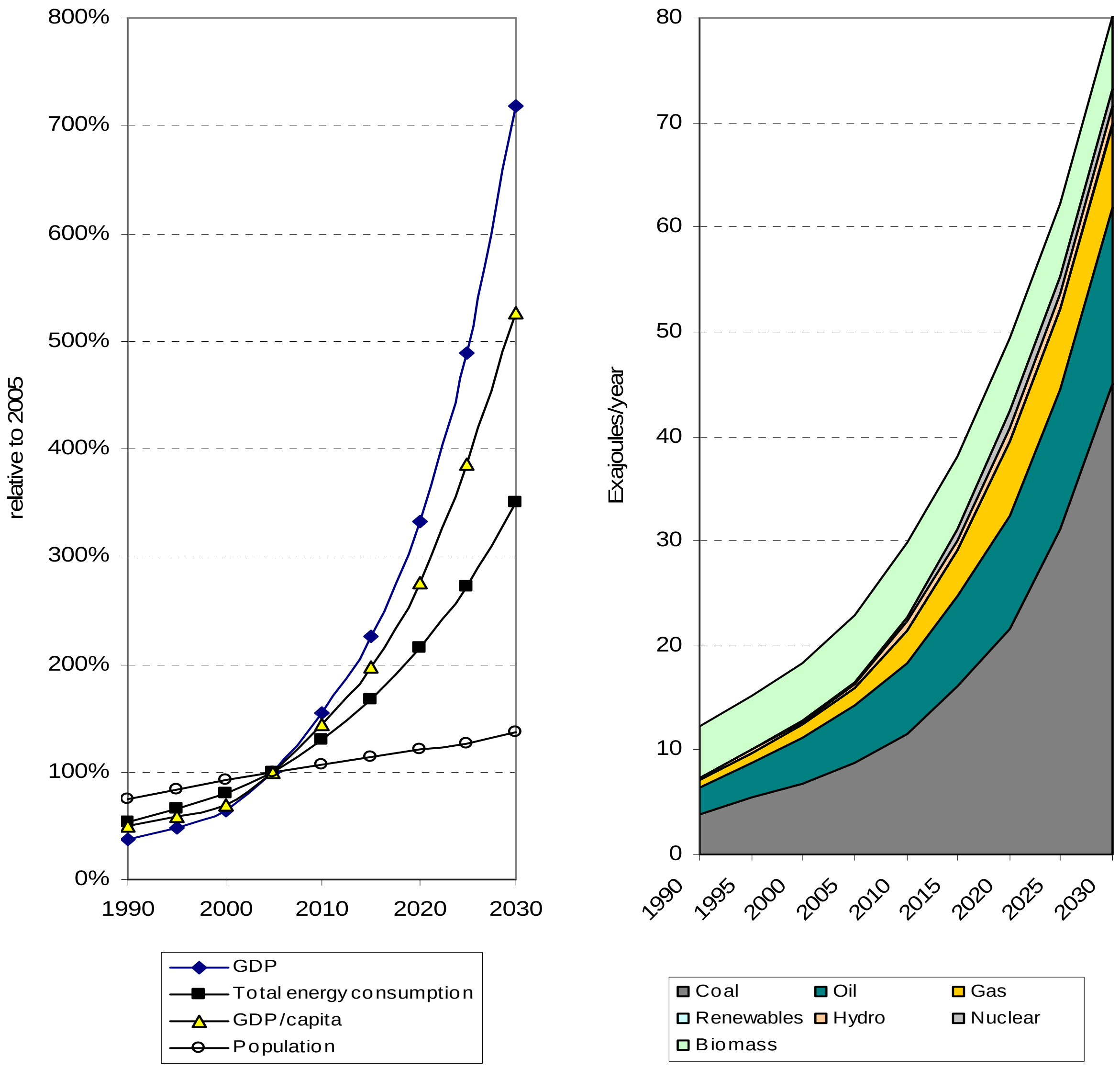

Figure 3.1: Assumptions on macro-economic development and energy consumption of the baseline projection. Left panel: Macro-economic indicators, relative to the year 2005. Right panel: Primary energy consumption (in Terajoules/year)

Obviously, these quantitative projections are associated with numerous uncertainties that could lead to different developments than outlined in this scenario. One of the factors with strong influence on the long-term development and which is most difficult to accurately predict, concerns the future rate of economic growth. With an assumed annual growth rate of 8 percent, this baseline represents a medium-range development path among the alternatives that are explored in the National Energy Map for India (TERI, 2006). While the Government of India has pledged for higher growth rates, other projections employ more modest assumption, e.g., the World Energy Outlook 2007 of the International Energy Agency with a 7.2% annual growth rate (IEA, 2007).

As a side effect, energy combustion and agricultural activities release a wide range of emissions to the atmosphere that have harmful effects at the local, regional and global scales. The rate of emissions of the various pollutants per unit of activity is determined, inter alia, by local fuel quality and combustion conditions as well as by specific measures to reduce emissions. Unless these factors will change in the future, emissions quantities are directly proportional to the volume of economic activities that release such emissions. While only limited changes are expected for fuel quality and other structural factors, the extent to which emission control measures will be applied is a major policy variable.

The projections of future agricultural activity have been derived from National Energy Map for India (TERI, 2006). Fertilizer consumption is estimated using the production of high-yielding varieties of crops. Total cattle numbers are expected to decrease by 20 percent until 2030, while the numbers of pigs and poultry are projected to increase by 29 and 82 percent, respectively. Fertilizer consumption is expected to grow by 62 percent (Figure 3.2).

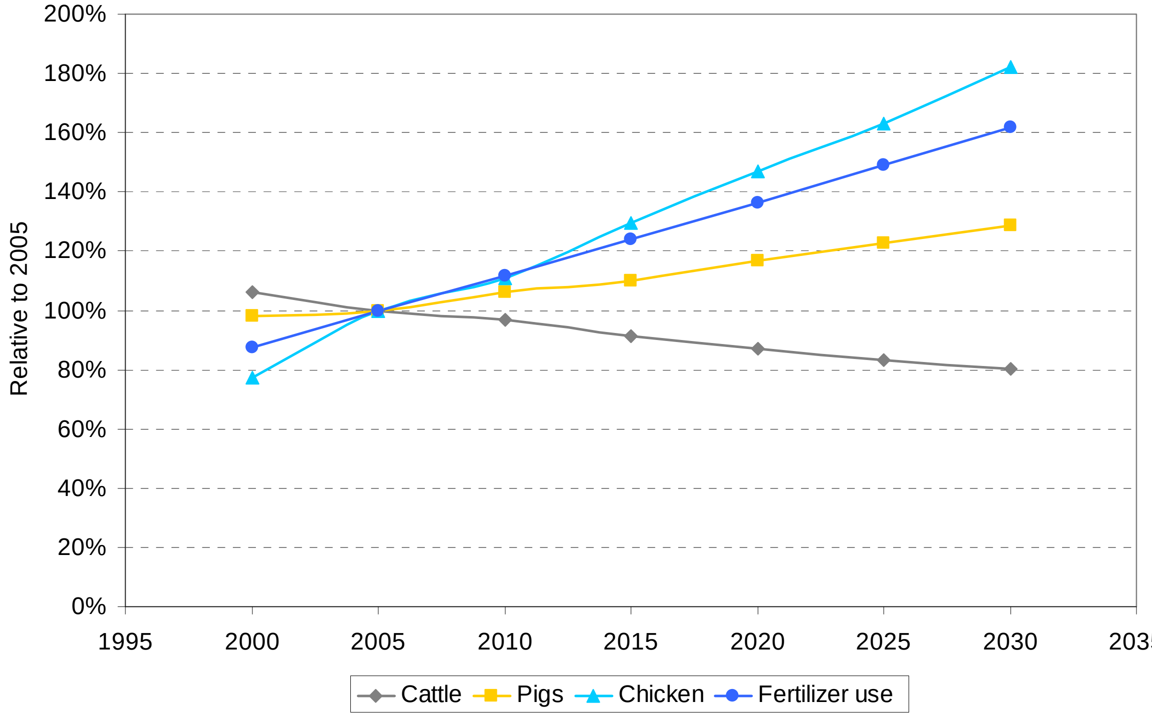

Figure 3.2: Projections of agricultural activities for India

3.2 Baseline projections for air pollution emissions

It is obvious that, as a consequence of sharply increasing fuel consumption in India, emissions of air pollutants and greenhouse gases will grow accordingly unless stricter measures for controlling emissions will be taken in the future. The exact level of future emissions will therefore be critically determined by the extent to which emissions will be controlled through targeted policy interventions.

To assess cost-effective policy interventions that maintain acceptable levels of air quality, a baseline projection is developed as a reference case. This baseline projection explores the likely development of air pollution and greenhouse gas emissions as well as their local impacts under the assumptions that (i) currently existing policies and regulations on air pollution control measures were fully implemented as foreseen, and (ii) no additional measures were adopted.

The baseline reflects the current Indian legislation on air pollution controls, such as the phased introduction of emission standards for different categories of vehicles and PM control for large stationary sources. It especially includes the significant progress made to date with respect to the control of particulate matter emissions from power stations to achieve the desired levels of 150 mg/Nm^3 for most of the 200 and 210 MW units, and of 100 mg/Nm^3 for the 500 MW units. It also takes into account that there are no mandatory controls for SO_2 and NO_x emissions from power stations (TERI, 2006). Assumed measures are summarized in Table 3.2. As it is assumed that these measures will be fully implemented and will effectively achieve the envisaged emission reductions, the baseline projection neither assumes nor explores implications of implementation failures.

Table 3.2: Emission control measures assumed in the baseline projection

Stationary sources	Mobile sources
• Large combustion plants: o Electrostatic precipitators (ESP) at large combustion plants to control emissions of particulate matter (TSP and PM2.5), with high removal efficiency (99%) for all plants built after 2005 o Less efficient ESP for large plants built before 2005 and all smaller plants • Small combustion plants in the power sector and industry: o Cyclones or less efficient ESP for large plants built before 2005 and all smaller plants • Domestic sector: o Low sulphur medium distillates: 0.25% S from 2000, 0.05% S from 2005, 10 ppm from 2015 o Slow penetration (0.4%/year) of improved cooking stoves using biomass	• Two-wheelers: o Euro-II (Stage-II) controls after 2005 • Light duty and heavy duty vehicles: o Euro-1/I after 2000 o Euro-2/II after 2004 o Euro-3/II after 2006 o Euro-4/IV after 2010 • Low sulphur gasoline (10 ppm) from 2015 • CNG for buses and three-wheelers in urban areas

If India would maintain its current legislation on air pollution emissions as outlined in Table 3.2 and not introduce stricter regulations, the steep increase in energy use for power generation, industry, transport and households will be paralleled by a drastic growth in emissions to the atmosphere. Table 3.3 presents the baseline projection of air pollutant emissions in India by sector. Emissions are scaled to the level of total emissions in 2005. Following the projected increases in economic activities, sulphur dioxide (SO_2) emissions would grow by a factor of five between 2005 and 2030, nitrogen oxides (NO_x) emissions by a factor of three, and fine particles (PM2.5) emissions by 30 percent (Figure 3.3). Lack of legislation on the control of emissions from agricultural sources will result in an increase of NH_3 emissions by 30 percent. VOC emissions would grow by 27 percent due to increasing combustion of solid fuels in households and higher use of solvents. However, the introduction of the Euro standards for mobile sources avoids an even higher growth of VOC emissions. Power generation and industry will remain the major sources of SO_2 emissions; NO_x emissions originate mostly from power generation, industry and transport. Combustion of biomass in the domestic sector constitutes the dominant source of PM2.5 and volatile organic compounds (VOC), and agricultural activities that of ammonia.

Table 3.3: Baseline projection of air pollutant emissions in India by sector (in kt)

	1990	2000	2005	2010	2020	2030
SO_2						
POWER GENERATION	1395	2110	2727	3396	4182	5743
INDUSTRY	1052	1374	1722	2397	3724	5439
DOMESTIC	348	373	337	352	353	350
TRANSPORT	265	296	299	241	135	79
AGRICULTURE	19	19	19	17	18	17
OTHER	10	3	3	3	3	3
TOTAL	**3089**	**4175**	**5106**	**6406**	**8415**	**11631**
NO_x						
POWER GENERATION	738	1399	1546	1821	2611	4718
INDUSTRY	316	538	804	1132	2167	4102
DOMESTIC	309	353	408	458	489	515
TRANSPORT	1240	1825	2290	2706	3238	4289
AGRICULTURE	17	18	16	16	16	15
OTHER	10	3	3	3	3	3
TOTAL	**2630**	**4136**	**5066**	**6136**	**8523**	**13641**
PM2.5						
POWER GENERATION	200	322	275	268	368	676
INDUSTRY	763	992	1434	1586	2157	2865
DOMESTIC	2483	2716	3107	3273	3127	2971
TRANSPORT	160	305	325	319	266	361
AGRICULTURE	546	549	513	514	494	474
OTHER	119	138	149	160	176	200
TOTAL	**4272**	**5022**	**5803**	**6120**	**6588**	**7548**
NH_3						
POWER GENERATION	0	0	0	1	1	2
INDUSTRY	21	33	38	42	51	61
DOMESTIC	43	47	55	59	58	57
TRANSPORT	0	2	5	8	18	24
AGRICULTURE	4967	5573	5875	6197	6823	7553
OTHER	502	612	665	714	805	908
TOTAL	**5535**	**6268**	**6638**	**7021**	**7756**	**8605**
VOC						
POWER GENERATION	25	43	44	48	41	54
INDUSTRY	1090	1822	2352	3046	4653	6519
DOMESTIC	7788	8716	10266	10822	10258	9679
TRANSPORT	778	1639	1744	1798	1502	2115
AGRICULTURE	702	705	656	658	630	602
OTHER	46	84	103	125	191	280
TOTAL	**10429**	**13010**	**15166**	**16496**	**17276**	**19249**

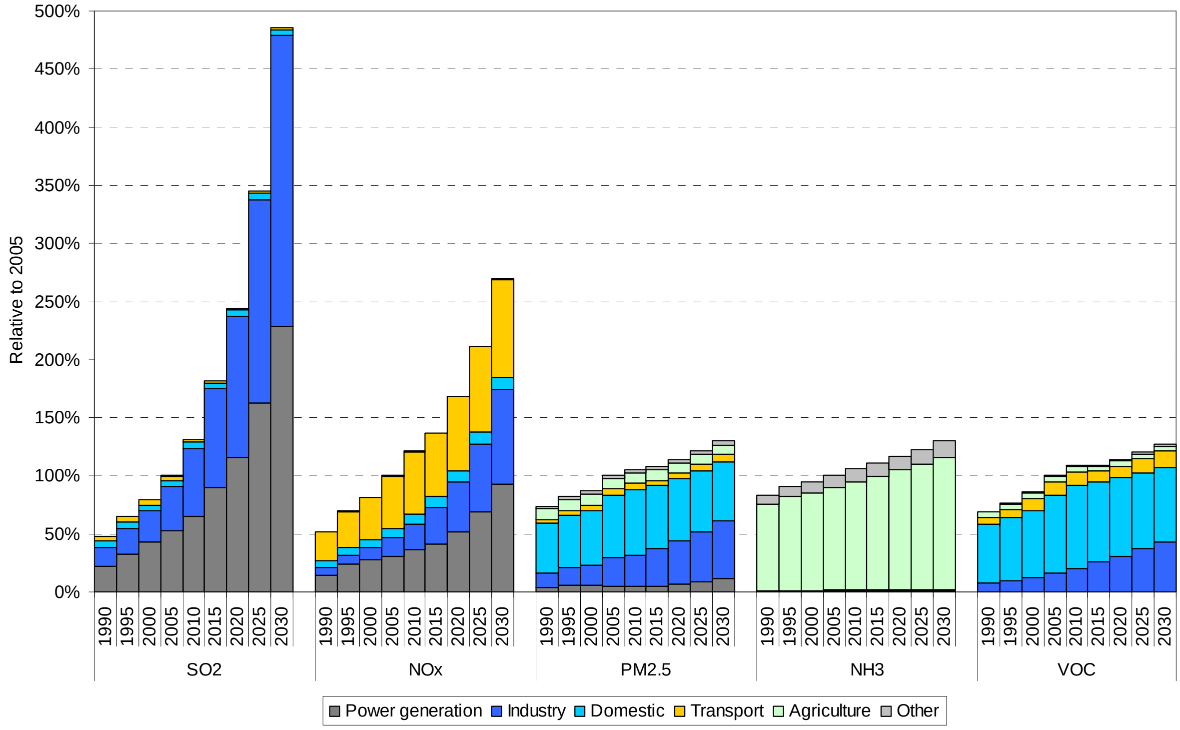

Figure 3.3: Baseline projection of air pollutant emissions in India 1990-2030 by sector. Emissions are scaled to the level of total emissions in 2005.

In contrast to air pollutants, the lack of effective mitigation measures will lead to a strong increase in greenhouse gas emissions (Figure 3.4). Table 3.4 presents the baseline projection of greenhouse gas emissions in India by sector. The projected increase in economic activities would multiply CO_2 emissions by more than a factor of four. CH_4 and N_2O emissions, which originate mainly from agricultural activities, are expected to increase by 29 and 51 percent respectively. As a consequence, total greenhouse gas emissions would triple.

Table 3.4: Baseline projection of greenhouse gas emissions in India by sector.

	1990	2000	2005	2010	2020	2030
CO_2 (Mt)						
POWER GENERATION	239	520	642	840	1608	2995
INDUSTRY	167	259	381	539	1065	2160
DOMESTIC	79	96	103	134	176	213
TRANSPORT	85	136	173	202	286	365
AGRICULTURE	12	4	3	3	3	3
OTHER	27	51	70	91	141	210
TOTAL	610	1066	1373	1809	3278	5946
CH_4 (kt)						
POWER GENERATION	12	7	9	13	27	44
INDUSTRY	23	6	7	10	19	38
DOMESTIC	1651	1737	1983	2036	1897	1759
TRANSPORT	58	126	165	196	182	229
AGRICULTURE	14115	15063	14916	15281	15983	16897
OTHER	5076	7767	9298	10432	13219	15129
TOTAL	20935	24706	26378	27968	31326	34096
N_2O (kt)						
POWER GENERATION	3	7	9	12	21	42
INDUSTRY	3	5	7	10	17	32
DOMESTIC	20	23	27	29	29	28
TRANSPORT	3	5	6	8	13	18
AGRICULTURE	494	600	654	711	824	947
OTHER	47	57	62	67	76	85
TOTAL	571	697	766	836	979	1153
All GHGs ($Mt\ CO_2eq./year$)						
POWER GENERATION	241	522	645	844	1615	3008
INDUSTRY	168	261	384	542	1070	2171
DOMESTIC	120	139	153	185	225	259
TRANSPORT	92	163	216	263	378	505
AGRICULTURE	450	502	516	541	591	649
OTHER	155	213	250	280	361	429
TOTAL	1226	1801	2164	2655	4239	7020

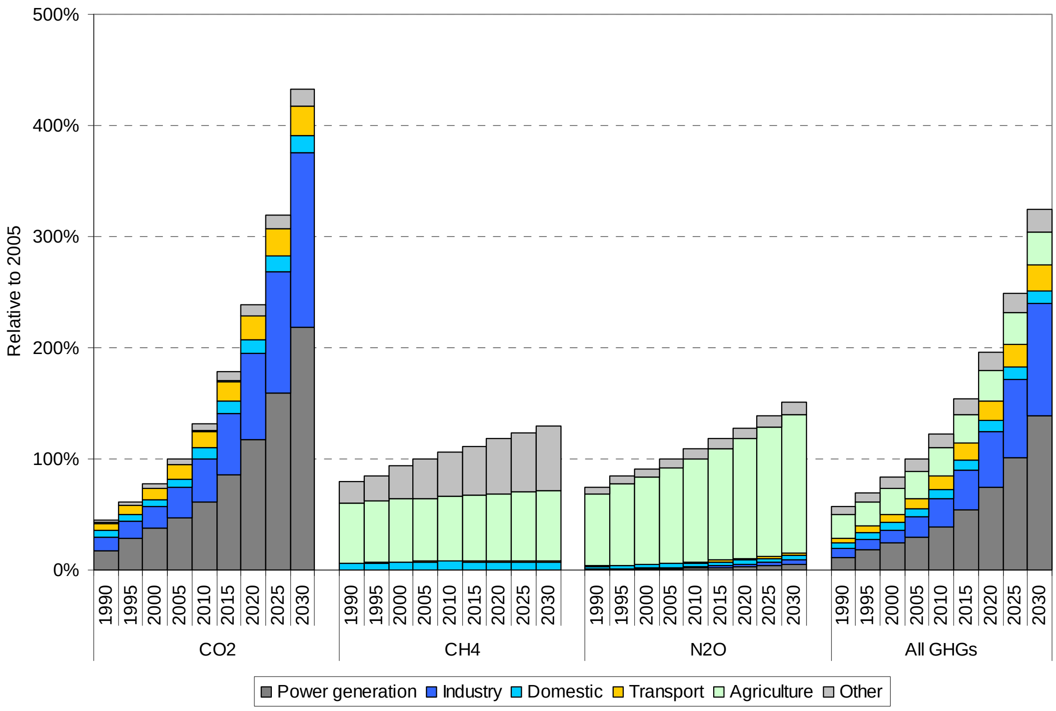

Figure 3.4: Baseline projection of greenhouse gas emissions in India 1990-2030 by sector. Emissions are scaled to the level of total emissions in 2005.

It is important to realize that the baseline emission projection assumes as an integral part the implementation of dedicated emission control measures as listed in Table 3.2. Thus, the baseline projection takes into consideration that significant economic resources will be spent for air pollution control. For 2005, the GAINS model estimates costs of implemented pollution control measures at €2.1 billion or 0.11 percent of the GDP. About 15 percent of the costs emerged for control of PM emissions from industrial facilities, 28 percent for PM controls in the power sector and 55 percent for controlling emissions from road transport (Table 3.5). In 2030, implementation of current emission control laws would involve costs of €16.3 billion, or 0.28 percent of GDP (expressed in PPP).

Table 3.5: Air pollution control costs in 2005 and 2030 in India

	2005		2030 baseline	
	billion €/yr	% of GDP	billion €/yr	% of GDP
POWER GENERATION	0.6	0.03%	2.4	0.04%
INDUSTRY	0.3	0.02%	2.5	0.04%
DOMESTIC	0.0	0.00%	1.2	0.02%
TRANSPORT	1.2	0.06%	10.2	0.17%
AGRICULTURE	0.0	0.00%	0.0	0.00%
TOTAL	**2.1**	**0.11%**	**16.3**	**0.28%**
GDP (PPP)	1905		5893	

3.3 Baseline projections of air quality and health impacts

The baseline increase in emissions would lead to profound deteriorations of air quality in India. Despite current efforts to control air pollution in India, the path in emissions as portrayed for the baseline projection would not result in major air quality improvements in the coming decades. Most relevant for health impacts, annual mean concentrations of fine particles (PM2.5) exceed already at present the guideline value of the World Health Organization of 10 μg/m^3 (WHO, 2006) virtually throughout India, and typically reach in the Ganges valley 50 to 100 μg/m^3. By 2030 such levels would extend over most of India, while in the Ganges valley concentrations would increase to more than 150 μg/m^3 (Figure 3.5).

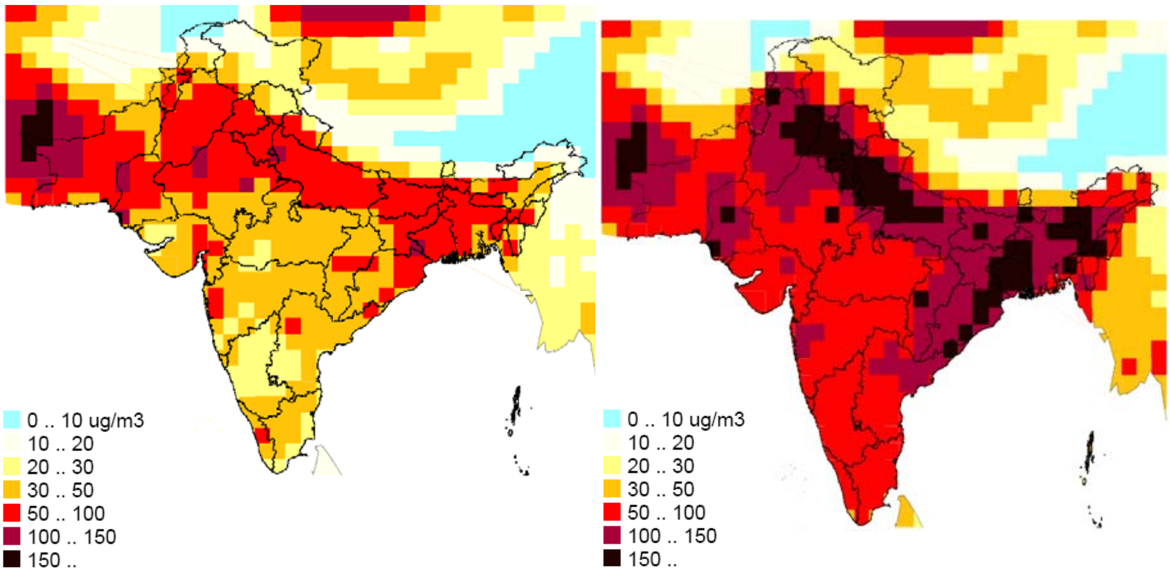

Figure 3.5: Computed annual mean concentrations of PM2.5 that are representative for rural and urban background sites, in 2005 (left panel) and for the baseline emission scenario in 2030 (right panel). This calculation includes particles from natural sources (e.g., soil dust).

As pointed out before, current economic plans without tightened air pollution emission control legislation imply drastic increases in air pollution emissions and significant deterioration of air quality. Consequently, health impacts from air pollution would sharply rise. For outdoor pollution, loss in statistical life expectancy is calculated to increase from 25 (13-34) months in 2005 up to 59 (30-82) months in 2030 for the Indian population on average, i.e., more than double over the 25 years (Table 3.6). Spatial variations in ambient PM2.5 concentrations lead to significant differences in health impacts across India: for 2030, life shortening in Delhi is calculated at 108 (55-150) months, while in contrast only 10 (5-14) months are computed for Andaman and Nicobar (Figure 3.6).

Table 3.6: Loss in statistical life expectancy in India estimated for 2005 and the baseline projection in 2030 (months)

	2005	2030		
		Central estimate	Lower estimate	Upper estimate
ANDAMAN NICOBAR	4.2	10.0	5.0	13.9
ANDHRA PRADESH	17.6	48.3	24.4	67.0
ARUNACHAL PRADESH	11.3	35.4	17.8	49.1
ASSAM	26.3	67.2	33.9	93.3
BIHAR	29.0	66.9	33.8	92.9
CHANDIGARH	34.9	82.3	41.5	114.3
CHHATTISGARH	21.9	60.6	30.6	84.1
DADRA NAGAR HAVELI	15.0	35.5	17.9	49.3
DAMAN DIU	12.7	26.3	13.3	36.6
DELHI	54.1	108.2	54.6	150.2
GOA	10.8	28.7	14.5	39.9
GUJARAT	20.1	34.9	17.6	48.4
HARYANA	35.3	80.3	40.5	111.4
HIMACHAL PRADESH	18.8	54.0	27.2	74.9
JAMMU KASHMIR	19.7	42.4	21.4	58.8
JHARKHAND	32.1	78.7	39.7	109.2
KARNATAKA	13.1	33.5	16.9	46.4
KERALA	17.6	35.9	18.1	49.9
MADHYA_PRADESH	16.3	39.3	19.8	54.5
MAHARASHTRA	16.0	38.4	19.4	53.3
MANIPUR	31.0	77.9	39.3	108.1
MEGHALAYA	31.1	91.1	45.9	126.4
MIZORAM	23.1	52.8	26.6	73.2
NAGALAND	18.2	53.8	27.1	74.6
ORISSA	25.4	74.1	37.4	102.8
PONDICHERRY	11.0	25.1	12.7	34.9
PUNJAB	35.4	88.9	44.8	123.3
RAJASTHAN	18.4	38.5	19.4	53.4
SIKKIM	10.0	24.0	12.1	33.4
TAMIL NADU	13.7	32.4	16.3	44.9
TRIPURA	40.1	85.2	43.0	118.3
UTTAR PRADESH	34.3	76.8	38.7	106.6
UTTRANCHAL	30.7	54.8	27.6	76.1
WEST BENGAL	37.6	91.9	46.3	127.5
TOTAL	24.9	58.8	29.7	81.7

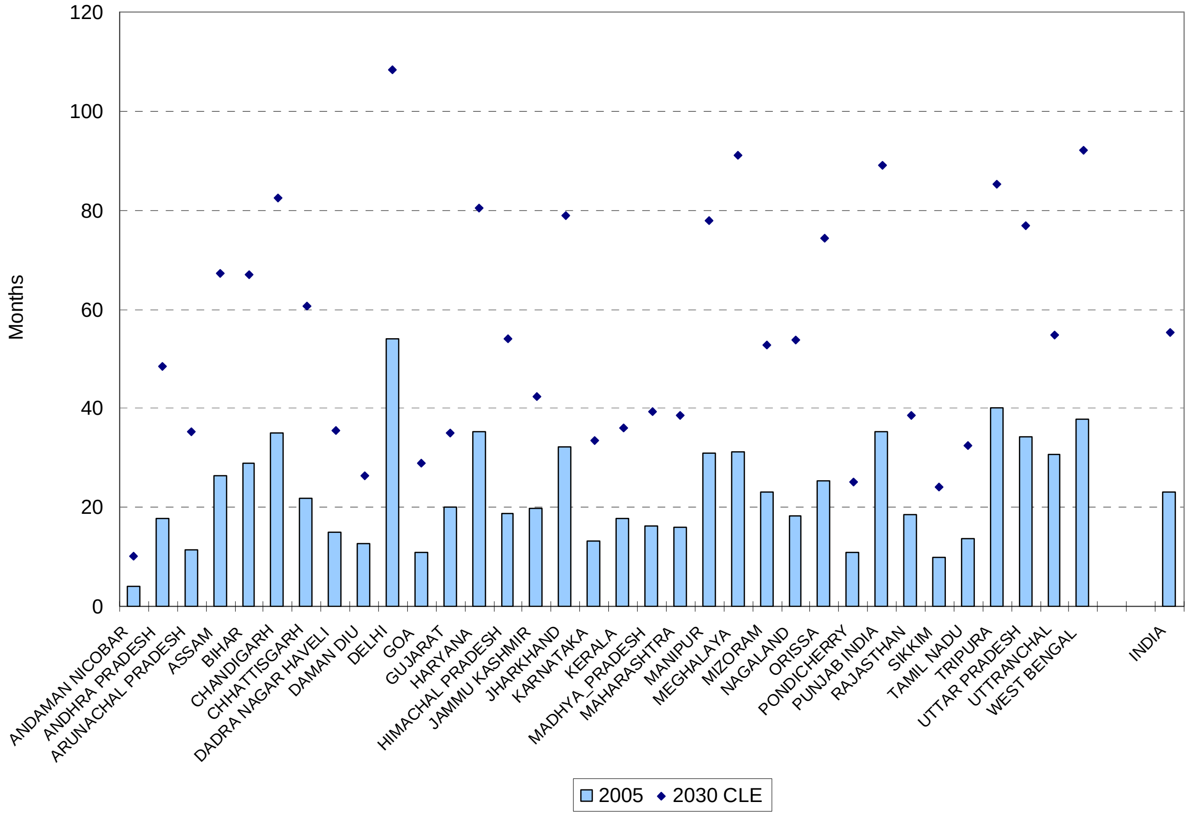

Figure 3.6: Loss in statistical life expectancy attributable to the outdoor exposure of fine particulate matter computed for 2005 and the 2030 baseline projection (central estimate)

The number of total life years lost due to outdoor pollution would grow by a factor of four (from 24 to 102 million years lost/year). This steeper growth is caused by the expected increase in total population and the aging of the society, which will rise the number of people older than 30 years for which health impacts are calculated from 463 million in 2005 to 830 million in 2030.

In contrast to outdoor pollution, health impacts from indoor sources are not expected to get substantially bigger in the future. Despite growing population, the baseline energy projection assumes no further increase in the number of households that burn biomass for cooking purposes, because (i) households below the poverty line and with low income will increase their economic wealth, and (ii) there is only little additional potential for sustainable use of biomass beyond what is currently harvested. Therefore, health impacts from indoor exposure remain almost unchanged compared to 2005 (Table 3.7). However, combustion of such fuels will cause 80 percent higher health impacts via outdoor exposure because of an increased susceptible population will be exposed. Thus it is estimated that by 2030 biomass combustion will be responsible for only one quarter of all air pollution health impacts, compared to more than half in 2005.

Table 3.7: Disability adjusted life years (DALY) attributable to indoor pollution from the combustion of solid fuels in the domestic sector in India for 2005 and the baseline projection in 2030 (1000 DALYs/year) (Specific diseases not mentioned in GAINS)

		2005	2030
CHILDREN	ALRI	9200	8848
WOMEN	COPD	2107	2026
WOMEN	Lung cancer	5	4
MEN	COPD	1508	1450
MEN	Lung cancer	9	7
TOTAL		12828	12335

In contrast to air pollutant emissions, for which emission control measures are currently being implemented, increased energy consumption associated with the rapid economic development will cause a substantial growth in greenhouse gas emissions. While the assessment of resulting climate impacts is beyond the scope of the GAINS model, the magnitude of the anticipated growth will certainly be relevant even at the global scale. Although Indian per-capita emissions will remain lower than those of other countries in the world, the increase in total emissions would include India among the countries with the highest GHG emissions (Figure 3.7).

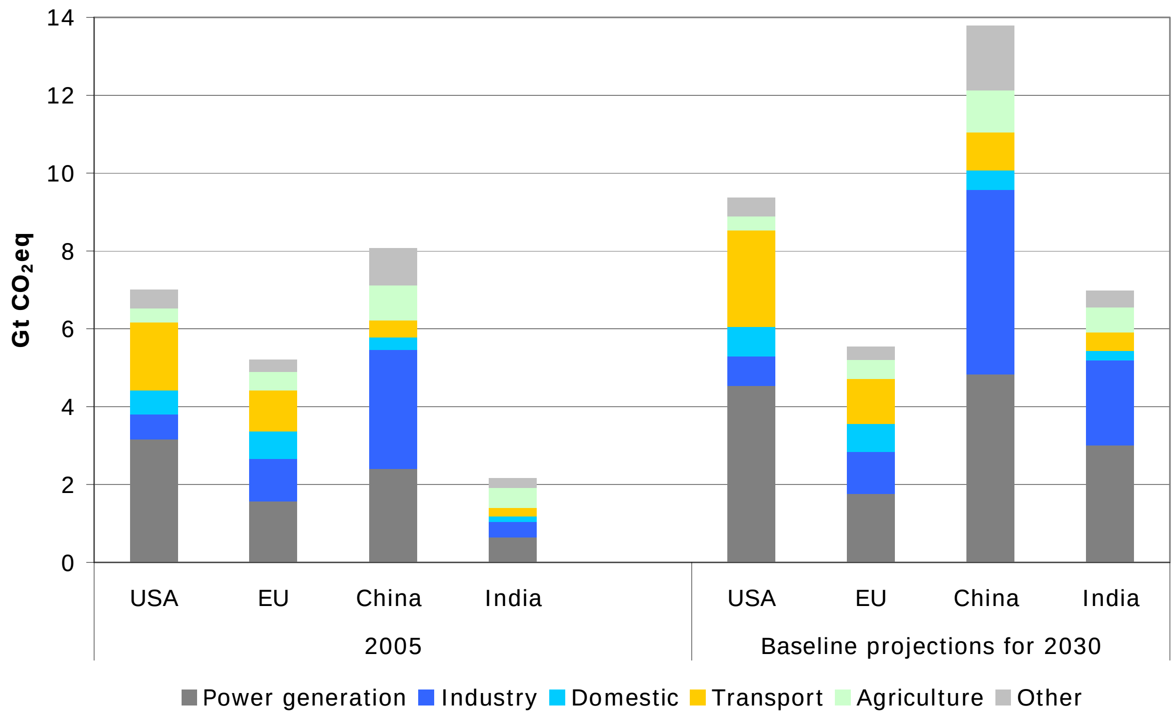

Figure 3.7: Greenhouse gas emissions of the USA, EU, China and India, 2005 and baseline projections for 2030, by sector

4 Alternative policy scenarios

As demonstrated in the preceding section, current emission control legislation will not be sufficient to substantially improve air quality in India. It will be shown in this section that application of a wide range of available measures that are not yet required by Indian law could reduce emissions and thereby lead to better air quality. Thus, there is a wide field of possible policy interventions to achieve more sustainable living conditions in terms of air quality. However, there are significant differences in the effectiveness and the costs of the available measures, so that ill-designed pollution control strategies might place unnecessary burdens on the economy.

This section explores the cost-effectiveness of alternative emission control strategies. It should be emphasized that the choice of the appropriate balance between the environmental ambition level and the willingness of a society to spend economic resources for achieving such levels is a genuinely political decision and certainly beyond the scope of a scientific analysis. Therefore, the scenarios presented in this report illustrate basic features of different conceptual approaches towards improved air quality, and the power of an integrated perspective on pollution control that could substantially reduce the expenditure of economic resources compared to conventional approaches.

4.1 Uniform application of advanced emission control technologies for large sources

As shown before, with the presently expected economic growth the current implementation schedule of further emission control measures will not be sufficient for reducing air pollution in India.

Industrialized countries in the West have demonstrated that air pollution emissions can be successfully decoupled from economic growth through the application of advanced end-of-pipe emission control technologies. Such measures include, inter alia, flue gas desulfurization to reduce SO_2 emissions, selective catalytic reduction to reduce NO_x emissions from large boilers, high-efficiency devices to control particle emissions from boilers and industrial processes, and advanced control technologies for light and heavy duty vehicles. Such control measures are widely applied in industrialized countries, and often requested from all installations in order to avoid distortion of economic competitiveness across different companies.

A hypothetical scenario is analyzed which assumes for 2030 the full implementation of the above mentioned measures to all relevant emission sources in India. Such a widespread and undiscriminating application of advanced emission control technologies could substantially reduce future emissions in India below the baseline case (Table 4.1). In particular, SO_2 emissions could be reduced by 17 percent in 2030 as compared to 2005; NO_x emissions could be reduced by 58 percent as compared to the current legislation case in 2030, and PM2.5 emissions would be one third lower than in 2005. However, the across-the-board application of advanced technologies comes at certain costs. By 2030, air pollution control costs would increase to €64 billion/yr, or 1.1 percent of the GDP. While this is substantially higher than the €16 billion/yr (0.28% of GDP) of the current legislation case, it should be remembered that the underlying economic projection for 2030 assumes GDP to grow by more than 600 % (in Market Exchange Rates) or by 300 % (based on Purchasing Power Parity).

Table 4.1: Emissions (Mt) and control costs (billion €/yr) of the Advanced Control Technology (ACT) scenario in 2030 compared to the Current Legislation (CLE) scenario and the estimates for the year 2005

	SO_2			NO_x			PM2.5			Costs		
	2005	2030		2005	2030		2005	2030		2005	2030	
		CLE	ACT		CLE	ACT		CLE	ACT		CLE	ACT
POWER	3.4	14.6	0.8	1.5	4.7	1.5	0.3	0.7	0.2	0.6	2.4	19.2
INDUSTRY	2.4	16.0	4.2	0.8	4.1	2.6	1.4	2.9	0.5	0.3	2.5	23.2
DOMESTIC	0.4	0.3	0.3	0.4	0.5	0.5	3.2	3.2	3.2	0.0	1.2	1.7
TRANSPORT	0.2	0.1	0.0	2.3	4.3	1.2	0.3	0.4	0.1	1.2	10.2	18.4
AGRICULT.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
OTHER	0.0	0.1	0.0	0.0	0.0	0.0	0.5	0.5	0.0	0.0	0.0	0.7
TOTAL	6.4	31.1	5.3	5.1	13.6	5.7	5.8	7.5	3.9	2.1	16.3	63.7
% OF GDP										0.11%	0.28%	1.08%

While such a pollution control strategy would involve considerable economic resources, it also yields significant health and environmental benefits. Population-weighted ambient concentrations of PM2.5 would decline from 115 μg/m^3 in the baseline case to 52 μg/m^3 (Figure 4.1). Thereby, by 2030 cleaner air would reduce the loss in statistical life expectancy attributable to fine particles from 59 months in the current legislation case to 26 (13-36) months. Since the strategy focuses on controls of large emission sources, however, health impacts from indoor pollution would not be affected.

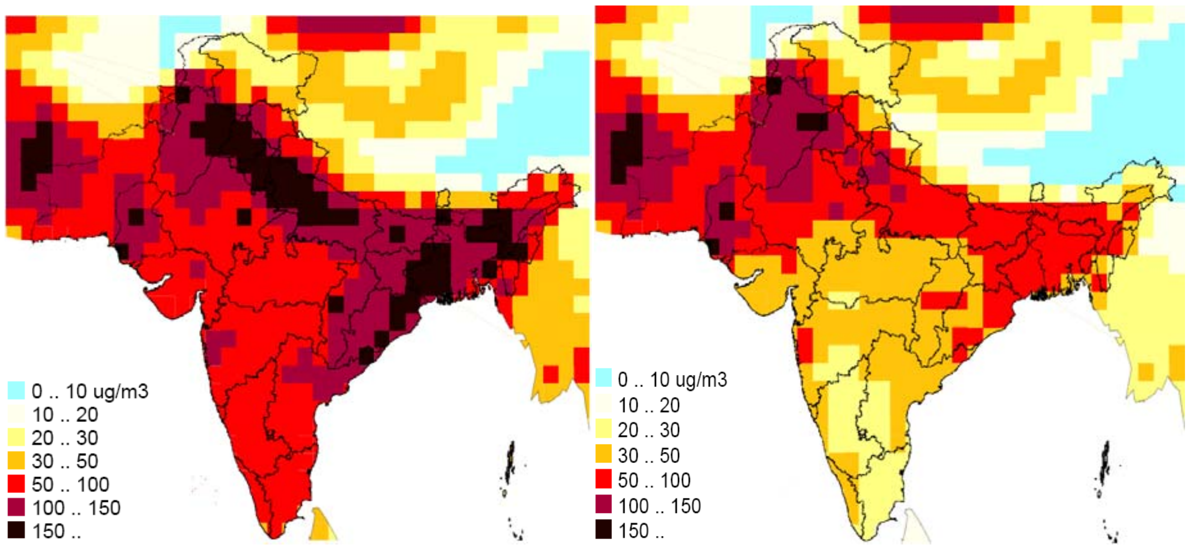

Figure 4.1: Ambient concentrations of PM2.5 computed for the Current Legislation (CLE) case in 2030 (left panel) and the Advanced Control Technology (ACT) case (right panel), including dust from natural sources

The reductions in precursor emissions would also lead to lower concentrations of ground-level ozone, and thereby to less health impacts and crop damage. The changes in baseline emissions (especially of NO_x) would lead to an increase in the cases of premature deaths that are attributable to the exposure to ground-level ozone by more than 58 percent between 2005 and 2030. In contrast, application of advanced control technologies would reduce health impacts from ozone by 43 percent in 2030 compared to the baseline projection (Table 4.2).

Table 4.2: Cases of premature deaths those are attributable to the exposure to ground-level ozone, for 2005, the Baseline Current Legislation (CLE) scenario in 2030 and the ACT scenario

	2005	Baseline CLE scenario 2030	Advanced control technology (ACT), 2030
ANDAMAN & NICOBAR	4	5	4
ANDHRA PRADESH	3050	8149	4067
ARUNACHAL PRADESH	25	56	33
ASSAM	343	899	484
BIHAR	2746	6742	3554
CHANDIGARH	18	44	29
CHHATTISGARH	1314	3537	1896
DADRA & NAGAR HAVELI	5	12	6
DAMAN & DIU	7	16	9
DELHI	619	1028	820
GOA	57	124	68
GUJARAT	2421	6119	3424
HARYANA	1491	3268	2268
HIMACHAL PRADESH	467	1068	696
JAMMU & KASHMIR	842	1659	1418
JHARKHAND	1342	3427	1806
KARNATAKA	1610	3874	1943
KERALA	782	1582	763
MADHYA PRADESH	3724	8779	5008
MAHARASHTRA	4442	10109	5439
MANIPUR	16	34	21
MEGHALAYA	33	86	46
MIZORAM	12	24	15
NAGALAND	14	30	18
ORISSA	2325	7031	3501
PONDICHERRY	4	8	4
PUNJAB	1680	4496	3311
RAJASTHAN	2552	6599	4374
SIKKIM	25	53	29
TAMIL NADU	2025	4353	2142
TRIPURA	31	88	45
UTTAR PRADESH	10734	23404	14030
UTTRANCHAL	618	1418	840
WEST BENGAL	2839	7179	3790
TOTAL	48215	115300	65900

In addition, lower emissions also reduce concentrations of ground-level ozone and thereby harmful impacts on human health and vegetation (Table 4.3). As an example, Figure 4.2 compares potential crop losses for wheat, which would be reduced by one third by the measures of the ACT scenario.

Table 4.3: Potential losses of agricultural production due to ground-level ozone, for the year 2005 and the Current Legislation (CLE) and Advanced Control Technology (ACT) scenarios in 2030, (in kilotons)

	Rice			Wheat			Soybean		
	2005	CLE	ACT	2005	CLE	ACT	2005	CLE	ACT
ANDHRA PRADESH	10	33	15	0	1	1	1	5	2
ARUNACHAL PRADESH	0	1	1	1	2	1	0	0	0
ASSAM	12	42	19	14	45	20	0	0	0
BIHAR	29	128	43	151	441	220	0	0	0
CHANDIGARH	3	9	6	19	56	41	0	0	0
CHHATTISGARH	2	10	4	1	3	1	13	52	24
DADRA NAGAR HAVELI	0	0	0	0	0	0	0	0	0
DELHI	9	17	12	35	74	54	0	0	0
GOA	0	0	0	0	0	0	0	0	0
GUJARAT	8	27	11	2	6	3	2	10	4
HARYANA	80	215	138	625	1710	1172	0	0	0
HIMACHAL PRADESH	12	48	30	169	469	313	0	0	0
JAMMU KASHMIR	9	43	33	98	251	188	0	0	0
JHARKHAND	31	128	49	26	72	38	0	0	0
KARNATAKA	5	18	7	1	3	1	2	12	4
KERALA	1	2	1	0	0	0	0	0	0
MADHYA PRADESH	13	40	19	482	1243	727	60	210	94
MAHARASHTRA	7	27	10	39	118	50	41	174	65
MANIPUR	1	1	1	0	0	0	0	0	0
MEGHALAYA	5	17	8	2	8	3	0	0	0
MIZORAM	0	1	1	1	2	2	0	0	0
NAGALAND	1	1	1	0	1	1	0	0	0
ORISSA	34	155	60	1	2	1	1	6	3
PONDICHERRY	0	1	0	0	0	0	0	0	0
PUNJAB	177	639	451	1025	3164	2391	0	0	0
RAJASTHAN	13	36	22	440	1262	841	13	44	21
SIKKIM	0	2	1	1	3	1	0	0	0
TAMIL NADU	51	142	50	0	0	0	0	1	0
TRIPURA	5	20	9	4	13	6	0	0	0
UTTAR PRADESH	142	395	181	1317	3573	2059	1	2	1
UTTRANCHAL	5	14	7	134	352	213	0	0	0
WEST BENGAL	126	475	189	49	165	73	0	0	0
TOTAL	791	2687	1376	4636	13039	8420	133	515	218

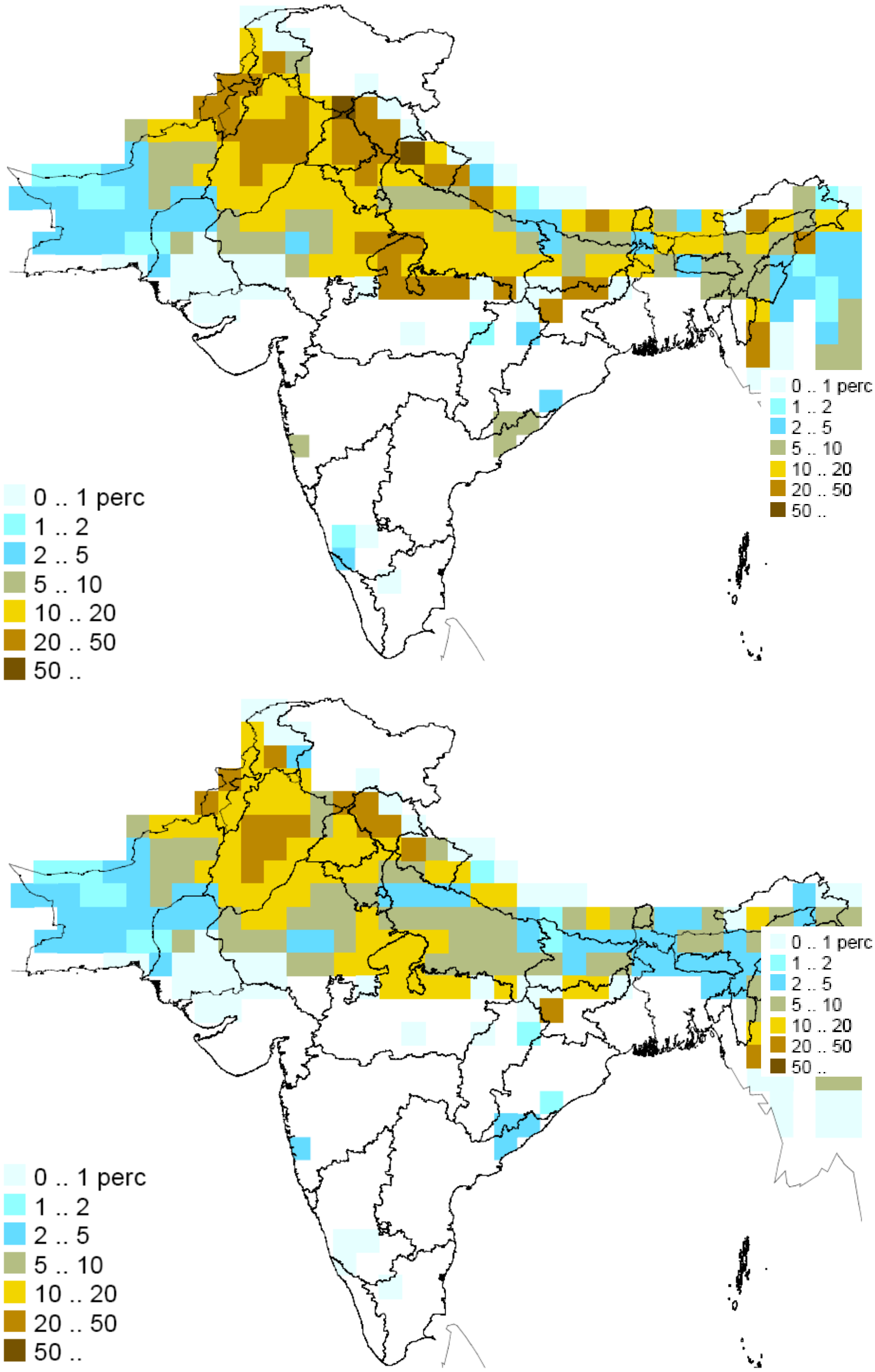

Figure 4.2: Potential crop losses for wheat computed for the Current Legislation (CLE) case in 2030 (top panel) and the Advanced Control Technology (ACT) case (bottom panel)

In summary, full application of advanced emission control measures to large sources could substantially reduce emissions in the future, which would lead to significantly improved air quality and lower air pollution damage to human health, agricultural crops and the natural environment (Table 4.4).

Table 4.4: Comparison of impact indicators for the Current Legislation (CLE) and Advanced Control Technology (ACT) scenarios in 2030, compared to the estimates for 2005

		2005	2030 CLE	2030 ACT
LOSS IN STATISTICAL LIFE EXPECTANCY	Months	24.9	58.8	26.5
YEARS OF LIFE LOST (YOLLS) FROM OUTDOOR POLLUTION	Million years/yr	24.0	102.0	46.0
DISABILITY ADJUSTED LIFE YEARS FROM INDOOR POLLUTION	Million years/yr	12.8	12.3	12.3
CASES OF PREMATURE DEATHS FROM GROUND-LEVEL OZONE	1000 cases/yr	48.2	115.3	65.9
POTENTIAL CROP LOSS FOR RICE	Million tons/yr	0.8	2.7	1.4
POTENTIAL CROP LOSS FOR WHEAT	Million tons/yr	4.6	13.0	8.4
POTENTIAL CROP LOSS FOR SOYBEAN	Million tons/yr	0.1	0.5	0.2

4.2 Cost-effective allocation of end-of-pipe air pollution controls

As shown above, full application of advanced emission control technology that is currently available on the world market could substantially reduce air pollution impacts in India. However, while such a uniform across-the-board strategy would cut, for instance, the loss in statistical life expectancy by 53 percent compared to the baseline case, its implementation would involve substantial economic resources and would increase the share of air pollution control costs in total GDP from 0.11 percent in 2005 to 1.1 percent in 2030. Although this fraction is small in comparison to the projected increase in India's total GDP (+300 percent in PPP between 2005 and 2030), it is higher than what industrialized countries typically spend on air pollution controls.

Numerous policy applications of the RAINS model in Europe have demonstrated that a uniform across-the-board application of advanced emission control measures is usually not a cost-effective way of improving air quality, and that a carefully selected portfolio of measures can achieve the same health and environmental benefits at much lower costs. The GAINS optimization tool offers a practical means for a systematic search for a balance of measures across economic sectors and locations that attain exogenously specified environmental targets at least cost.

To explore the potential cost savings from such an approach for India, an alternative emission control scenario has been developed that identifies the cost-effective portfolio of measures that achieves the same health benefits as would result from the across-the-board application of advanced control technologies (i.e., the ACT case as described above). This scenario assumes the same levels of economic activities (i.e., energy consumption, traffic volumes, industrial production, and agricultural activities) as the baseline projection and explores alternative allocations of air pollution emission control measures that achieve the same number of life years lost from PM2.5 as computed for the ACT scenario at lower overall costs. The calculation assumes that measures that are laid down in current Indian air pollution legislation will be maintained, so that only additional measures that are currently not legally required are considered.

Table 4.5: Emissions in 2030, for the Current Legislation (CLE) case, the scenario with across-the-board application of advanced control technologies (ACT) and the cost-effective allocation determined with the GAINS model (OPT), kilotons (OPT model is not visible in GAINS)

	SO_2			NO_x			PM2.5		
	CLE	ACT	OPT	CLE	ACT	OPT	CLE	ACT	OPT
POWER GENERATION	14614	800	2076	4718	1519	3860	676	170	186
INDUSTRY	16044	4195	4349	4102	2561	3063	2865	470	740
DOMESTIC	346	333	325	515	469	514	2971	2970	1759
TRANSPORT	115	12	204	4289	1195	4289	361	60	361
AGRICULTURE	16	0	0	15	0	0	474	24	25
OTHER	3	3	3	3	3	3	200	196	186
TOTAL	31138	5343	6957	13641	5746	11728	7548	3889	3257

To increase the cost-effectiveness of the control strategy, the optimization identifies the least-cost allocation of emission control measures across pollutants, economic sectors and states. In terms of pollutants, the cost minimizing approach reduces less SO_2 and NO_x emissions compared to the uniform ACT case, but puts higher emphasis on the control of PM emissions (Table 4.5).

Cost savings can also be accrued by emphasizing measures at sources that make the largest contribution to population exposure, and relieving the pressure on other sources that contribute less. There is a large cost saving potential by a geographical reallocation of further control measures, to reflect differences in population densities across India and regional differences in the control potentials and costs for different pollutants. Table 4.6 compares the cost-effective allocation of measures for SO_2, NO_x and PM emissions across states with the distribution resulting from an across-the-board application of advanced emission control technologies. Differences are represented in graphical form in Figure 4.3 to Figure 4.5.

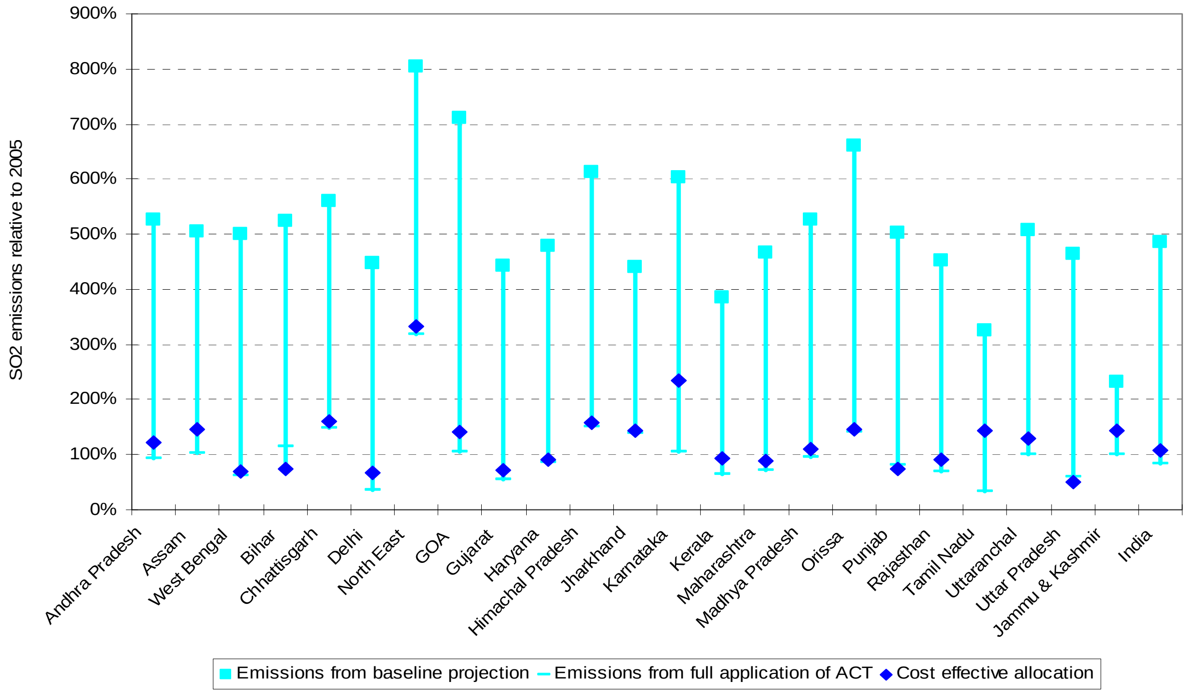

Figure 4.3: Cost-effective allocation of SO_2 emission reductions (diamonds) compared to the reductions from an across-the-board application of advanced control technologies for large sources (ACT) in 2030. The squares indicate the level of baseline emissions resulting from the implementation of current emission control legislation.

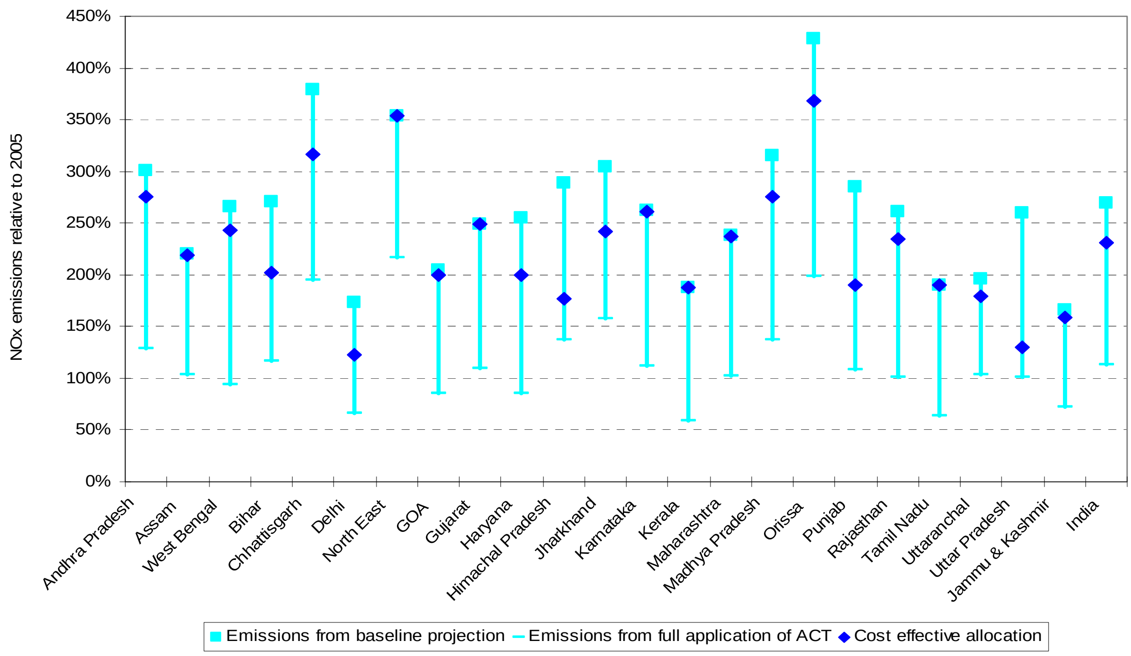

Figure 4.4: Cost-effective allocation of NO_x emission reductions (diamonds) compared to the reductions from an across-the-board application of advanced control technologies for large sources (ACT) in 2030. The squares indicate the level of baseline emissions resulting from the implementation of current emission control legislation.

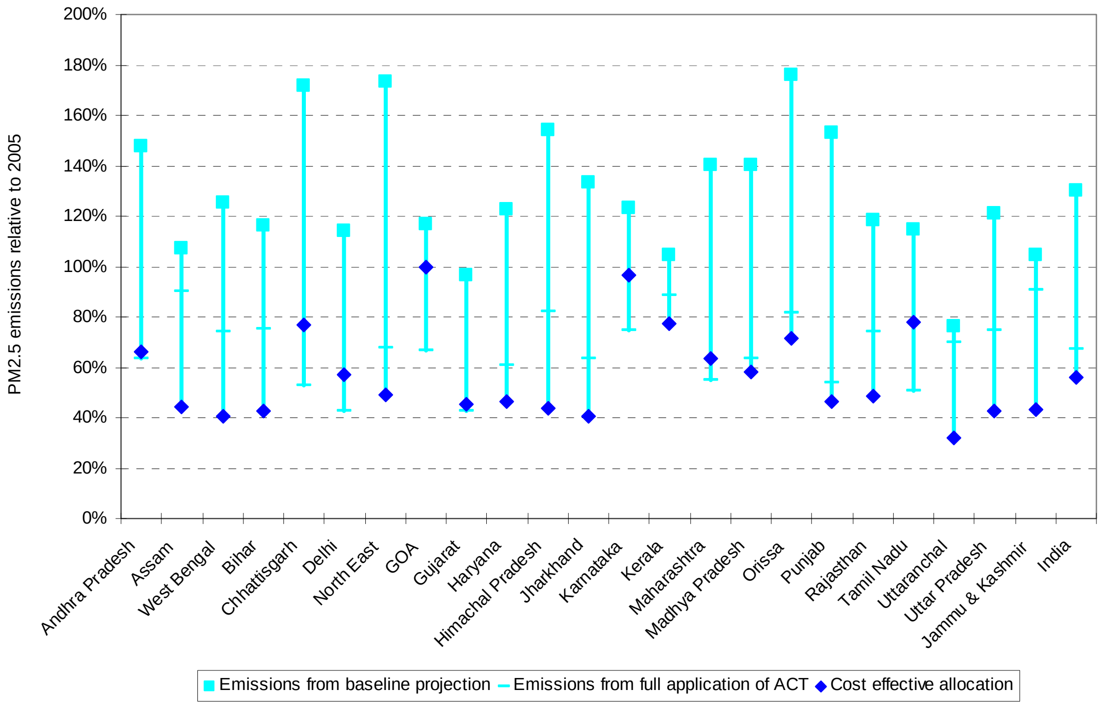

Figure 4.5: Cost-effective allocation of PM2.5 emission reductions (diamonds) compared to the reductions from an across-the-board application of advanced control technologies for large sources (ACT) in 2030. The squares indicate the level of baseline emissions resulting from the implementation of current emission control legislation.

Table 4.6: Air pollution emissions by state for 2005 and 2030, for the Current legislation (CLE) baseline projection, the case with across-the-board application of advanced control technologies for large sources (ACT) and the cost-effective allocation determined with the GAINS model (OPT), in kilotons

	SO_2				NO_x				PM2.5			
	2005	CLE	ACT	OPT	2005	CLE	ACT	OPT	2005	CLE	ACT	OPT
ANDHRA PRADESH	523	2755	492	633	425	1278	547	1171	412	608	262	273
ASSAM	51	258	52	74	69	152	71	151	135	145	122	60
WEST BENGAL	487	2432	302	335	377	1003	355	916	434	545	321	175
BIHAR	117	613	134	86	125	339	146	252	232	270	175	99
CHHATTISGARH	343	1922	509	550	227	861	442	719	271	465	143	208
DELHI	54	242	19	36	109	189	72	134	28	32	12	16
NORTH EAST	89	716	284	297	112	396	243	396	181	314	123	89
GOA	17	121	18	24	20	41	17	40	6	7	4	6
GUJARAT	706	3130	388	510	376	938	412	936	410	396	175	186
HARYANA	140	671	120	129	171	436	146	341	118	145	72	55
HIMACHAL PRAD.	44	270	66	69	43	124	59	76	50	77	41	22
JHARKHAND	175	769	243	252	118	359	186	285	194	259	123	79
KARNATAKA	217	1311	227	508	201	527	225	526	303	373	227	293
KERALA	122	471	80	115	126	237	75	237	178	186	158	138
MAHARASHTRA	870	4063	635	763	534	1272	546	1267	462	649	253	293
MADHYA PRADESH	391	2056	376	426	313	985	431	862	361	506	229	209
ORISSA	345	2281	485	503	205	878	408	755	314	553	256	224
PUNJAB	173	870	141	129	172	490	187	326	132	202	71	61
RAJASTHAN	209	944	143	189	284	742	286	666	471	557	349	228
TAMIL NADU	677	2204	229	976	452	862	287	861	238	273	120	185
UTTARANCHAL	14	71	14	18	29	57	30	52	132	101	92	42
UTTAR PRADESH	636	2947	379	325	547	1423	551	708	675	819	503	288
JAMMU&KASHMIR	9	21	9	13	32	53	23	51	65	68	59	28
TOTAL	6406	31138	5343	6957	5066	13641	5746	11728	5803	7548	3889	3257

In terms of sectors, a cost-effective approach allocates more resources to control emissions from households. This transfer acknowledges the fact that (i) there is a significant potential for cheap emission reductions in the domestic sector that are not employed in the ACT strategy which focuses on emissions from large sources such as power plants and industrial boilers, and (ii) that emissions from low-level sources such as households make a larger contribution to population exposure than emissions from the high stacks of large sources. The environmental benefits of these additional controls of emissions from households allow less stringent emission controls in the power sector, which reduces the additional costs (on top of the CLE case) in this sector by one third. Also the need for pollution controls for industrial sources is substantially reduced, with costs declining by 55 percent. Further tightening of emission standards for mobile sources beyond what is already required by current legislation, though technically possible, turns out to be an economically inefficient means for improving health effects of air pollution as long as basic measures for controlling household emissions are not adopted. Overall, in such a cost-effective allocation, costs of additional measures that would cut health impacts by 53 percent would be 50 percent lower than in the case where advanced emission control technologies are applied to all sources across the board (Table 4.7, Figure 4.6).

Table 4.7: Emission control costs by sector in 2030, for the Current Legislation (CLE) case, the scenario with across-the-board application of advanced control technologies (ACT) and the cost-effective allocation determined with the GAINS model (OPT), in billion €/yr

	Total air pollution control costs			Costs of additional measures on top of current legislation	
	CLE	ACT	OPT	ACT	OPT
POWER GENERATION	2.5	19.3	13.5	16.8	11.1
INDUSTRY	2.5	23.5	12.0	21.0	9.5
DOMESTIC	1.2	1.7	4.1	0.5	3.0
TRANSPORT	10.2	18.4	10.5	8.2	0.3
AGRICULTURE	0.0	0.6	0.0	0.6	0.0
OTHER	0.0	0.3	0.0	0.3	0.0
TOTAL COSTS	16.3	63.7	40.2	47.4	23.9
% OF GDP	0.28%	1.08%	0.68%	0.80%	0.41%

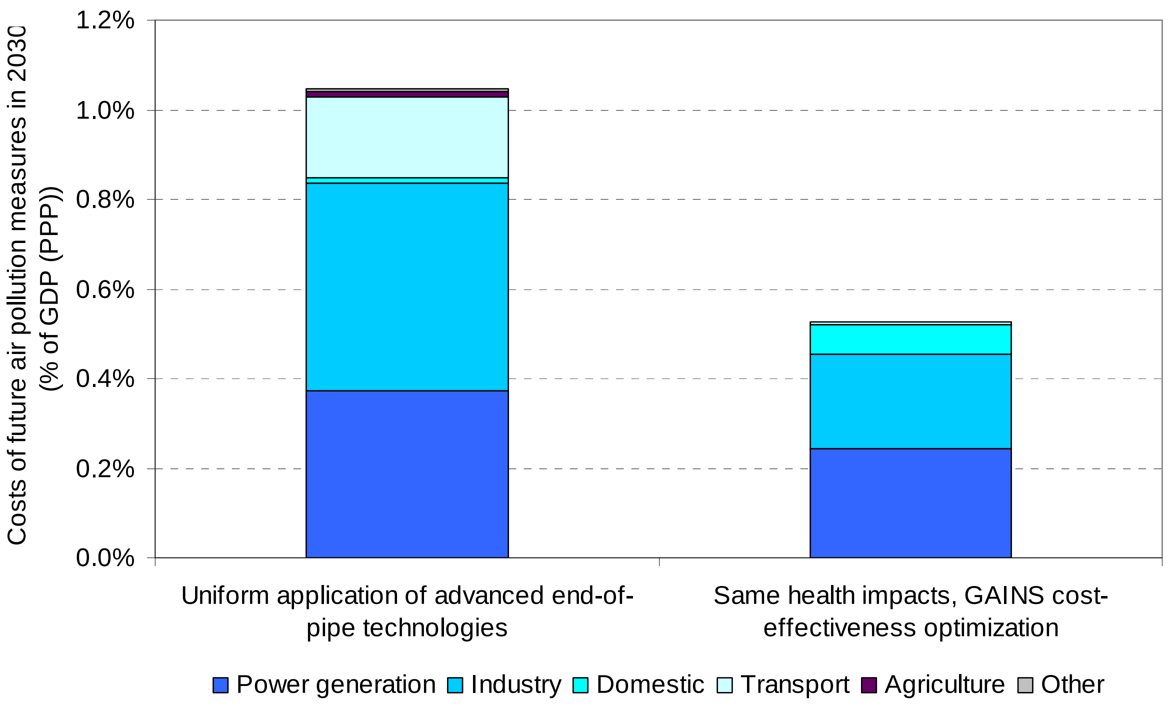

Figure 4.6: Costs of additional emission controls (beyond the measures required by current legislation) of the ACT scenario (left column) and the cost-effective allocation determined with the GAINS model (right column) in the year 2030. Both scenarios achieve a 53 percent reduction in health effects from PM pollution.

4.3 Cost-effective air pollution reductions including structural changes

It has been demonstrated in the above scenario that a targeted allocation of emission controls can lead to substantial cost savings. Obviously, the extent of possible cost savings is determined, inter alia, by the available scope for re-arranging emission control measures. In general, a larger scope for re-allocation increases the potential for cost savings. The portfolio of measures that is considered in the scenario above includes air pollution control measures in all sectors, and the cost savings of the optimized solution are achieved through re-allocation of these measures across sectors, pollutants and states.

However, air pollution emissions can be reduced not only through end-of-pipe measures. In general, air pollution emissions also decline if levels of anthropogenic activities that generate air pollution are reduced. Such changes could happen through technical measures, such as improved energy combustion efficiency, energy savings through, e.g., improved insulation, co-generation of heat and electricity, and through substitution of polluting fuels by cleaner fuels. Lower activity levels could also result from non-technical behavioural changes, such as changes in transport modes, use of smaller vehicles, less living area heated, etc.

Since these non-technical measures require changes in personal life styles, they were traditionally beyond the portfolio of air quality managers. This also applies to most of the technical interventions that imply structural changes in the energy systems with direct implications on national energy policies. With growing concern about greenhouse gas emissions, however, such measures are now increasingly considered by policy makers who deal with the negative impacts of emissions to the atmosphere.

To explore the possible role of such structural measures in cost-effective air pollution control strategies, and their interactions with greenhouse gas emissions, the GAINS optimization also allows searching for least-cost solutions to achieve air quality targets that include these measures. Therefore, an illustrative scenario has been developed that explores a cost-effective portfolio of measures that, in 2030, cuts air pollution health impacts by 60 percent compared to the baseline case. In addition to the measures considered in the ACT scenario, the portfolio includes technical structural measures such as energy efficiency improvements through more efficient combustion processes and improved insulation, combined heat and power generation, fuel substitution and advanced clean coal technologies such as integrated gasification combined cycle (IGCC) plants. The portfolio, however, does not consider measures that change lifestyle and behaviour of people, such as lower demand for transport and heating services, changes of transport modes, etc.

As shown in Table 4.8, a cost-effectiveness optimization that allows for structural changes leads to substantial overall cost savings in comparison to the corresponding optimization that excludes the possibility of structural changes. To reduce health impacts in 2030 by 60% relative to baseline, costs of pollution control measures (beyond what is required by current Indian legislation) would shrink from €30.6 billion/yr (0.52% of GDP) to €8.9 billion/yr (0.15% of GDP). The cost-effective portfolio includes measures to increase energy efficiency in households and industry, enhanced co-generation of heat and electricity, and the substitution of coal and oil by renewable energy. The increased use of renewable energy (substituting coal and oil) and improvements of energy efficiency at the household level cost €14 billion/yr, whereas the more widespread use of co-generation of heat and electricity, improved energy efficiency in industry, and improved fuel efficiency of vehicles all would effectively reduce overall system costs (Figure 4.7).

Table 4.8: Costs of emission control measures for the GAINS optimization with air pollution measures only (left column) and the optimization with structural changes (billion €/yr)

	GAINS optimization with end-of-pipe air pollution control measures only	GAINS optimization with structural measures
END-OF-PIPE AIR POLLUTION CONTROL MEASURES:		
LARGE PLANTS, SO_2 CONTROLS	19.6	15.1
LARGE PLANTS, NO_x CONTROLS	2.7	1.2
LARGE PLANTS, PM CONTROLS	1.6	1.0
HOUSEHOLDS, PM CONTROL	4.4	0.5
OTHER	2.2	0.9
SUB-TOTAL	30.6	18.7
STRUCTURAL MEASURES:		
ELECTRICITY SAVING, RENEWABLE ENERGY		14.1
CO-GENERATION, FUEL SWITCHES		-16.9
ENERGGY EFFICIENCY, INDUSTRY		-3.7
ENERGY EFFICIENCY, HOUSEHOLDS		1.2
FUEL EFFICIENCY, VEHICLES		-4.5
SUB-TOTAL		-9.8
TOTAL	30.6	8.9

Inclusion of structural measures in the portfolio allow further reductions of primary particulate matter (PM2.5) beyond what end-of-pipe measures alone could deliver (Table 4.9). Given the fixed targets on health effects, the 13 percent lower PM2.5 emissions relax the requirements for SO_2 and NO_x controls, so that SO_2 and NO_x emissions could be 35 and 4 percent higher respectively than in the end-of-pipe only case.

It is important to mention that, because these structural measures reduce the levels of energy consumption, they also lead to lower greenhouse gas emissions. Therefore, the inclusion of structural measures in the pollution control portfolio leads, as a side-effect, to seven percent lower CO_2 emissions.

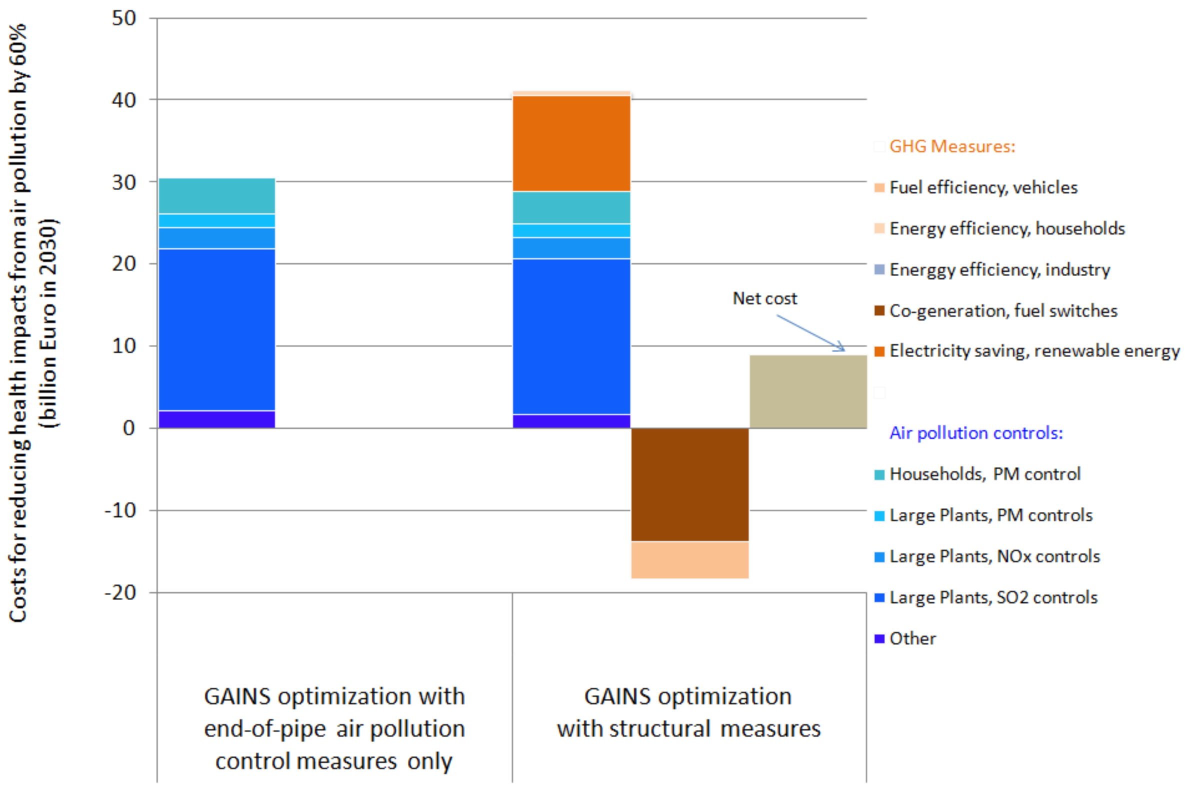

Figure 4.7; Costs for reducing health effects of air pollution in 2030 by 60 percent. Note that the optimization that includes greenhouse gas mitigation measures also results in seven percent less CO_2 emissions as a side-benefit of air pollution control.

Table 4.9: Emissions in 2030, for the GAINS optimization with end-of-pipe air pollution measures only and the optimization with structural measures, in kilotons

	SO_2		NO_x		PM2.5		CO_2	
	End-of-pipe only	With structural measures	End-of-pipe only	With structural measures	End-of-pipe only	With structural measures	End-of-pipe only	With structural measures
Power generation	1,388	3,005	3,285	3,923	170	222		
Industry	3,395	3,762	2,909	2,942	433	765		
Domestic	325	215	510	277	1,346	627		
Transport	204	204	4,289	4,289	361	361		
Agriculture	0	0	0	0	25	25		
Other	2	3	2	3	181	181		
Total	5,314	7,189	10,994	11,432	2,516	2,181	5,946	5,509
Difference to end-of-pipe		+35%		+4%		-13%		-7%

4.4 Air pollution control through greenhouse gas mitigation strategies

As demonstrated above, certain greenhouse gas mitigation measures form part of a cost-effective portfolio of air pollution control measures. The question arises to what extent a strategy that aims at reducing greenhouse gas emissions would create positive co-benefits on air quality.

A fourth scenario has been developed by The Energy and Resources Institute (TERI) that outlines an alternative development of the energy system responding to increased concerns on energy supply security and local environmental pressure. While the underlying assumptions on population growth and economic development are identical to those of the baseline projection, the alternative scenario quantifies the consequences of a wide range of practical policy interventions aiming at a more sustainable development path of the Indian economy. The scenario assumes rapid enhancement of end-use efficiencies, adoption of advanced coal and gas-based power generating technologies, enhancement of efficiency in the transport sector by modal shifts, and exploitation of renewable energy and nuclear energy resources to accelerate the conversion of the Indian economy towards less energy intensive industries.

With these assumptions, the alternative scenario projects 32 percent less coal and 14 percent less oil consumption than the Baseline case for 2030. Nuclear energy based power generation will increase by a factor of 3.3 whereas contribution of renewables will double. (Table 4.10, Figure 4.8).

Table 4.10: Fuel consumption in India in 2005 and in 2030, for the Baseline projection and the Alternative scenario (PJ)

	2005	2030 Baseline projection	2030 Alternative scenario
COAL	8788	45096	30518
OIL	5538	16846	14528
GAS	1627	7873	8003
RENEWABLES	13	105	204
HYDRO	306	1693	1751
NUCLEAR	165	1619	5352
BIOMASS	6484	6896	6896
TOTAL	22922	80129	67251

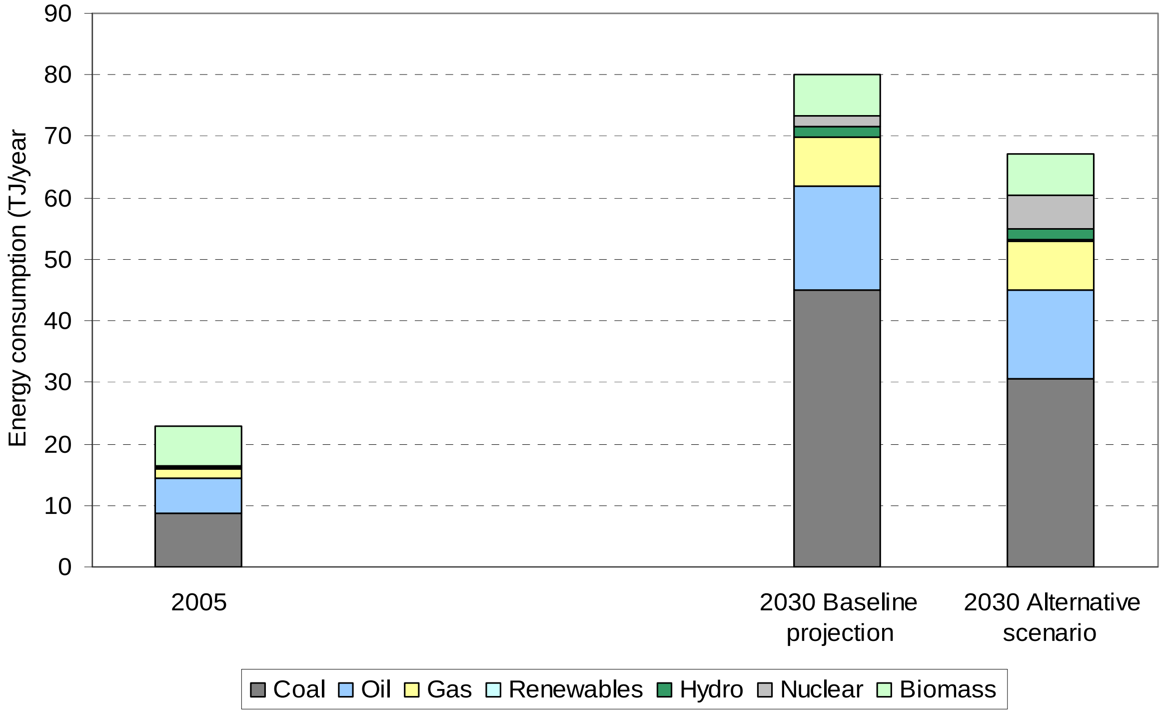

Figure 4.8: Energy consumption in India by fuel in 2005 and 2030, for the Baseline projection and the Alternative scenario

These lower consumption levels of carbonaceous fuels lead to distinctly lower emissions to the atmosphere. Assuming implementation of current emission control legislation in 2030, SO_2 and NO_x emissions are 32 and 22 percent lower than in the baseline projection because of less coal and oil consumption. The changed energy consumption structure also leads to lower emissions of particulate matter, however the difference (-9 percent) is less than for SO_2 and NO_x due to biomass use. In addition, such a strategy would also cause 40 percent lower CO_2 emissions than the baseline projection (Table 4.11).

Table 4.11: Emissions of the Baseline projection and the Alternative scenario in 2030

	SO_2 (kt)		NO_x (kt)		PM2.5 (kt)		CO_2 (Mt)	
	Baseline	Alternative	Baseline	Alternative	Baseline	Alternative	Baseline	Alternative
POWER GENERATION	14565	9190	4700	2867	664	418	2984	1805
INDUSTRY	16044	11393	4102	3246	2859	2437	2098	1662
DOMESTIC	346	318	515	509	3160	3141	213	206
TRANSPORT	115	109	4289	3967	361	348	494	467
AGRICULT.	0	0	0	0	25	25	0	8
OTHER	68	68	36	36	478	478	157	165
TOTAL	31138	21078	13641	10624	7548	6847	2984	1805
DIFFERENCE TO BASELINE		-32%		-22%		-9%		-40%

Obviously, such lower emissions cause lower health impacts through reduced levels of PM2.5 in ambient air. It is estimated that the Alternative scenario reduces the loss in statistical life expectancy that is attributable to PM2.5 to 45 (23-63) months, compared to 59 (28-77) months of the Baseline projection, i.e., by 18 percent.

It should be mentioned that these lower emissions and health impacts occur as a mere side benefit of the assumed energy policy measures, and not of stricter air pollution emission control legislation. In fact, such an alternative energy strategy would reduce costs for implementing current air pollution legislation by €1.4 billion/yr or 0.03 percent of GDP (Table 4.12). These saving are caused by the lower levels of coal and oil consumption which also require fewer installations of air pollution control equipment.

Table 4.12: Air pollution control costs for implementing current Indian legislation to the activity levels of the Baseline projections and the Alternative scenario in 2030 (billion €/yr)

	Baseline projection	Alternative scenario
POWER GENERATION	2.4	1.5
INDUSTRY	2.5	2.2
DOMESTIC	1.2	1.1
TRANSPORT	10.2	10.1
AGRICULTURE	0.0	0.0
OTHER	0.0	0.0
TOTAL	**16.3**	**14.9**
% OF GDP	0.28%	0.25%

At the moment the differences in costs between an energy policy that follows the Baseline projection and a strategy along the lines of the Alternative scenario cannot be quantified with the GAINS model. However, a comprehensive evaluation of the costs and benefits of these policy alternatives must include the cost savings from reduced air pollution controls as well as the health (and climate) benefits that result from lower emissions (Figure 4.9).

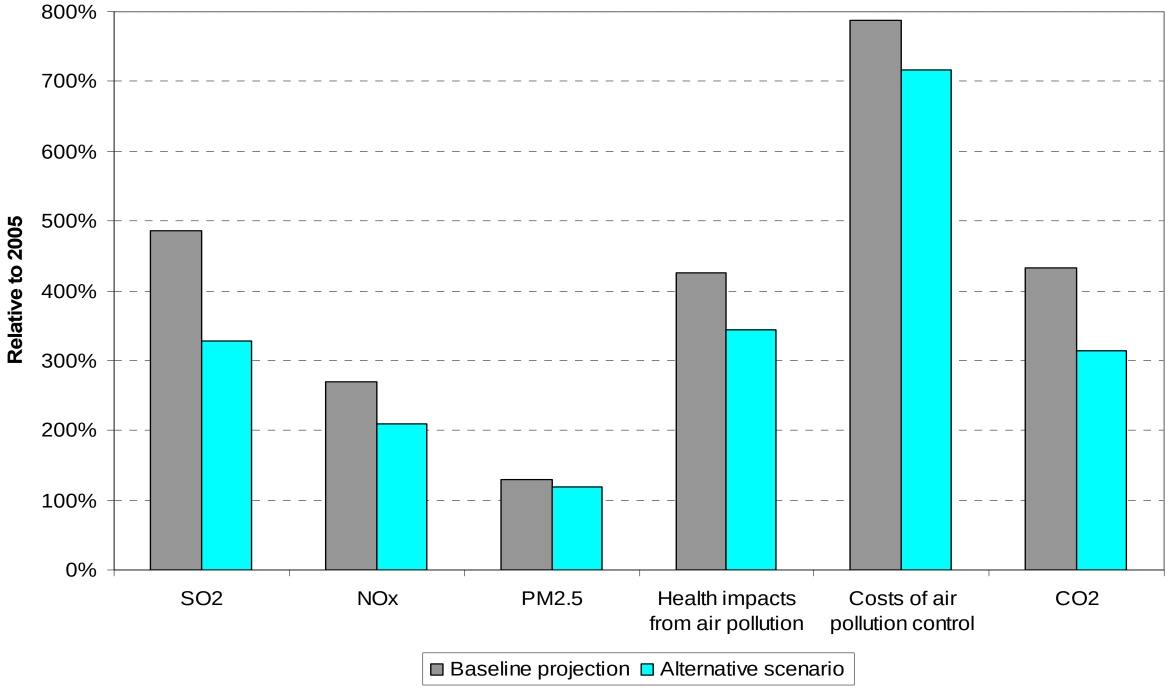

Figure 4.9: Comparison of key indicators of the Baseline projection and the Alternative scenario for 2030

5 Conclusions

Current and future economic growth in India will counteract ongoing efforts to improve air quality through controls of fine particulate emissions (PM2.5) from large stationary sources and nitrogen oxide (NO_x) emissions from vehicles. Unless further air pollution policies are implemented, the increase in coal consumption to fuel additional industrial production and provide more electricity to a wealthier population would lead to a five-fold increase in SO_2 emission over the next two decades in India. NO_x emissions in India would increase by a factor of three in 2030 due to the lack of regulations for controlling emissions of NO_x from large stationary sources despite the tight emission control legislation that has been recently imposed for mobile sources. As a consequence, without further air pollution control policies, negative impacts on human health and vegetation that are currently felt across India will not substantially improve in the coming decades. For instance, it is estimated that present exposure to fine particulate matter (PM2.5) is shortening life expectancy of the Indian population by approximately 25 (13-34) months, and that it would double in a business-as-usual case for the coming decades. Emissions of greenhouse gases that contribute to global climate change would increase by a factor of three till 2030.

Yet, advanced emission control technologies are available to maintain acceptable levels of air quality despite the pressure from growing economic activities. Full application of currently available technical end-of-pipe emission control measures in India could achieve substantial improvements in air quality. It is estimated that negative health impacts from air pollution could be reduced by 53 percent in 2030 by applying such advanced emission control technology to all large sources in India. However, such an undifferentiated across-the-board approach would impose significant burden on the economy, involving an additional expense of 0.80 percent of GDP.

In contrast, a cost-effective emission control strategy developed with the GAINS optimization tool that selectively allocates specific reduction measures across economic sectors, pollutants and regions, could achieve equal air quality improvements at only 50 percent of the costs of a conventional across-the-board approach. An integral element of such an air pollution control strategy will be measures to eliminate indoor pollution from the combustion of solid fuels. The investment will also reduce crop losses by around 40 percent and have far ranging positive impacts on the environment.

Well-designed air pollution control strategies can also reduce emissions of greenhouse gases as a co-benefit. An optimized scenario developed with the GAINS model demonstrates that low carbon strategies result in lower emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x) and fine particulate matter (PM) at no additional costs. GAINS estimate that each percent of CO_2 reduction will typically reduce health impacts from fine particulate (PM) air pollution by one percent.

This also means that, for achieving given targets on ambient air quality, the cost of air pollution can be further reduced by adopting certain low carbon measures. A GAINS scenario demonstrates that the additional costs of some climate-friendly measures, e.g., energy efficiency improvements, co-generation of heat and power, fuel substitution, integrated coal gasification combined cycle (IGCC) plants, etc., are to a large extent compensated for by savings in air pollution control equipment. Preliminary results based on analysis of various scenarios carried out for India indicate that by selecting a smart mix of measures to simultaneously cut air pollution and greenhouse gas emissions, air pollution reduction could be achieved at lower costs than through conventional end-of-pipe control technologies, while at the same time reduce greenhouse gas emissions by seven percent.

This report highlights the scope for measures that maximize co-benefits between air pollution control and greenhouse gas mitigation in qualitative terms. A quantitative policy analysis, however, will require a more in-depth review of the input data that have been compiled by the project.

For policymakers, industry, NGOs and researchers wishing for more information and to conduct independent analyses, the GAINS-Asia model and documentation is freely available online at http://gains.iiasa.ac.at.

Annex-I: Comparison of emission inventories and projections

Table A1: Emission estimates of GHGs in India

1990	1995	2000	2005	2010	2015	2020	2025	2030	REFERENCES
CO_2 EMISSIONS (MT)									
606	831	1061	1367	1802	2436	3260	4357	5904	GAINS/IIASA_CLE (2008)
606	831	1061	1367	1538	1898	2383	3131	4305	GAINS/IIASA_ALT (2008)
593	778		1229						Garg et al. (2001)
		928		1486		2093		2567	Garg et al. (2004)
			1100		1760			3300	IEA/OECD (2007)
615	849	1032	1229						Garg et al. (2006)
	1228								UNFCCC (2004)
682	916	1155	1343						United Nations
		1261							EDGAR
			1000					5500	Planning Commission (2006)*
								3900	Planning Commission (2006)**
		1031							REAS ver.1.1
589			1250		1798	2187	2686	3293	IEA/OECD (2009)
587			1147		1804			3314	IEA/OECD (2009)
				1500-2000				4000	NCAER CGE Model
								4900	TERI MoEF Model
								4230	IRADe AA Model
								7300	TERI Poznan Mode
								5700	McKinsey India Model
CH_4 EMISSIONS (KT)									
20935	22243	24706	26378	27968	29288	31326	32682	34096	GAINS/IIASA_CLE (2008)
20935	22243	24706	26378	27957	29275	31355	32755	34221	GAINS/IIASA_ALT (2008)
17000	18000								Garg et al. (2001)
		18630		20080		21730		24360	Garg et al. (2004)
17920	18850	19610	20080						Garg et al. (2006)
		34399							EDGAR
		25730							REAS ver.1.1
N_2O EMISSIONS (KT)									
571	645	697	766	836	905	979	1060	1153	GAINS/IIASA_CLE (2008)
571	645	697	766	832	897	966	1041	1129	GAINS/IIASA_ALT (2008)
200	300								Garg et al. (2001)
		308		505		689		807	Garg et al. (2004)
158	185	217	253						Garg et al. (2006)
		901							EDGAR
		864							REAS ver.1.1

Table A2: Emission estimates of air pollutants in India

1990	1995	2000	2005	2010	2015	2020	2025	2030	REFERENCES
SO_2 EMISSIONS (KT)									
3106	4253	5128	6413	8597	11825	15969	22478	31520	GAINS/IIASA_CLE (2008)
3106	4253	5128	6413	6987	8511	10628	14881	21445	GAINS/IIASA_ALT (2008)
3668			6699		9759			16546	IEA/OECD (2007)
								12079	IEA/OECD (2007)
2850	3660	4260	4800						Garg et al. (2006)
		7920							EDGAR
		6141							REAS ver.1.1
	4330								Reddy and Venkataraman (2002)
NO_x EMISSIONS (KT)									
2630	3516	4135	5065	6134	6943	8520	10714	13638	GAINS/IIASA_CLE (2008)
2630	3516	4135	5065	5423	5767	6668	8220	10622	GAINS/IIASA_ALT (2008)
2791			4109		5165		3	8528	IEA/OECD (2007)
								6567	IEA/OECD (2007)
2640	3460	4310	5020						Garg et al. (2006)
		6579							EDGAR
VOC EMISSIONS (KT)									
9396	10253	11295	12953	13646	13075	13076	13302	13573	GAINS/IIASA_CLE (2008)
9396	10253	11295	12953	13591	12984	13057	13328	13687	GAINS/IIASA_ALT (2008)
7369	8124	9372							WRI
			2800[#]						Parashar et al. (2005)
PM2.5 EMISSIONS (KT)									
4272	4745	5022	5803	6120	6245	6588	7051	7548	GAINS/IIASA_CLE (2008)
4272	4745	5022	5803	5989	6022	6200	6509	6847	GAINS/IIASA_ALT (2008)
4206			4681		4469			4192	IEA/OECD (2007)
	4040[##]								Reddy and Venkataraman (2002)
NH_3 EMISSIONS (KT)									
5535	6032	6268	6638	7021	7371	7756	8147	8605	GAINS/IIASA_CLE (2008)
5535	6032	6268	6638	7020	7370	7748	8134	8592	GAINS/IIASA_ALT (2008)
	6764								REAS ver.1.1

[*]High coal use scenario
[**]Low coal and renewable dominant scenario
[#]OC+BC
[##]50% control scenario for 1996-97

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