

Policies and Options for Abating Urban Air Pollution from Mobile Sources in Karachi, Pakistan

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Introduction

Pakistan's urban air pollution is among the most severe in the South Asia region and it engenders significant damages to human health and the economy¹. Pakistan is the most urbanized country in South Asia and it is undergoing rapid motorization and increasing energy use. Over the last 20 years, the number of motor vehicles in Pakistan has risen from 0.8 million to nearly 5 million; an average annual growth rate in excess of 14%. Air pollution, particularly in large urban centers, damages the populations' health and quality of life and contributes to environmental degradation (Aziz and Bajwa, 2004; Aziz, 2006; Colbeck et al., 2010a). Estimates from the Global Model of Ambient Particulates indicate that as of 2002, average PM₁₀ in Pakistan was 165µg/m³ (World Bank, 2006)². From 2007 to 2011, the reported levels of PM, SO₂, and Lead (Pb) were many times higher than the World Health Organization air quality guidelines. This paper outlines the contribution of mobile sources to the urban air pollution problem in Pakistan, particularly in Karachi, and examines a series of options that address the significant cost imposed upon the economy and populace by ever-worsening air quality.

Data Availability and Methodology While there is a paucity of available air quality data for Pakistan, an air quality monitoring network (funded by the Japan International Cooperation Agency from 2006 to 2011) is collecting information on concentrations of particulate matter (PM), carbon monoxide, sulphur and nitrogen oxides, ozone and other parameters in Pakistan's major cities. However, daily average ambient air quality data is available for less than fifty percent of the days between July 26, 2007 to April 27, 2010. Table 1 shows the temporal (percent of days) coverage for all the air quality data, and points to the lowest coverage for PM_{2.5}.

Table 1: Data coverage (%) for air quality parameters for five cities in Pakistan

Data coverage (%)	PM _{2.5}	SO ₂	NO ₂	O ₃	CO
Islamabad	42	31	78	87	96
Quetta	5	46	53	29	53
Karachi	10	23	29	24	24
Peshawar	17	35	66	28	60
Lahore	12	54	75	79	44
Average	17	38	60	49	55

Source: Estimates by M. Dalosto for the World bank NLTA on Policy Options for Air Quality Management in Pakistan

Despite its flaws, these data provide the best picture of air quality in Pakistan. Using this data, average values were calculated for all air quality pollutants. Principal component analysis (PCA) was performed using the STATISTICA v4.2 software on a dataset composed of meteorological parameters, gaseous pollutants and PM_{2.5} mass. This methodology combines a factor analysis

¹ The paper is based on the World Bank Non-Lending Technical Assistance on Policy Options for Air Quality Management in Pakistan. The document is based on consultant reports prepared by Bjorn Larsen, John Skjelvik, and Manuel Delostto

² These estimates were based on an econometrically estimated model for predicting PM levels

that results in the identification of potential pollution sources, indicates the seasonal evolution of the sources, and quantifies the annual mean contribution for each one.

The environmental health and economic analysis relies on primary data obtained from various ministries, agencies and institutions in Pakistan as well as from international development agencies. The analysis also uses several hundred reports and research studies from Pakistan and other countries. Quantification of health effects from environmental risk factors is grounded in commonly used methodologies that link health outcomes and exposure to pollution and other health risk factors, and the economic costs of these health effects are estimated using standard valuation techniques. The assessment of the benefits and costs of interventions to mitigate health effects and improve natural resource conditions is based on these same methodologies and valuation techniques, as well as on international evidence of intervention effectiveness, and, to the extent available, on data regarding the costs of interventions in Pakistan.

Analysis

An analysis of the available data from 2007 to 2010 shows very high concentrations of fine particle matter ($PM_{2.5}$) in Lahore ($143\mu g/m^3$), Peshawar ($71\mu g/m^3$), Karachi ($88\mu g/m^3$), Islamabad ($61\mu g/m^3$) and Quetta ($49\mu g/m^3$). The high value concentrations reported in this analysis are likely to be even higher if the monitoring instruments had been working all the time. PM_1 and PM_{10} measurements were not available, and $PM_{2.5}$ measurements were partially affected by low data coverage (average 17%)

The analysis of the 2007 to 2010 time series on sulphur dioxide (SO_2) confirmed that Lahore was the city with the highest SO_2 concentrations ($74\pm 48\mu g/m^3$), with maximum daily values of $309\mu g/m^3$. Other cities presented very high values of SO_2 : Quetta ($54\pm 26\mu g/m^3$), Karachi ($34\pm 34\mu g/m^3$) and Peshawar ($39\pm 34\mu g/m^3$). Overall, SO_2 values were found to be increasing over the course of the study period (2007-2010).

The annual Nitrogen Dioxide (NO_2) concentrations derived from the 48-h revealed that the current levels in the country are slightly higher than the WHO air quality guideline value of $40\mu g/m^3$, with the highest concentrations in Peshawar ($52\pm 21\mu g/m^3$), Islamabad ($49\pm 28\mu g/m^3$), Lahore ($49\pm 25\mu g/m^3$), Karachi ($46\pm 15\mu g/m^3$). Concentrations were somewhat lower in Quetta ($37\pm 15\mu g/m^3$). Results from an analysis of data from 2007 to 2011 shows that concentrations of ozone (O_3) and carbon monoxide (CO) were found to be well within the WHO guidelines

SO_2 and $PM_{2.5}$, tend to have higher concentrations during winter periods, whereas O_3 shows the opposite trend. Since sunlight and heat drive ozone formation, warm sunny days usually have more ozone than cool or cloudy days. A statistical analysis shows that the strongest correlations (expressed as R^2) among key parameters are found between $PM_{2.5}$ and CO, implying road traffic is a main source of fine particulate matter in Pakistan (Table 2). Since $PM_{2.5}$ correlates better with CO than with SO_2 and NO_2 , it is possible that fresh direct traffic emissions are important contributions to the fine particulate mass levels. Other sources, including industries and natural dust or sea salt may contribute too, but the current study suggests that direct traffic emissions are more related to high concentrations of ambient aerosols. The low correlations obtained at Lahore may be due to the very high levels of PM (which may be associated with natural factors, such as dust and emissions from industrial and agricultural sources).

Table 2: Correlations between $PM_{2.5}$, SO_2 , NO_2 , O_3 and CO for Islamabad (ISL), Quetta (QUE), Karachi (KAR), Peshawar (PES), and Lahore City (LAH..

City	R^2	$PM_{2.5}$	SO_2	NO_2	O_3	CO
ISL	$PM_{2.5}$	---	0.35	0.45	-0.37	0.7
	SO_2		---	0.5	-0.25	0.5
	NO_2			---	-0.2	0.4
	O_3				---	-0.4
	CO					---
QUE	$PM_{2.5}$	---	0.55	0.75	-0.4	0.85
	SO_2		---	0.7	-0.45	0.7
	NO_2			---	-0.55	0.85

	O₃				---	-0.5
	CO					---
KAR	PM_{2.5}	---	0.2	0.4	0	0.45
	SO₂		---	0.55	0	0.1
	NO₂			---	0	0.7
	O₃				---	0
	CO					---
PES	PM_{2.5}	---	0.2	0.5	0	0.6
	SO₂		---	0.4	0	0.4
	NO₂			---	0	0.8
	O₃				---	0
	CO					---
LAH	PM_{2.5}	---	0	0	0	0
	SO₂		---	0.6	0	0.6
	NO₂			---	0	0.6
	O₃				---	
	CO					---

Source: Estimates by M. Dalosto for the World bank NLTA on Policy Options for Air Quality Management in Pakistan

When considering factor analysis, the “Primary” factor includes traffic (NO₂, CO) and industrial (SO₂) gases as well as PM_{2.5}. The “Primary” factor is mainly associated with primary anthropogenic emissions and it represents the major component for the cities of Islamabad, Karachi and Peshawar (33-43%). The “Secondary” factor is seen mainly during summer times and it is associated with ozone and high temperature values. It was the second main factor found (22-33%), and it is associated more with summer regional pollution events. (Table 3),

Table 3: Principal component analysis: results for Islamabad, Lahore, Karachi and Peshawar

CITY	PCA FACTORS		
	Primary	Secondary	Visibility
ISLAMABAD			
<i>PM_{2.5}</i>	0.9	0.1	0.0
<i>SO₂</i>	0.9	0.2	0.0
<i>NO₂</i>	0.9	0.2	0.0
<i>O₃</i>	0.1	0.8	0.2
<i>CO</i>	0.9	0.0	0.1
<i>Variance explained (%)</i>	33	27	10
KARACHI			
<i>SO₂</i>	0.9	0.1	0.3
<i>NO₂</i>	0.9	0.2	0.2
<i>O₃</i>	0.1	0.9	0.1
<i>CO</i>	0.7	0.5	0.1
<i>Variance explained (%)</i>	35	22	14
PESHAWAR			
<i>PM_{2.5}</i>	0.7	0.1	0.3
<i>SO₂</i>	0.9	0.3	0.2
<i>NO₂</i>	0.9	0.3	0.1
<i>O₃</i>	0.5	0.6	0.2
<i>CO</i>	0.9	0.0	0.1
<i>Variance explained (%)</i>	43	23	11
LAHORE			
	Primary	Secondary	Visibility

<i>PM_{2.5}</i>	0.6	0.3	0.3
<i>SO₂</i>	0.8	0.2	0.2
<i>NO₂</i>	0.8	0.5	0.2
<i>O₃</i>	0.2	0.8	0.1
<i>CO</i>	0.8	0.4	0.1
<i>Variance explained (%)</i>	22	33	11

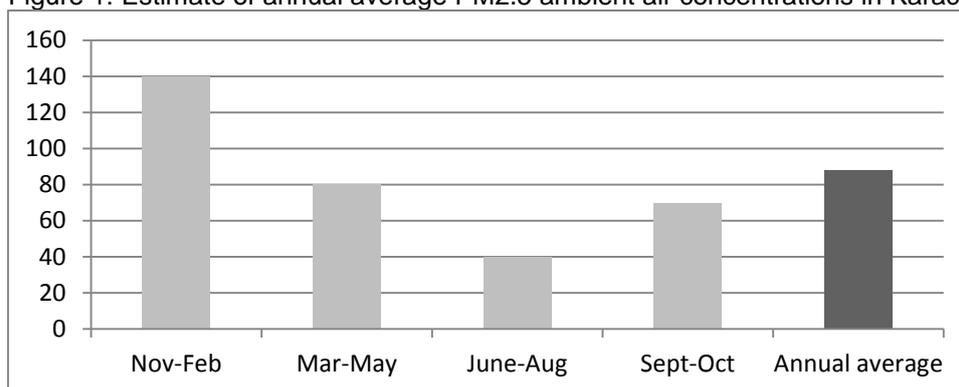
Islamabad (ISL), Quetta (QUE), Karachi (KAR), Peshawar (PES), and Lahore City (LAH).
Source: Consultant report prepared by Manuel Del Source: Estimates by M. Dalosto for the World Bank NLTA on Policy Options for Air Quality Management in Pakistan

The analysis found that $PM_{2.5}$ is strongly correlated with CO and NO_2 , indicating the importance of road traffic as a source, especially in winter months. By contrast, in the summer months, with higher wind speed, the influence of resuspended surface dusts and soils and of secondary particulate matter may play a bigger role. However, the strong correlation between road traffic markers (such as CO) and $PM_{2.5}$ suggest anthropogenic pollution is a major source of fine particulate matter, leaving natural sources as minor ones.

Health Impacts of Air Pollution in Karachi

An analysis of the $PM_{2.5}$ concentrations in Karachi indicates that annual average $PM_{2.5}$ ambient air concentrations in Karachi are estimated at 88 micrograms per cubic meter ($\mu g/m^3$) (Figure 1). The analysis of primary data from 2006 to 2009 estimates that 24-28% of ambient $PM_{2.5}$ concentrations in Karachi is from road vehicles, 19-20% is from industry, 8-14% is from burning of solid waste in the city, 4-5% is from domestic use of wood/biomass, 2.3-2.8% is from oil and natural gas consumption by power plants and the domestic/public/commercial sectors, 12-13% is secondary particulates (sulfates and nitrates) formed in the atmosphere from sulphur dioxide and nitrogen oxides from combustion of fossil fuels, and 23-24% is from area-wide sources including natural dust, resuspended road dust due to poor street cleaning, construction dust, agricultural residue burning, and salt particles from the sea. Around 2/3rd of PM emissions from road vehicles is estimated to be from diesel trucks, diesel buses and minibuses, and light duty diesel vehicles. About 1/3rd, however, appears to be from motorcycles and rickshaws which almost exclusively have highly polluting two-stroke engines. A major source of PM emissions from industry corresponds to ferrous metal sources (steel mills, foundries, scrap smelters).

Figure 1: Estimate of annual average $PM_{2.5}$ ambient air concentrations in Karachi, 2006-2009



Source: Estimates by B.Larsen and J. Skjelvik based on Mansha et al (2011), Ghauri (2008), Sindh-EPA, and Alam et al (2011).

These $PM_{2.5}$ concentrations are estimated to cause over 9,000 premature deaths each year, representing 20% of acute lower respiratory infections (ALRI) mortality among children under five years of age, and 24% of cardiopulmonary mortality and 41% of lung cancer mortality among adults 30 or more years of age in these cities. About 12% of the deaths are among children under five years of age and 88% are among adults. Nearly 80% of the deaths are in Karachi.³

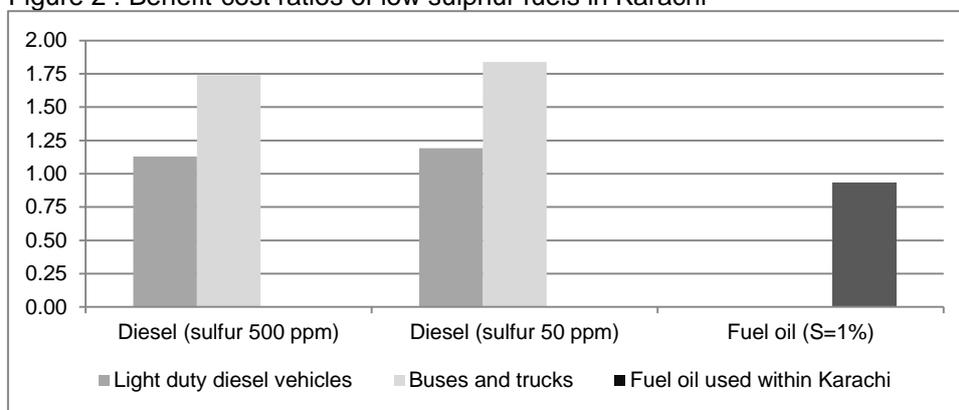
³ Mortality is estimated based on Ostro (2004), Pope et al (2002) and Pope et al (2009).

Possible interventions to control and reduce PM emissions include: (i) reducing sulphur in diesel and fuel oil; (ii) retrofitting in-use diesel vehicles with PM emission control technology; (iii) converting diesel-fueled minibuses and vans to compressed natural gas (CNG); (iv) controlling PM emissions from motorcycles; and (v) converting three-wheelers (rickshaws) to CNG. These interventions would not only reduce PM emissions but low sulphur fuels would also reduce secondary particulates by reducing sulphur dioxide emissions. Government plans to further expand the use of CNG buses will also reduce PM emissions. Other potential interventions that should be assessed include curtailing burning of solid waste in the city (and using the informal recycling industry), controlling PM emissions from ferrous metal sources and other industrial sources, improving street cleaning, and controlling construction dust.

Sulphur in diesel is being reduced to 500 ppm in Pakistan this year, but no confirmed timetable has been established for 50 ppm sulphur diesel. The analysis estimates that the health benefits of using 500 ppm diesel in road transport amount to at least US \$2.3 – 3.5 per barrel of diesel for light diesel vehicles and large diesel buses and trucks used primarily within Karachi. Lowering the sulphur content further to 50 ppm would provide additional health benefits of US \$3.0 – 4.6 per barrel.⁴ This compares to an approximate cost of US \$1.5 -2.5 per barrel for lowering the sulphur content to 500 ppm and US \$2 – 3 per barrel for lowering sulphur from 500 ppm to 50 ppm. Thus the mid-point estimated health benefits per dollar spent (i.e., benefit-cost ratio) on cleaner diesel are in the range of about US \$1.1 – 1.2 for light duty diesel vehicles and US \$1.7 – 1.8 for large buses and trucks for both 500 ppm and 50 ppm diesel (Figure 2).

Fuel oil in Pakistan generally has a sulphur content that averages around 3%, but some fuel oil with 1% sulphur is being imported. PM emission rates from combustion of fuel oil are greatly influenced by the sulphur content. Reducing sulphur from 3% to 1% is estimated in this report to have health benefits of US \$35-47 per ton of fuel oil. The additional cost of low sulphur fuel oil in then international markets fluctuates and has recently been around US \$50 per ton. Thus use of low sulphur fuel oil in Karachi should be targeted at users within the city where all PM emissions contribute of PM ambient concentrations and health benefits are highest. Additional health benefits of low sulphur fuel oil include reduced sulphur dioxide emissions and, thus, lower secondary particulates formation.

Figure 2 : Benefit-cost ratios of low sulphur fuels in Karachi



Source: Source: Estimates B.Larsen and J. Skjelvik for the World Bank NLTA on Policy Options for Air Quality Management in Pakistan

Note: Mid-point estimate of incremental cost of low sulphur fuels.

More stringent PM emission standards and control options can be implemented for diesel vehicles once low sulphur diesel is available. EURO standards can be mandated on new diesel vehicles (and second-hand imports) and PM control technologies can effectively be installed on in-use diesel vehicles, such as diesel oxidation catalysts (DOC) and diesel particulate filters (DPF).

⁴ Nearly 90% of premature mortality from PM pollution in Karachi is among adults. These individuals may be losing around 10 years of life due to PM pollution. The report estimates the social cost of premature mortality using two values (i.e., the human capital value and the value of statistical life) which, for adults, give vastly different cost estimates. In the assessment of benefits and costs of PM control interventions the value of statistical life is applied, as this value is more likely than the human capital value to be closer to the actual value that individuals place on a reduction in the risk of death.

DOCs require a maximum of 500 ppm sulphur in diesel and DPFs require a maximum of 50 ppm to function effectively. A DOC generally reduces PM emissions by 20-30% while a DPF reduces PM by more than 85%. DOCs had been installed on over 50 million diesel passenger vehicles and more than 1.5 million buses and trucks worldwide already five-six years ago. All new on-road diesel vehicles in the United States and Canada are equipped with a high-efficiency DPF. And all new diesel cars and vans in the European Union were equipped with DPF from 2009. Worldwide, over 200,000 heavy duty vehicles had already been retrofitted with DPF five-six years ago. DOCs and DPFs have also been used for retrofitting buses and trucks in many countries and locations, both on a wide scale and in demonstration projects.

Potential candidates for retrofitting with a DOC, or with a DPF when 50 ppm sulphur diesel becomes available, are high usage commercial diesel vehicles that are on the roads of Karachi today and primarily used within the city. The health benefits of retrofitting per vehicle per year are estimated in this report to be in the range of about US \$95-568 for a DOC and US \$216-1,295 for a DPF depending on type of vehicle and annual usage (Table 4).

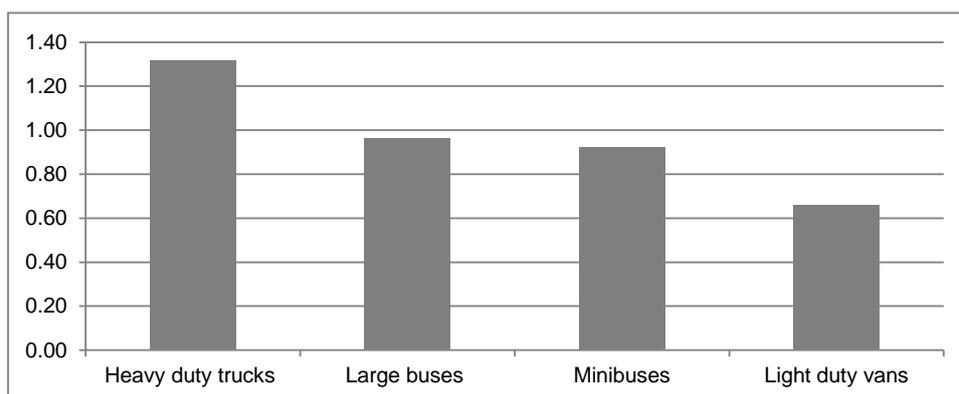
Table 4: Estimated health benefits of retrofitting diesel vehicles with PM control technology (US\$/vehicle/year)

	Diesel oxidation catalyst (DOC)		Diesel particulate filter (DPF)	
	Vehicle usage		Vehicle usage	
	35,000 km/year	70,000 km/year	35,000 km/year	70,000 km/year
Heavy duty trucks	284	568	647	1295
Large buses	208	417	475	949
Minibuses	133	265	302	604
Light duty vans	95	189	216	432

Source: Estimates B.Larsen and J. Skjelvik for the World Bank NLTA on Policy Options for Air Quality Management in Pakistan

A DOC costs US \$1,000-2,000 and a DPF as much as US\$ 6,000-10,000. The expected number of years that the vehicle will continue to be in use and years that the devices will be effective is therefore an important consideration. The mid-point estimate of dollars of benefits per dollar of costs spent on retrofitting in-use diesel vehicles with a diesel oxidation catalyst, once 500 ppm diesel is available, is about 1 – 1.3 for large buses and trucks used within the city but less than cost for minibuses and light duty vans (figure 3).⁵ Estimated health benefits of a DPF are currently lower than its cost for all classes of diesel vehicles, but should be reassessed once 50 ppm sulphur diesel is available in the future.

Figure 3: Benefit-cost ratios of retrofitting in-use diesel vehicles with DOC in Karachi



Source: Source: Estimates B.Larsen and J. Skjelvik for the World Bank NLTA on Policy Options for Air Quality Management in Pakistan

Note: Seven years of useful life of DOC; 50,000 km/year vehicle usage.

Given the relatively high cost of DOCs per unit of PM emission reduction, alternative options can be considered for in-use diesel-fueled minibuses and light duty vans. One such option is conversion to CNG, which almost entirely eliminates PM emissions. Health benefits of CNG

⁵ A cost of a DOC of US \$1500 was applied for heavy duty trucks and large buses and a cost of US\$1000 for minibuses and light duty vans. A discount rate of 10% was applied to annualize the cost of the DOC.

conversion are estimated in this report to be in the range of about US \$455-1288 per vehicle per year depending on type of vehicle and annual usage (Table 5).

Table 5: Estimated health benefits of conversion to CNG (US\$/vehicle/year)

	Vehicle usage	
	35,000 km/year	70,000 km/year
Minibuses	644	1288
Light duty vans	455	909

Source: Estimates B.Larsen and J. Skjelvik for the World Bank NLTA on Policy Options for Air Quality Management in Pakistan

Conversion of such vehicles to CNG in Pakistan is reported to cost in the range of Rs. 150-200 thousand per vehicle, or US \$1,900 – 2,550 at exchange rates in 2009. Applying a cost of Rs. 200 thousand, the mid-point estimate of dollars of health benefits per dollar spent (i.e., benefit-cost ratio) on conversion to CNG are 1.7 for minibuses and 1.2 for light duty vans.⁶ The benefit-cost ratios for vans are somewhat lower than for minibuses due to a difference in estimated PM emissions per kilometer of vehicle use.

Two-stroke rickshaws are also a large source of PM emissions and urban noise. Conversion to a four-stroke engine using compressed natural gas (CNG) is an option and is reported to cost around Rs. 40-60 thousand in Pakistan. At a cost of Rs. 60 thousand the mid-point estimate of health benefits is two times the conversion cost. Two-stroke motorcycles tend to have high PM emissions per ton of gasoline consumption. They also contribute greatly to urban noise. Many countries have and are therefore limiting or banning the use of two-stroke motorcycles. Four-stroke motorcycles emit substantially less PM, are more fuel efficient and cause substantially less noise. The additional cost of a four-stroke motorcycle engine is on the order of US \$50 but varies with engine size. At this cost, and for a two-stroke motorcycle emitting 0.25 grams of PM per kilometer, the health benefits of switching to a four-stroke motorcycle are around US \$2.9 per dollar of additional engine cost. With fuel savings the benefit-cost ratio is as high as 4.2.

In view of CNG supply constraints and more energy efficient alternative uses of CNG (e.g thermal power generation), it would be advisable to restrict CNG in automobiles (which make ubiquitous use of inefficient CNG conversion kits) and reserve its use for commercial and public service vehicles (buses, vans, utility trucks, and rickshaws). Emissions from spark-ignition automobiles and other vehicles could be better controlled by requiring Euro 2 and higher emission standards on both locally –assembled and imported automobiles (including used cars), now that unleaded gasoline is locally refined and is available in the country.

Conclusions

The air quality data coverage in Pakistan is yet not satisfactory. However, the concentrations of key air quality parameters herein reported clearly reflect the severity of the problem; several cities in Pakistan have very high concentrations of air pollutants. There is the urgent need for collection of primary air quality information, and follow-up investigation in both the short and the medium term. This action includes improving the quality of data collection locally on the site, including training personnel. Data for SO₂, NO₂, O₃ and CO as well as PM₁, PM_{2.5} and PM₁₀ should continue to be recorded and coverage should be improved, in order to better understand the sources causing poor air quality. In other words, much more emphasis has to be put on strengthening the continuous air quality monitoring sites and improving data collection in order to implement the basic control strategies. There is also an urgent need to carry out in depth studies with more sophisticated instruments in order to better address the chemical and physical properties of the particulate matter, especially in the fine mode.

Economically efficient interventions for reducing air pollution include, among others:

- Moving to 500 ppm sulphur diesel in the short term and to 50 ppm in the medium-term
- Continuing to convert diesel-fueled minibuses and city delivery vans to CNG and install diesel oxidation catalysts on existing large buses and trucks used in the city.

⁶ A discount rate of 10% was applied to annualize the cost of conversion to CNG.

- Continuing to introduce new CNG full size buses, as diesel particulate filters cannot be used with 500 ppm sulphur in diesel.
- Converting existing 2-stroke rickshaws to 4-stroke CNG.
- Banning new two-stroke motorcycles and rickshaws and exploring options to control PM emissions from in-use two-stroke motorcycles.
- Introducing low sulphur fuel oil (1% sulfur) to major users located in urban centers
- Controlling emissions from large point sources
- Restricting use of CNG in spark-ignition automobiles and introduction of Euro 2 and higher standards on locally-assembled and imported private automobiles and light-duty utility vehicles.

Actions that the government is already pursuing, to various degrees, include conversion of rickshaws to CNG, banning two-stroke vehicles, selectively introducing low sulphur fuel oil, and banning waste burning within Karachi.

References

- Alam, K., Blaschke, T., Madl, P., et al. 2011. Aerosol size distribution and mass concentration measurements in various cities of Pakistan. *J. Environ. Monit.*, 2011, 13, 1944-1952.
- Aziz A, Bajwa IU (2004) Energy and pollution control opportunities for Lahore. *Urban Transport X* 16:751–760,
- Aziz JA. (2006) Towards establishing air quality guidelines for Pakistan. *East Mediterr Health J.* 12(6):886-93m,.
- Colbeck, I, Nasir, Z. A, and Ali, Z2010a. 'The state of air quality in Pakistan – a review', *Environmental Science & Pollution Research*. 17, pp.49-63,
- Faiz, A., Weaver, C.S, and Walsh, M.P, 1996. *Air Pollution from Motor Vehicles –Standards and Technologies for Controlling Emissions*. World Bank, Washington DC.
- Ghauri, B. 2008. Satellite data applications in atmospheric monitoring, SUPARCO. Powerpoint presentation, Graz, Austria. September 2008.
- Mansha, M. and Ghauri, B."Assessment of fine particulate matter (PM2.5) in metropolitan Karachi through satellite and ground-based measurements", *J. Appl. Remote Sens.* 5; doi:10.1117/1.3625615, 2011
- Mansha, M. Ghauri, B. Rahman,S. Amman, A. Characterization and source apportionment of ambient air particulate matter (PM2.5) in Karachi. *Science of The Total Environment*, doi:10.1016/j.scitotenv.2011.10.056, 2011
- Ostro, B. 2004. Outdoor Air Pollution - Assessing the environmental burden of disease at national and local levels. *Environmental Burden of Disease*, Series, No. 5. World Health Organization. Geneva.
- Pope CA III, Burnett RT, Krewski D, et al. 2009. Cardiovascular mortality and exposure to airborne fine particulate matter and cigarette smoke: shape of the exposure-response relationship. *Circulation*, 120: 941-948.
- Pope CA III, Burnett RT, Thun MJ, Calle, E., Krewski, D., Ito, K., and Thurston, G. 2002. Lung cancer, Cardiopulmonary mortality, and Long-term exposure to Fine particulate air pollution. *Journal of the American Medical Association*, 287: 1132-1141.
- World Bank (2006) *Pakistan Strategic Country Environmental Assessment* Washington, D.C.
- World Bank (2011) *Policy Options for Air Quality Management in Pakistan*. Report delivered to the Government of Pakistan. Washington DC.
- World Bank (2012) *Environmental Priorities and Climate Change in Sindh*. Report delivered to the Government of Sindh (Pakistan). Washington DC.