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Pallav Purohit [a], Tahira Munir [b] & Peter Rafaj [a]

[a] International Institute for Applied Systems Analysis (IIASA), Mitigation of Air Pollution & Greenhouse Gases (MAG) Programme, Schlossplatz 1, Laxenburg, A-2361, Austria

[b] Environment Section, Global Change Impact Studies Centre (GCISC), National Centre for Physics Complex (NCP), Quaid-i-Azam University Campus, Shahdra Valley Road, Islamabad, 44000, Pakistan

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Pallav Purohit[a]*, Tahira Munir[b] and Peter Rafaj[a]

[a]*International Institute for Applied Systems Analysis (IIASA), Mitigation of Air Pollution & Greenhouse Gases (MAG) Programme, Schlossplatz 1, Laxenburg A-2361, Austria*
[b]*Environment Section, Global Change Impact Studies Centre (GCISC), National Centre for Physics Complex (NCP), Quaid-i-Azam University Campus, Shahdra Valley Road, Islamabad 44000, Pakistan*

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This study presents an initial analysis of potential implications of the current economic development plans of Pakistan on local and regional air pollution and explores alternative approaches that could limit the envisaged deterioration of air quality. The study summarizes exogenous projections of energy use and application of emission control measures for sulfur dioxide, nitrogen oxides, and particulate matter up to 2030 and discusses the resulting implications on air quality. Illustrative emission control scenarios are used to assess health benefits of additional measures and associated costs. Scenarios investigate the policy options of employing cleaner fuels and of applying end-of-pipe emission control measures.

Keywords: air pollution; abatement policies; emission control technologies; cost of emission mitigation; health impacts

1. Introduction

Air pollution is a rapidly growing environmental problem in Pakistan (Alam et al. 2007). According to the Pakistan Environmental Protection Agency (Pak-EPA), air pollution levels for the major Pakistani cities have been recorded seven times higher than those prescribed by the World Health Organization (*The News* 2011). Highly inefficient energy use, accelerated growth in vehicle number and vehicle kilometers traveled, increasing industrial activity without adequate air pollution control, and open burning of solid waste including plastic are some of the key factors for declining ambient air quality in Pakistan (Parekh et al. 2001; ADB 2006; Tahir et al. 2010). At the same time, the expansion of economic activities also spurs greenhouse gases (GHGs) emissions (Ansuategi and Escapa 2002; Hyder et al. 2006; Ali and Athar 2008; UNFCCC 2011). Therefore, it is critically important to limit the increase or even reduce emissions of air pollutants that deteriorate local air quality in Pakistan, while also emissions of GHGs should be kept at a minimum.

With a population over 177 million people in 2011, Pakistan (situated in the South Asian region) is the sixth most populous country in the world. Pakistan's gross domestic product (GDP) in 2011 was US$488 billion at purchasing power parity (PPP). The annual per capita GDP was estimated at US$2800 (CIA 2012). It is South Asia's second largest economy, representing about 15% of regional GDP. The real GDP growth for 2011–2012 has been estimated at 3.7% as compared to 3.0% in the previous fiscal year 2011

*Corresponding author. Email: purohit@iiasa.ac.at

(Pakistan Economic Survey 2012). After the year 1990, following an industrial revolution of its own, Pakistan's energy requirement was increasing rapidly every year. The primary energy consumption in Pakistan grew by almost 80% in the past 15 years from 1423 PJ in 1994–1995 to 2554 PJ in 2009–2010 (Abbas 2011; PIP 2011). The country's energy supply currently comes primarily from indigenous natural gas, which covers 45%, while oil imports account for 35% of the energy mix. The reminder of primary energy supplies consists of hydropower contributing 12%, coal 6%, and nuclear 2% of the fuel-mix (PIP 2011).

Similar to other developing countries, Pakistan has focused in recent decades on achieving self-sufficiency in food production, meeting energy demands, and containing its high rate of population growth rather than on curtailing emissions or other environmental hazards (MoF 2009). Yet, as Pakistan's cities suffer from the effects of air pollution and other environmental degradation (Ghauri et al. 2007; Ilyas et al. 2010; Stone et al. 2010; Mansha et al. 2012), environmental issues have become more salient (Azizullah et al. 2011; Nadeem and Fischer 2011). In an attempt to redress the previous inattention to the nation's mounting environmental problems, in 1992 the government issued its National Conservation Strategy Report (NCSR) outlining Pakistan's state of environmental health, its sustainable goals, and viable program options for the future with the national conservation goals (Hanson et al. 2000). As indicated in NCSR, the rapid urbanization puts the available insufficient infrastructure under enormous pressure and causes environmental debacles of great magnitude. Serious risks of irreversible damages occur due to air and water pollution, mismanagement of solid waste, and destruction of fragile ecosystems (Pakistan Economic Survey 2011).

This study presents results of a quantitative analysis to explore the scope for managing future emissions of air pollutants in Pakistan using the Greenhouse Gas and Air Pollution Interaction and Synergies (GAINS) model (Amann et al. 2008a, 2008b; Purohit et al. 2010). In addition to estimating costs and health impacts of air pollution reduction strategies, GAINS allows identifying synergies between the control of air pollution and the reduction of GHG emissions (Amann et al. 2011). Alternative scenarios in which emissions are changed through (a) changes in the structure of energy supply and (b) applications of end-of-pipe emission control measures are also analyzed. These scenarios address short- to middle-term environmental benefits of air pollution reduction. Detailed assessment of implications of air pollution control on GHG emissions and – vice versa – impacts of climate policies on air quality was beyond the scope of this paper, but is a subject of ongoing analyses.

2. Methodology and modeling framework

The GAINS model developed by the International Institute for Applied Systems Analysis (IIASA) has been widely used as an effective tool for evaluating air pollution impacts, GHG emissions, and for defining suitable mitigation measures (Klimont et al. 2009; Purohit et al. 2010; Amann et al. 2011). The GAINS model produces (a) emission scenarios for all major air pollutants (SO_2, NO_x, $PM_{2.5}$, NH_3, CO, etc.) for any exogenously supplied projection of future economic activities, (b) mitigation potentials and costs, as well as (c) interactions in abatement between various pollutants (Amann et al. 2011). GAINS considers measures for the full range of precursor emissions that cause negative effects on human health via the exposure to fine particles ($PM_{-2.5}$) and ground-level ozone (O_3), damage to vegetation via excess deposition of acidifying and eutrophying compounds, as well as computes the six GHGs (CO_2, CH_4, N_2O, HFC, PFC, and SF_6) considered in the Kyoto protocol. Thereby, GAINS 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.

2.1 Emission estimates

For each of the pollutants mentioned above, GAINS estimates current and future emissions based on activity data, uncontrolled emission factors, the removal efficiency of emission control measures, and the extent to which such measures are applied:

$$E_{i,p} = \sum_k \sum_m A_{i,k}\, \mathrm{ef}_{i,k,m,p}\, X_{i,k,m,p}, \tag{1}$$

where i, k, m, and p, respectively, represent the country, activity type, abatement measure, and pollutant, $E_{i,p}$ the emissions of pollutant p in country i, $A_{i,k}$ the activity level of type k (e.g. coal consumption in power plants) in country i, $\mathrm{ef}_{i,k,m,p}$ the emission factor of pollutant p for activity k in country i after application of control measure m, and $x_{i,k,m,p}$ the share of total activity of type k in country i to which a control measure m for pollutant p is applied (Amann et al. 2011).

2.2 Emission control measures and their costs

A wide range of technical measures have been developed to capture emissions at their sources before they enter the atmosphere. Emission reductions achieved through these end-of-pipe options neither modify the driving forces of emissions nor change the structural composition of energy systems or agricultural activities. Another mitigation strategy includes structural measures that supply the same level of (energy) services to the consumer but with less polluting activities. The GAINS concept does not internalize behavioral changes, but reflects such changes through alternative exogenous scenarios of the driving forces. Further information about different control measures is discussed in detail by Amann et al. (2011) and Rafaj et al. (2012). GAINS computes emission control costs from the perspective of a social planner, with a focus on resource costs of emission controls to societies. Costs are calculated based on the assumption that, at a free market for emission control technologies, the same technology will be available to all countries at the same costs. Also, technological progress is assumed in the performance and cost data, based on literature estimates. Country- and sector-specific circumstances (e.g. size distributions of plants, plant utilization, fuel quality, energy and labor costs, etc.) lead to justifiable differences in the actual costs at which a given technology removes pollution at different sources.

3. Baseline and alternative scenarios for Pakistan

Using the methodology of the GAINS model, this study consists of (a) an analysis of the activity data at regional and sectoral level, (b) development of emission control scenarios based on energy activity projections and control strategies, and (c) assessment of how different rates of implementation of available emission control technologies would affect air quality in Pakistan and the associated abatement costs. The following scenarios have been developed to explore the potential for minimizing adverse impacts of air pollution through alternative policies and various means of energy supply.

3.1 Baseline scenario

Pakistan has responded to the overall environmental challenge by adopting several pieces of legislation and policy initiatives aimed at incorporating environmental concerns into mainstream development planning [Pakistan Environmental Protection Act (PEPA) 1997; UNEP 2001; Munir 2008]. This policy response is embedded in the PEPA enacted on 6 December 1997 with the Pakistan Environmental Protection Council (PEPC) being the apex decision-making body. PEPA-1997 covers air, water, soil, and noise pollution, including hazardous waste disposal and vehicular pollution (Khwaja and Khan 2005). The associated implementation frameworks, consisting of the Ministry of Environment (MoE) and the EPAs at federal and provincial levels, have been formalized through the National Environment Policy (NEP) 2005. In addition, Pakistan has approved an array of environment-related policies including: National Energy Conservation Policy (2006), National Renewable Energy Policy (2006), Policy for Development of Renewable Energy for Power Generation (2006), and National Forest Policy (2010). NEP (2005) calls for setting of regulations for ambient and indoor air quality, and standards for vehicles, industrial emissions, and fuel quality, and energy conservation and building codes (MoE 2005).

Under the National Environmental Quality Standards (NEQS) for motor vehicle exhaust and noise, the environment ministry has set standards (maximum permissible limits and measuring methods) and measuring methods for smoke, carbon monoxide, and noise (Pak-EPA 2005; Schwela 2007). Recently, EURO-II standards for vehicle emissions were adopted for newly registered vehicles (Khan 2012). On the Climate Change front, Pakistan signed the United Nations Framework Convention on Climate Change (UNFCCC) as a non-Annex-I Party in June 1994. The country, subsequently, adopted the Kyoto Protocol in 1997 and acceded to it on 11 January 2005. The government recently approved the draft of National Policy on Climate Change, which provides a framework for addressing the issues that Pakistan face or will face in future due to the changing climate (Muhammad 2012).

As a starting point for the business-as-usual (BAU) scenario, the energy projection for Pakistan developed by Shahid (2008) has been employed. The implementation of emission control measures, as described in more detail in Section 3.3, has been updated based on current environmental legislations, the national environmental quality standards, and the environmental policy of Pakistan formulated by the Government of Pakistan (MoE 2005).

3.2 A clean fuel scenario

To explore a scope for replacing the most polluting fuels with cleaner alternatives, a "clean fuel" scenario (CFS) has been developed that aims to provide the same level of energy services to Pakistan's industry and households as is assumed in the BAU scenario, however, by maximizing the use of clean fuels. Pakistan is rich in natural gas resources and has intentions for more exploration, inter alia jointly with neighboring countries such as Iran (APP Services 2012). With the basic idea of minimizing health impacts caused by particulate matter, SO_2, and NO_x emissions from the domestic sector, power plants, and transport, the CFS assumes that gradually enhanced use of liquefied petroleum gas (LPG) will substitute more polluting fuels in the domestic sector, natural gas will substitute coal and oil in the power plant sector, and compressed natural gas (CNG) will substitute diesel and gasoline in the transport sector.

It is assumed in this scenario that the following measures will be implemented by the year 2020:

- For the domestic sector, the scenario assumes that LPG will substitute the use of solid fuels (i.e. brown coal, fuelwood, cow dung, and agricultural residues). It may be noted that the rural households traditionally use fuelwood and cow dung cakes as a source of energy in Pakistan (Khurshid 2009). Substitution of solid fuels by LPG might not only result in less outdoor pollution, but also improve indoor pollution levels, which are detrimental to human health causing coughing, asthma, lung cancer, and pulmonary diseases.
- For the transport sector, the scenario explores the maximum scope for using CNG. The scenario assumes that CNG would substitute gasoline and diesel oil in the transport sector by 2020. While Pakistan already has a certain share of vehicles run by CNG (2.5 million) at present (Pakistan Economic Survey 2011), the scenario assumes that 50% of motorcycles, mopeds, and cars with two-stroke engines, 50% of light-duty vehicles, 50% motorcycles with four-stroke gasoline engines, and 25% of light-duty vehicles will operate on CNG.
- For the power sector, the scenario considers a far-reaching penetration of natural gas. While the share of power sector in natural gas consumption was 23.81% during July–March 2010–2011 (Pakistan Economic Survey 2011), the CFS scenario assumes further increase whereby gasoline, heavy fuel, brown coal, and light fuel oil combustion will be replaced by gas-fired power plants.

3.3 Technology-based emission control scenarios

Three emission control scenarios, namely low control scenario (LCS), current legislation scenario (CLS), and advanced control technology (ACT) scenarios have been developed which explore how different degrees of implementation of available technical emission control measures could impact Pakistan's air pollution emissions.

- The LCS scenario assumes a continuation of the current situation of Pakistan regarding the implementation of environmental policies and laws. Pakistan does have environmental legislation and national environmental quality standards, although they are not completely enforced as yet. Therefore, LCS scenario is the same to the BAU case.
- The CLS scenario assumes that the current situation will prevail until 2030 but with few reduction effects in certain sectors in CLS scenario. In this scenario, it is assumed that the current legislative framework and environment-related polices that have been decided by the Government of Pakistan will be fully implemented after 2015.
- The ACT scenario explores a case where advanced emission control technologies available in the industrialized countries will be introduced in Pakistan after 2020.

Clearly, there are other options and alternatives for defining additional policy scenarios in terms of future fuel mix or air quality legislation. The purpose of the scenario exercise reported here is to illustrate the scope of potential benefits the policy interventions can induce in the coming decades. Optional development of the energy sector might anticipate for example a larger utilization of renewable energy forms, such as solar, wind, or biomass resources. Because of numerous existing barriers that currently bound the utilization of renewables at a large scale under Pakistani conditions, our set of scenarios is limited to the extent as described above.

4. Results and discussion

The scenarios introduced above have been implemented within the GAINS Asia model (Amann et al. 2008a, 2008b; Purohit et al. 2010). As mentioned in Section 2 of this study, the GAINS model holds activity data and control strategies for future years as an emission model. It estimates emissions and costs of current and future air quality policies and estimates change in environmental impacts as a consequence of policy change (Amann et al. 2011). Although the emission scenarios are developed in GAINS for four subregions of Pakistan [Punjab, Sindh, Karachi,[1] and North West Frontier Provinces (NWFP) – Baluchistan], the results are presented herein as national aggregates.

4.1 Activity data and macroeconomic parameters

The activity data for Pakistan in the GAINS model have been implemented by Shahid (2008). Energy and transport data were collected from the Hydrocarbon Development Institute of Pakistan (HDIP), the Ministry of Petroleum, Government of Pakistan and the Pakistan Energy Year Book (1990–2005). Transport-related data have been collected from the National Transport Research Centre (NTRC) of Pakistan. The activity data for agriculture sector were collected from the Ministry of Food, Agriculture and Livestock, and agricultural statistics has been collected from the Federal Bureau of Statistics, Islamabad. Activity data for industrial processes in Pakistan have been received from the Ministry of Industries, Pakistan Bureau of Statistics, and provincial statistical bureaus. Gross value added of different products has been obtained from the Statistical Bureau of Pakistan and the Ministry of Economics and Finance (Shahid 2008). Additional data for scenario development were obtained from Pakistan environmental legislation and the national environmental quality standards, country synthesis report, environmental policy of Pakistan, Planning Commission of Pakistan, Male Declaration on control and prevention of air pollution and its likely transboundary effects, initiatives for clean fuels, etc.

Under BAU conditions, consumption of total primary energy is estimated to increase by a factor of 4.7 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 economy (Figure 1(a)). Energy demand from households will be strongly influenced by the expected increase in urbanization[2] and the general rise in economic wealth. Nevertheless, consumption levels of fuelwood, cow dung, and agricultural residue in households (i.e. mainly for cooking purposes) are not expected to change significantly, as these remain sources of cheap energy (Figure 1(b)).

Obviously, these quantitative projections are associated with numerous uncertainties that could lead to different developments than are 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. Figure 2 presents the fuel consumption trends across the sectors. Share of primary energy consumption in the domestic sector will decrease from 39% in 2005 to 23% in 2030, whereas energy consumption in power and industrial sectors will increase their contribution significantly from 2005 to 2030.

4.2 Emissions in the current legislation and alternative scenarios

It is obvious that, as a consequence of sharply increasing fuel consumption in Pakistan, emissions of air pollutants will grow accordingly unless stricter measures for controlling

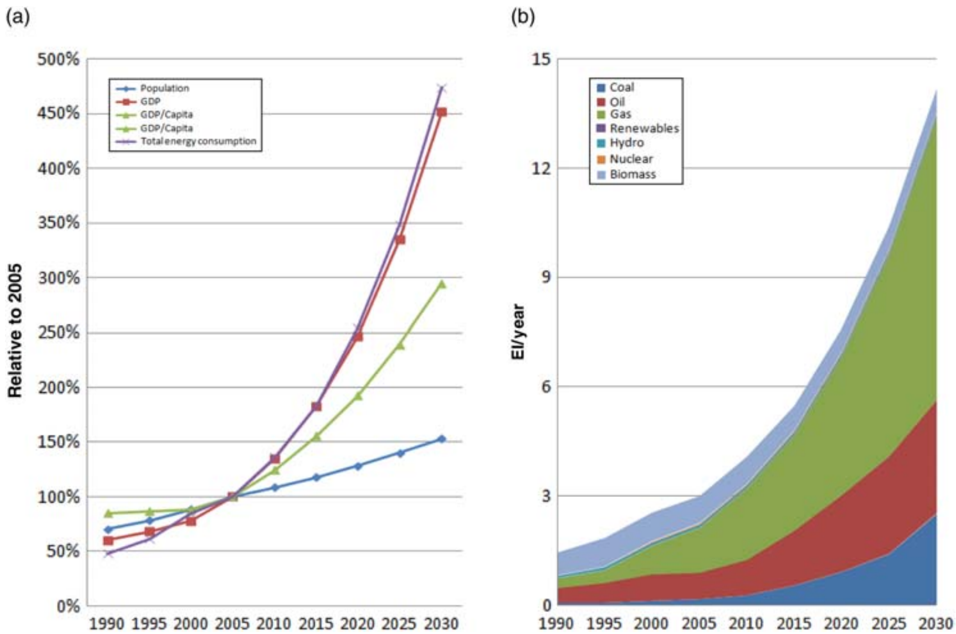

Figure 1. Assumptions on macro-economic development and energy consumption in the BAU scenario (a) macro-economic indicators, relative to the year 2005 and (b) primary energy consumption (in EJ/year).

emissions will be adopted in the future. The future emission trends will therefore be critically determined by the extent to which air pollutants will be controlled through targeted policy interventions. As mentioned earlier, Pakistan already has environmental legislation and national environmental quality standards; however, they are not completely enforced as yet. Therefore, the BAU projection explores the likely development of air pollutant emissions as well as their local impacts under the current assumptions that (i) current situation of air pollution control policies and regulations were fully implemented as foreseen and (ii) no additional measures were adopted in coming time periods.

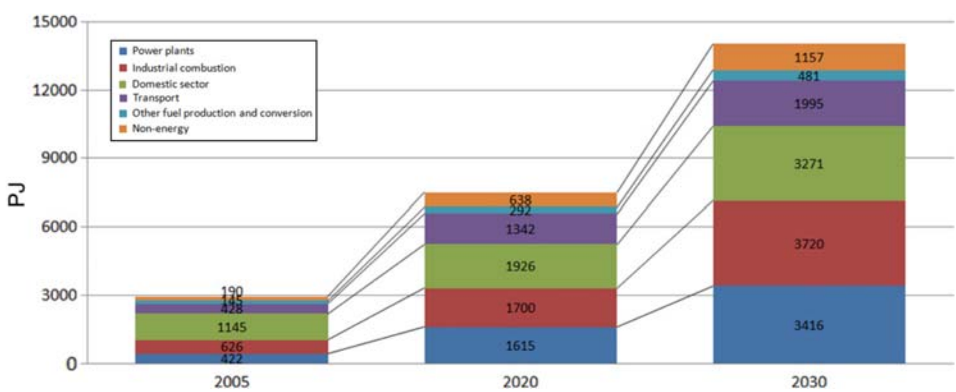

Figure 2. Energy consumption trends across the sectors in the BAU scenario.

Under the assumptions for BAU, 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. Figure 3 presents the change in emissions of SO_2, NO_x, and $PM_{2.5}$ in the BAU scenario by sector relative to the year 2005. Following the projected increases in economic activities, sulfur dioxide (SO_2) emissions would grow by a factor of 8.7 between 2005 and 2030, nitrogen oxides (NO_x) emissions by a factor of 4.6, and fine particles ($PM_{2.5}$) emissions by a factor of 3.2.

The graph in Figure 4 displays the development of $PM_{2.5}$, SO_2 and NO_x emissions for the BAU and CFS scenarios. In 2030, larger reductions from clean fuel use occur for particulate matter (−39%) and SO_2 emissions (−31%) as compared to NO_x emissions (−7%). It is noteworthy that, despite the significant increase in economic development and energy consumption, the CFS would bring $PM_{2.5}$ and SO_2 emissions in 2030 below current levels, much in contrast to the BAU scenario, in which $PM_{2.5}$ and SO_2 emissions would grow by more than a factor of three and six, respectively. The biggest factor leading to lower emissions is the higher penetration of natural gas as a clean fuel in all the three important sectors (domestic, power, and transport).

Figure 5 presents the sectoral SO_2 emissions for the three technology scenarios (low control, current legislation, and advanced control scenario) compared with the BAU scenario taking 2005 as base year. As mentioned earlier, the LCS scenario is identical to the BAU case in which it is assumed that the current legislative framework and environment-related polices that have been decided by the Government of Pakistan are not fully implemented, whereas in the CLS scenario, it is assumed that the current legislative framework and environment-related polices will be fully implemented after 2015. It is observed that SO_2 emissions will increase by a factor of 6.7 in the CLS in 2030 as compared to 2005 base level. SO_2 emissions can be reduced to 69% by complying with

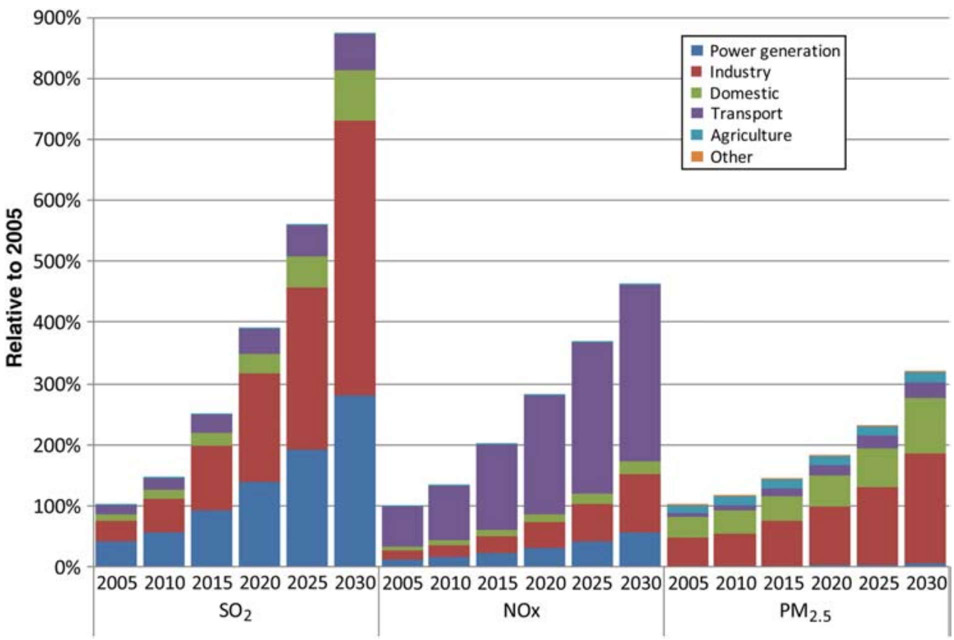

Figure 3. Change in emissions of SO_2, NO_x, and $PM_{2.5}$ in the BAU scenario by sector relative to the year 2005.

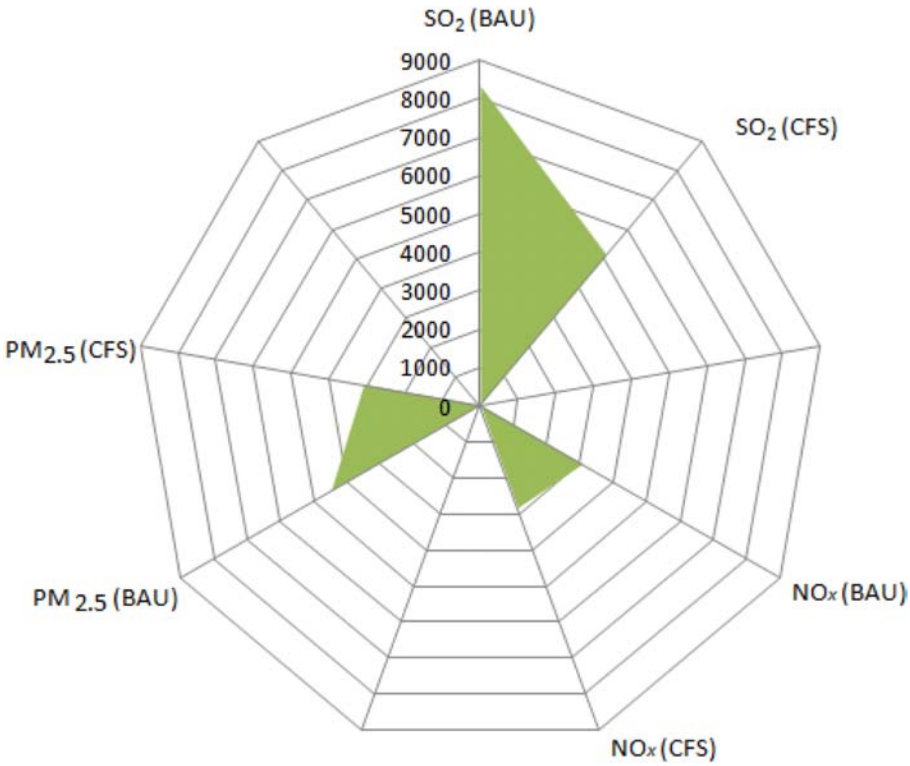

Figure 4. SO_2, NO_x, $PM_{2.5}$ emissions (in kt) in the BAU and CFS scenarios in 2030.

ACT as compared to LCS (for 2030 level). Similarly, full implementation of advanced control technologies will reduce SO_2 emissions by 61% in 2030 as compared to the CLS scenario. Industrial combustion is contributing most toward total SO_2 emissions (0.6 million of total 0.9 million in 2005 base level).

Similarly, NO_x emissions for the three technology-based scenarios are compared to the BAU scenario as shown in Figure 6. Transport sector is responsible for the highest NO_x

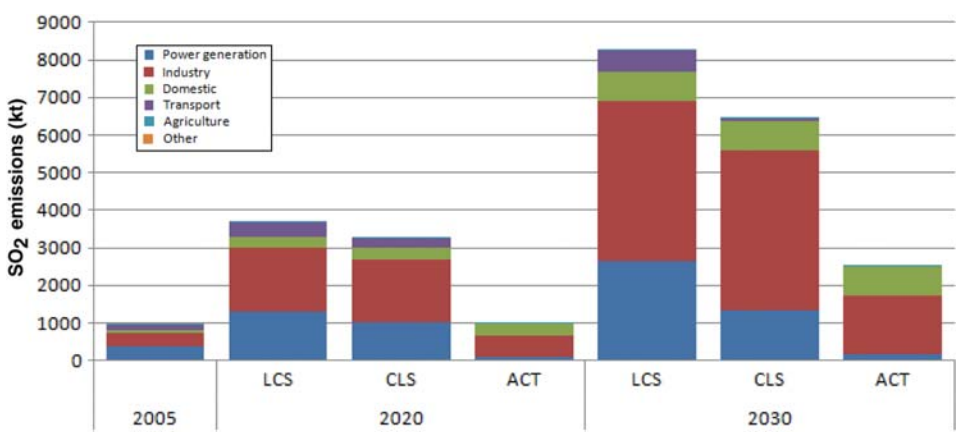

Figure 5. Evolution of SO_2 emissions by sector in three technology scenarios.

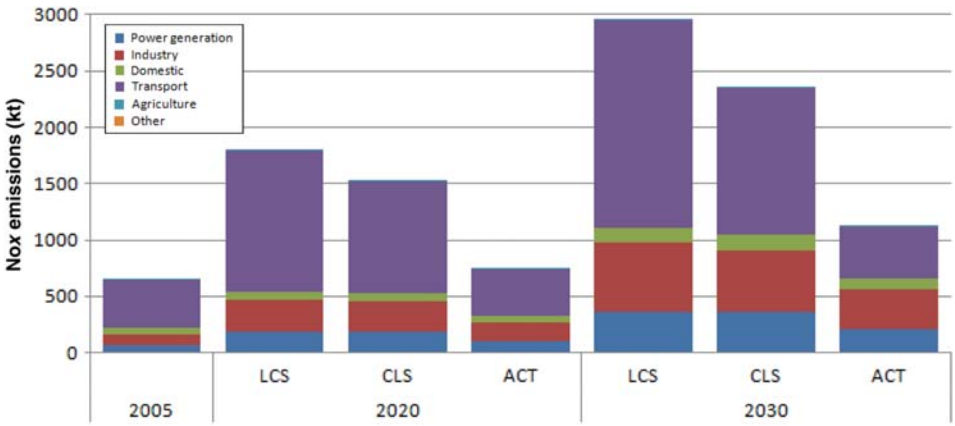

Figure 6. Evolution of NO_x emissions by sector in three technology scenarios.

emissions due to combustion of gasoline and diesel oil in automobiles, and it is increasing with the increasing number of vehicles (Qadir 2002; Hyder et al. 2006; Liaquat et al. 2010). In 2005, NO_x emissions amounted to more than 0.6 million tons in Pakistan. The results indicate that NO_x emissions will increase by a factor of 3.6 (as compared to the 2005 base level) in 2030 in CLS scenario. Full implementation of advanced control technologies will reduce NO_x emissions by half in 2030 as compared to the CLS scenario. Similarly, strict implementation of emission controls policies will reduce NO_x emissions by 37% in 2030 when compared with 2020 LCS. Main source of emissions is road transport that is contributing 0.4 million tons in total NO_x emissions. The recent trends indicate that the number of two-stroke vehicles in Pakistan is increased by 143% in 2010–2011 as compared with the year 2000–2001. Rickshaws have grown by more than 24% while motorcycles and scooters have more than doubled since 2000–2001 (Pakistan Economic Survey 2011). Motorcycles and rickshaws, due to their two-stroke engines, are the most inefficient in burning fuel and contribute most to transport emissions.

Finally, $PM_{2.5}$ emissions in the low control, current legislation, and ACT scenarios are shown in Figure 7. Emissions of $PM_{2.5}$ originate mostly from combustion in

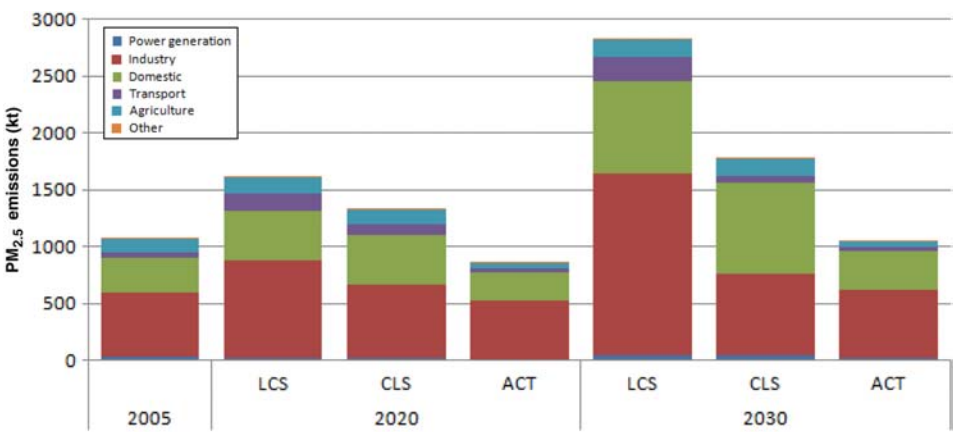

Figure 7. Evolution of $PM_{2.5}$ emissions by sector in three technology scenarios.

manufacturing industries as well as from industrial processes such as cement and lime production, etc. $PM_{2.5}$ emissions are expected to increase by a factor of 2.6 in LCS in 2030 as compared to 2005. But if the emission controls technologies are more strictly enforced in CLS case, then $PM_{2.5}$ emissions could be reduced up to 37% in 2030 (as compared to the LCS scenario). Industrial sector is imparting its main role in total emissions that is 2.9 times higher in LCS compared with 2005 levels. Full implementation of advanced control technologies will reduce $PM_{2.5}$ emissions by 63% in 2030 as compared to the LCS scenario.

4.3 Cost of $PM_{2.5}$ emissions control

Nearly 2500 people die every year in Pakistan due to air pollution related to vehicular emissions inflicting economic losses of about 250 to US$350 million (Uqaili et al. 2005; Brohi et al. 2007). The loss to the national exchequer is large when compared to the costs of pollution abatement (Harijan et al. 2009). Failure in the incorporation of these factors in economic policies causes losses in GDP and creates many health and environmental problems. This heavy burden of environmental degradation is also affecting adversely every sector of the national economy.

Implementation costs of air pollution control measures (primarily for reducing $PM_{2.5}$ emissions) have been estimated using the GAINS model for different technology-based scenarios discussed above and compared with the GDP (Figure 8). By 2030, the costs of implementing air pollution control measures prescribed in the current legislation are estimated at 0.3% of GDP, and this share would increase to 1.02% in 2030 with the application of advanced control technologies.

4.4 Health impacts

The most recent study on the impacts of particulates on health in Pakistan conducted by the Pakistan EPA and the World Bank showed that it causes 22,000 premature deaths in adults and 700 in children annually (Pak-EPA/World Bank 2006). The GAINS model also quantifies health impacts from the exposure to fine particulate matter in terms of years of life lost (YOLL). The baseline increase in emissions would lead to

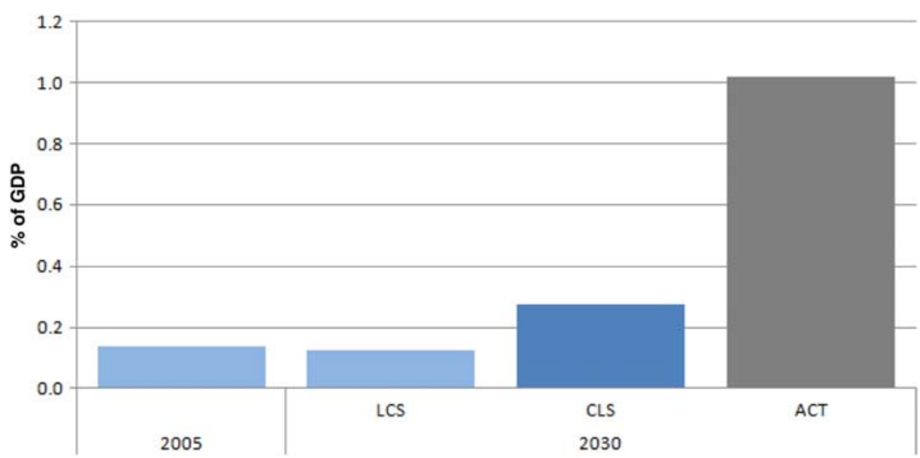

Figure 8. Air pollution control cost in terms of percentage of annual GDP (PPP) for Pakistan.

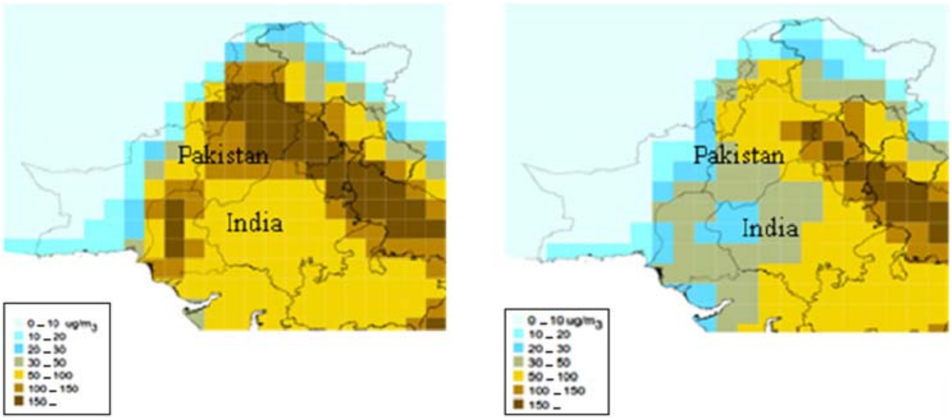

Figure 9. Ambient concentrations of $PM_{2.5}$ in Pakistani regions within the GAINS South Asia map for BAU (left panel) and the ACT scenarios for 2030 (right panel).

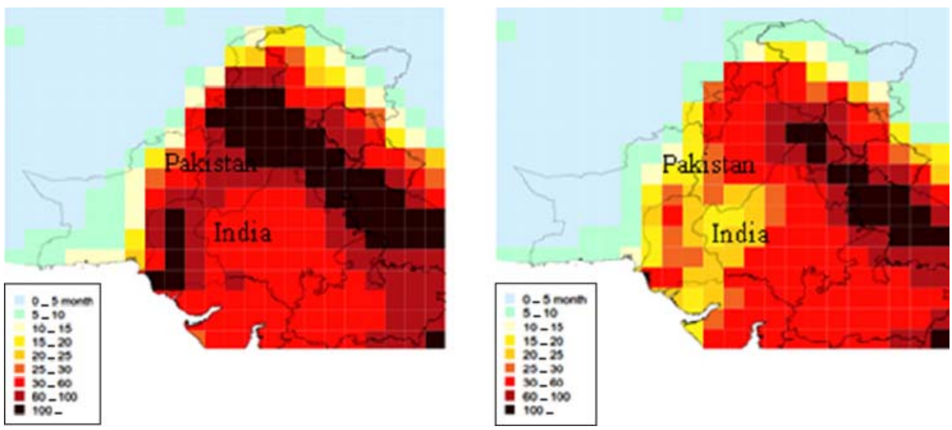

Figure 10. Loss in statistical life expectancy (months) due to ambient concentration of $PM_{2.5}$ in Pakistani regions within the GAINS South Asia map for BAU (left panel) and the ACT scenarios for 2030 (right panel).

profound deteriorations of air quality in Pakistan. Most relevant for health impacts, annual mean concentrations of fine particles ($PM_{2.5}$) exceed already the present guideline value of the World Health Organization of 10 $\mu g/m^3$ (WHO 2006) virtually throughout Pakistan.

Figure 9 shows a comparison of ambient $PM_{2.5}$ concentrations computed for the year 2030. In the BAU scenario, large parts of Pakistan will experience an annual mean $PM_{2.5}$ concentration of more than 100 $\mu g/m^3$ and exceeding to 150 $\mu g/m^3$ in few regions.

Not surprisingly, such high $PM_{2.5}$ concentrations lead to significant health impacts. Figure 10 displays the estimated loss in statistical life expectancy that could be envisaged in 2030 from the concentrations displayed in Figure 9. While absolute health impacts are significant, there is a large difference between the two emission control scenarios. In the most polluted areas, life shortening would exceed 100 months on average in the BAU scenario, but remain around 60–100 months in the ACT case.

5. Conclusions

In this study, an initial attempt has been made to develop policy scenarios for the abatement of air pollutants in Pakistan. On the basis of a detailed assessment of air pollution mitigation strategies in Pakistan, it is observed that continuation of the current practices in the implementation of emission control standards, paired with the progressing increase in energy consumption that accompanies the rapid economic development, will lead to a significant increase in air pollution levels throughout Pakistan. As a consequence, serious health impacts are expected for Pakistan's population by 2030, and statistical life expectancy could shorten on average by more than 100 months due to air pollution, keeping all other factors constant.

Nevertheless, there is an array of policy interventions that could avoid such negative impacts of economic development. Control measures are available that are able to provide clean air to Pakistan and increase well-being in physical terms, in addition to the expected increase in material welfare from the ongoing economic development. Such measures include selective replacement of the most polluting fuels by cleaner energy carriers and effective implementation of dedicated end-of-pipe control technologies.

On the basis of different policy scenarios considered in this study, it is suggested that in case of ACT scenario, the $PM_{2.5}$ emissions, taken as an example, are reduced by two-thirds in 2030 when compared to the scenario assuming a continuation of present status of emission control. Different portfolios of technology measures selected for the scenarios under examination result in different levels of health benefits and involve different levels of economic resources. The policy scenarios, as modeled in the integrated GAINS framework, can be used to identify control-technology portfolios and legislative set-ups that reach effective health and environmental improvements while putting least burden on the economic development. This study provides a first step in quantitative analyses needed for systematic impact assessment of such policy portfolios under Pakistani conditions.

Notes

1. Karachi has the highest concentration of emission sources as compared to rest of the Sindh-province therefore Karachi is kept as a separate region in the GAINS model.
2. In 2010, 36% of the total population in Pakistan was living in urban areas and the annual urbanization rate for 2010–2015 was expected to be 3.1% (see http://www.indexmundi.com/pakistan/demographics_profile.html).

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