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A SCENARIO-BASED MODELING SYSTEM TO PREDICT THE AIR QUALITY IMPACT FROM FUTURE GROWTH

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ABSTRACT

This study presents the development and application of a scenario-based modeling system composed of a series of multiple modules within a GIS (Geographic Information System) framework to predict the air quality impact of *Alternative Futures* projected in a study area located in south western California. In this context, four future land use scenarios were developed each having two-population variants. Through a coupled system of transportation, meteorology/air quality, and emissions modeling, a spatially and temporally resolved emissions inventory reflecting future land use scenarios was calculated on a daily basis for an ozone (O_3) episode during July 2003. The Comprehensive Air Quality Model with extensions (CAMx) was used to estimate the photochemical processes in the system. Simulation results indicated varying impacts between the scenarios and predicted an increase in O_3 for all future development patterns.

Key Words: Urban Growth, Land Use Scenarios, Air Quality Modeling, Biogenic Emissions, Emissions Modeling.

1. Introduction

Air pollution is often associated with urbanization and industrialization. Starting from the early 20th century, a series of regulations targeted the reduction of air pollutant emissions from industrial sources; however, urbanization still remains an issue on both local and regional scales. The structure and design of urban developments can have significant adverse effects on pollutant emissions as well as other ecological factors (Southerland, 2004; Kepner et al., 2004). Diverse and poorly planned urban development (i.e., urban sprawl) can force higher rates of motor vehicle use and in return increase levels of pollutant emissions. Increased flood frequencies and habitat reduction of endangered species are also among the risks of such land cover changes (Kepner et al., 2004). Given the diversity and complexity of all these issues that adversely affect environment and air quality, there is a need to develop advanced tools which can predict the impact of future urban growth on all scales and recommend optimum approaches for achieving more sustainable environments. One effective method of assessing the future impact of urban growth is known as *Alternative Futures*, which is based on scenario analysis. Scenario techniques in land use planning have been around since the late 40's and been tested in many different applications to help the authorities in decision making (Schwartz, 1996; Steinitz, 1990; Shearer et al., 2004). In this study we introduce the development of an advanced interactive scenario-based land use and atmospheric chemistry modeling system coupled with a GIS (Geographical Information System) framework. The modeling system is designed to be modular and includes land use/land cover information, transportation, meteorological, emissions, and photochemical modeling components. The methods and modularity of the developed system allow its application to a broad region of interest. This paper describes the development and application of the modeling system to the rapidly developing area in south western California.

2. LAND USE SCENARIOS

To investigate the impact of possible land use change and urbanization, a set of alternative future patterns of land use were developed concerning the northern San Diego area and parts of Riverside and Orange Counties, California (Shearer et al., 2004). The study area for this purpose was defined as a rectangle of 73 miles east-west and 68 miles north-south. As discussed in Shearer et al. (2004), the set of alternative future land use scenarios or the *Alternative Futures* were based on a large spectrum of critical uncertainties representing the possible futures which are both difficult to predict and likely to have significant impact on social, economic, political, technological, and environmental trends. Issues were identified by looking at the critical uncertainties in the study area and addressed topics such as water, energy and possible changes in social and environmental regulations. To address these questions, four land use scenarios were developed each having two variants: a 500k population increase and a 1,000k population increase. The existing land use and land cover patterns were compiled using a Landsat Enhanced Thematic Mapper (ETM) image dated in November 18, 2000 and available information obtained from different sources. Land use maps for the future growth patterns including the existing land use are shown in Figure 1 (from Shearer et al., 2004). In all of the *Alternative Futures* the existing development (built) was left intact (Shearer et al., 2004).

The *Coastal Future* is built upon a scenario that encourages the conservation of future resources such as water and energy. As a result, high-density urban residential development is concentrated west of Interstate Highway 15 (I-15) close to the coast and the amount of low-density housing in more rural locations is reduced. Eighty eight percent of the new residential areas are located in San Diego County and ten and two percent in Riverside and Orange Counties, respectively.

The *Northern Future* represents a development plan that supports low density housing concentrated in the northern portion of the study area. Hence, the new suburban and rural residential development is concentrated in western Riverside County (44%) with the remaining development distributed in San Diego (55%) and in Orange (1%) Counties. Overall, the majority of housing is placed in subdivisions that are relatively close to incorporated cities and their associated infrastructure.

The *Regional Low-Density Future* best emulates the urban sprawl pattern of development present in the Western U.S. In this future scenario, the entire urban development is spread throughout the study area with new housing being predominantly developed on large lots. The majority of new housing is located in rural and ex-urban areas within San Diego (69%), Riverside (30%) and Orange (1%) Counties.

The *Three-Centers Future* concentrates development and assists in the conservation of some habitat. Much of the future housing is located close to existing development near the cities of Temecula, Vista, and Ramona. This lessens the amount of rural development sprawled throughout the southeastern part of the study area but adds some more rural residential development in the north. Percent distribution of the houses to the counties in the study area is the same as in the Regional Low-Density Future.

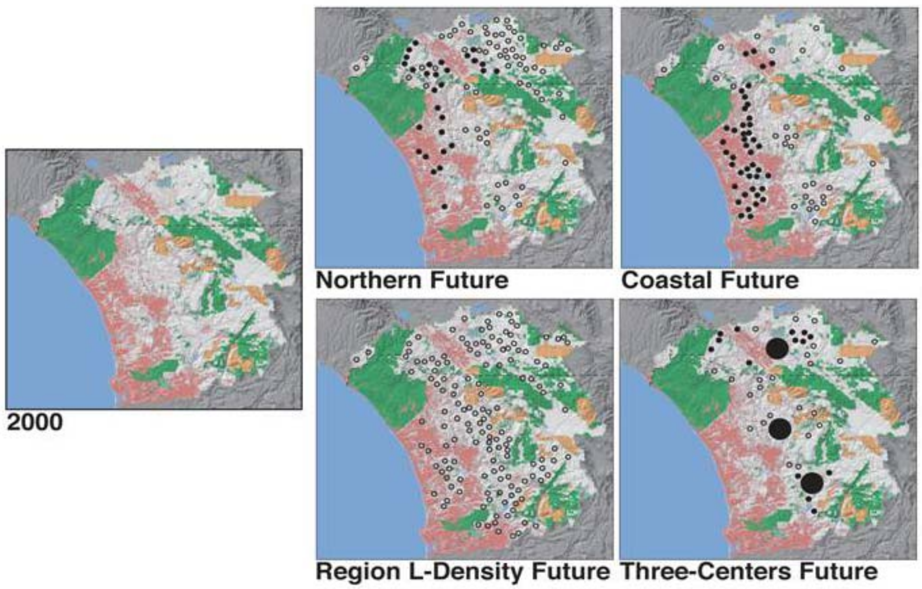

Figure 1. Land use map for the study area. (a) Existing land use (b) The *Coastal Future* (c) The *Northern Future* (d) The *Regional Low-Density Future* (e) The *Three-Centers Future.*

3. MODELING SYSTEM

In this section, an overview of the approach used to develop, test, and apply a modeling system to assess the impact of future scenarios on regional air quality is presented. A GIS based land cover and infrastructure system was coupled with pollutant emissions, meteorology, and air chemistry models. The modeling framework included a number of individual models involving future land use, emissions, air quality, and their subsequent linkages. The overall framework may be envisioned as a series of loosely coupled models with outputs and inputs shared among the models (Figure 2). The backbone of the framework is a GIS capable of operating at multiple spatial and temporal scales. Thus, each individual model encapsulated within the framework contains a spatial allocation, which can be mapped.

To create input scenarios for the emissions components, two models were constructed which describe the land use and transportation infrastructure in the region. The land use predictions, termed the development model, and the transportation model were linked to assist computation of commuting routes, which provided estimates of future vehicle miles traveled (VMT). Future emission assessments require knowledge on how an area may change and these rely on the development and transportation models for input. Air quality modeling requires inputs from all aspects of an emissions assessment. Any future alterations in population, technology, or laws will factor in as inputs into scenarios that have the potential to alter the outputs of any one model through cascading linkages. Thus, the modeling framework linkages were constructed to account for potential scenario-based changes.

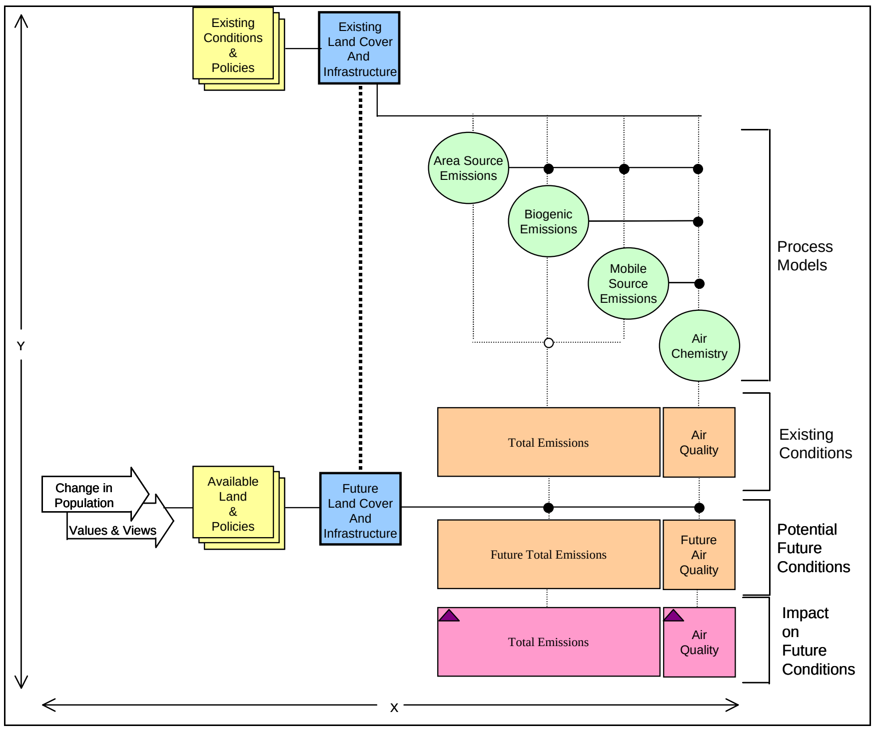

Figure 2. Framework for the assessment of air quality impacts using an *Alternative Futures* methodology. Process models, on the upper y-axis, reflect aspects of air pollution in the region of interest. The small black dots represent interaction points among process models. The region's social context, along the left portion of the x-axis, reflect varying future scenarios, including available land, policies, and the subsequent urban development and infrastructure. The relative future impact of these potential development changes is determined by integrating development changes with process models, as reflected by variations on "potential future conditions", on the lower y-axis. From the potential future conditions an assessment of how the development patterns change the air quality was done as reflected by the "impact on future conditions".

Brief descriptions of the three primary components of the modeling system (Transportation, Emissions, and Air Quality) are described below:

Transportation Modeling: Transportation models attempt to describe the flow of traffic between locations to allow for forecasting and analyzing future passenger and/or freight movement (Beimborn et al., 1996). The transportation model developed for this system accommodated all the basic conditions that are required

(Beimborn et al., 1996), with a minimal level of complexity. The primary intent of this modeling approach was to route present and future passenger cars in the study region from their home locations to their destinations along the quickest path. The model was structured in a GIS platform to coordinate all the spatial aspects and linkages of spatial information with the future land use data using Tiger line transportation files and the associated attribute information as a foundation for determining the VMT between home and work (USCB, 2002a). Based on the results of the development model, starting points were identified as new housing units defined in a 30x30 m^2 cell within a GIS layer. The ending locations were determined as thirteen major commuting points or work centers within the study area or as locations where commuters would exit the study area heading mainly north to Los Angeles or to northern Riverside County. Although substantially more work centers exist in the region, this assumption was based on the fact that many of these are clumped into the represented commercial-industrial centers. Homes were randomly assigned a path to a commercial-industrial work center as a percentage derived from U.S. Census county commuter information (USCB, 2002b).

Emissions Modeling: The emissions component of the model incorporated emissions models for biogenic, area-wide, and mobile sources. Emissions were computed for the five pollutants: NO_x, sulfur dioxide (SO_2), volatile organic carbon (VOCs), carbon monoxide (CO), and particulate matter (PM). Existing emissions estimates served as a base for estimating future emissions. The final product of the emissions modeling was a 5x5 km^2 gridded hourly day specific emissions inventory for the modeling episode of July 7 – 11, 2003.

Spatially and temporally variable biogenic emissions were estimated for the photochemical modeling domain. Estimated biogenic emission species consisted of biogenic volatile organic carbons (BVOC) such as isoprene, monoterpenes, and methylbutenol. The California Air Resources Board's (CARB) biogenic emissions model, BEIGIS, was used as the basis for the biogenic emissions component of the model. BEIGIS is a GIS based biogenic emissions model that is built upon biomass and emissions studies performed in Southern California (Horie et al., 1991; Benjamin et al., 1996). Default emission rates given in BEIGIS come mostly from Horie et al. (1991) and Benjamin et al. (1996, 1997).

Area-wide emissions of the future land uses were estimated based on the use of consumer products, residential natural gas consumption, dry cleaning, and residential and commercial lawn maintenance. These categories were determined according to the given details in the future scenarios. Methodologies used for area source emission estimates were based on the CARB's Emissions Inventory Procedure Manual (CARB, 1997). Total emission rates were allocated spatially and temporally for each land use scenario. In contrary to biogenic emissions estimates, area-wide emissions of the future scenarios were superimposed on the current emissions layer due to the fact that existing land use was preserved in the scenarios.

To estimate future on-road mobile source emissions, the GIS-based travel simulation algorithm described in the transportation model section was utilized in conjunction with EMFAC2002, the on-road emissions model specific to California (CARB, 2002). This model calculates emission factors and/or emission rates for the vehicle fleet in California as categorized in 13 vehicle classes and accounts for six criteria pollutant types. Total VMT served as the major input for EMFAC2002 as calculated by the transportation model.

Meteorological and Photochemical Modeling: In order to evaluate the impact of the future scenarios on the formation of secondary pollutants, the spatially and temporally resolved output from the emissions model was coupled with an air quality modeling system that can operate over multiple domains. This took place in two steps: meteorological and photochemical air quality modeling. As part of this study, simulations were performed for an episode from July 7 through July 11, 2003. During this period, the San Diego area experienced high levels of air pollution and so it provided an opportunity to investigate the possible highest impact of the future land use change on air quality.

A prognostic forecast model, the Fifth Generation Penn State/NCAR Mesoscale Model (MM5) (Grell et al., 1995), was used to generate all required field variables and parameters for the emissions model and the air quality model. MM5 is a well-known mesoscale, nonhydrostatic, terrain-following sigma coordinate model that is used in predictions of mesoscale and regional air circulation. MM5 provided the photochemical model with 3-dimensional field variables such as horizontal wind, temperature, pressure and other parameters, which are used by the photochemical model for the atmospheric transport and dispersion calculations. Temperature and ground level shortwave radiation variables used in biogenic emissions model were also predicted by MM5.

To address the formation of secondary species and transport/dispersion of emissions, the Comprehensive Air Quality Model with extensions (CAMx) was employed (Environ, 2003). CAMx is a photochemical Eulerian dispersion “one-atmosphere” modeling system with multi pollutants and scaling that can be applied to regional or local domains to predict all phases of air chemistry. The model requires a variety of input variables including meteorological fields, photochemical reaction rates, gridded and/or point emissions, surface characteristics, initial conditions (IC), and boundary conditions (BC). For all the simulations, IC and BC were set according to the U.S. EPA’s standard profiles.

4. RESULTS AND DISCUSSION

4.1. Emissions

Total future emission estimates were generated on a daily basis for the same time period as the air quality model was run. The final product of the emissions modeling was a 5x5 km^2 gridded hourly emissions inventory of NO_x, SO_2, VOCs, CO, and PM. Within the study time period, the greatest change in emissions occurred on July 10 and was due to changes in biogenic emissions driven by the ambient temperatures. In terms of the other anthropogenic emission sources, it was assumed that the modeling period extended throughout the weekdays with the same activity rate and therefore no changes were predicted on a daily basis. Land use differences had the greatest influence on two categories: mobile and biogenic sources. Area wide emissions showed a linear dependence on population, and stationary/industrial sources were assumed unchanged in this study. Although the difference between the four scenarios was small in terms of the mobile source contribution, the *Northern*

Future generated the highest emissions and the *Three-Centers Future* generated the smallest values. This was attributed to the longer commuting paths and associated higher VMT rates for the *Northern Future*.

VOC emissions from biogenic sources, on the other hand, demonstrated completely different characteristics and have very distinct differences among the scenarios. This change was by virtue of the quantity and quality of the altered land in the future scenarios. In some of the scenarios, the amount of rural housing built on large lots that leads to higher emission rates (Benjamin et al., 1997) was larger than for the other scenarios and was the major factor for higher emission estimates. The *Regional Low-Density Future*, for example, had twice as much land allocated as new residential areas than the other scenarios and 80% of it was classified as rural. This, and the fact that most of the low emitting or non emitting land (e.g., barren, grassland, etc.) was converted into residential vegetation uses, led to the highest amount of biogenic VOC emissions, an increase of 44 tons from the base case. In contrast, the lowest biogenic emissions occurred in the *Three-Centers Future*, which has the smallest percentage of higher-emitting rural lots. Overall biogenic emissions were greater than or nearly the same as the total estimated anthropogenic VOCs. This highlights the importance and magnitude of biogenic emissions from urban areas.

4.2. CAMx Simulations

The air quality simulations using CAMx were performed for the period of July 7 through July 11, 2003 and covered an observed O_3 episode in the region. The first day of the simulations, July 7, was excluded from the analysis and was used as the model's spin-up time.

For all the simulations, the maximum predicted O_3 concentrations occurred on July 11. This situation was associated with low daytime wind speeds and relatively stagnant conditions. The location and time of the peak concentration over San Diego and Riverside Counties were approximately the same for all days. Table 1 presents the simulated peak O_3 concentrations for the base case and scenarios on a daily basis. It is seen from this table that the peak O_3 increases 10 ppb, on average, for the *Regional-Low Density Future* and ranges from 2 to 9 ppb for the other scenarios, suggesting that the most of the impact is local. These results show that both the regional and local impact is the least for the *Three-Centers Future*, which also had the smallest incremental changes in emissions.

The results shown in Table 1 indicate that while the base case is below the one-hour average federal standard for O_3 on July 9 and 11, all scenarios with 1,000k new residents are likely to exceed this standard. Unless the future growth plans include some mitigation measures, the area will be classified as non-attainment. Such measures could include newer and cleaner technologies in motor vehicles and the planting of selected plant species to reduce BVOCs (Benjamin and Winer 1998; Pun et al., 2002; Mendoza-Dominguez et al., 2000).

Table 1. One-hour average predicted peak O_3 concentrations (ppb) over the study area and San Diego County for the entire simulation period. *Max* O_3 column designates the predicted peak O_3 concentration and *Change* (ppb) column designates the difference with respect to the base case.

Simulations	July 8		July 9		July 10		July 11	
	Max O_3	Change	Max O_3	Change	Max O_3	Change	Max O_3	Change
Base Case	100		114		106		117	
Coastal Future (500k)	102	2	119	5	110	4	120	3
Coastal Future (1,000k)	105	5	123	9	115	9	124	7
Northern Future (500k)	103	3	119	5	111	5	121	4
Northern Future (1,000k)	105	5	122	8	114	8	124	7
Reg. Low-Density Future (500k)	104	4	121	7	113	7	124	7
Reg. Low-Density Future (1,000k)	108	8	126	12	118	12	128	11
Three-Centers Future (500k)	102	2	118	4	109	3	120	3
Three-Centers Future (1,000k)	103	3	121	7	112	6	122	5

6. SUMMARY AND CONCLUSIONS

In this paper we described the development and application of a scenario-based modeling system that couples a GIS based land cover and infrastructure system with pollutant emissions, meteorological and air chemistry models to predict the impact of growth on future emissions and air quality. Four land use and land cover scenarios with each having a 500k and 1,000k population increase were developed within a GIS system to depict the possible future growth and its consequences within the study area (Shearer et al., 2004). Subsequently, we linked this GIS system with transportation, emissions, meteorological and air quality models to predict air quality impacts for each scenario.

Emission estimates and air quality simulations were performed for an observed episode in the South Coast region and San Diego County from July 7 to 11, 2003. Estimates of future emissions were distinctly different for the four scenarios. Changes in BVOC emissions were comparable to the changes in the total anthropogenic VOC emissions. Overall the *Regional Low-Density Future* was seen to have the highest pollutant emissions and the greatest impact on air quality. On the other hand, the *Three-Centers Future* appeared to be the most beneficial alternative future in terms of air quality. For all cases, the increase in population was the main factor leading to the change on predicted pollutant levels.

As standards for air quality become more stringent, the need for predictive tools that can assess the impact from future growth and developments is critical. The modeling system and simulation results presented in this paper were aimed to answer the question of what and how *Alternative Futures* should be designed if we are to implement effective strategies to reduce future air quality impacts. Since the system is fully modular and capable of integrating new sub-systems, it can be modified to include additional features as desired and applied a variety of regions where future development and growth plans are needed.

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COMPLEX AIR QUALITY MANAGEMENT SYSTEM IN A LARGE CITY: EXAMPLE OF RIGA CITY, LATVIA

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ABSTRACT

Complex air quality (AQ) management system consists of a number of elements which could be divided into 4 main functional blocks: 1) Data and information generation and gathering; 2) Assessment, reporting and dissemination of information; 3) Decision making and public involvement; 4) Implementation of actions. Environmental monitoring is the main tool for data and information generation. Besides, AQ modelling plays more and more important role.
Riga is the biggest city in the country (~764 thousands or 32 % of Latvia's total population) with intensive traffic and economic activities. It is the only one agglomeration with respect to AQ management nominated in Latvia.
Until 1997 AQ monitoring in Riga was based on manual methods. Since 1998 the core of observation system is based on automatic measuring devices mainly employing the method of differential optical absorption spectroscopy (DOAS). In 2005 the eight stations are representing different institutional systems of AQ monitoring – state (3), municipal (3) and enterprise (2). All of them are technically and methodologically (data quality assurance and control) maintained by Latvian Environment, Geology and Meteorology Agency (LEGMA). More separated are information dissemination patterns including on-line access to information published on Internet homepages both of LEGMA and Riga municipality.
AQ problems in Riga are represented by elevated concentrations of NO_2, PM_{10} and benzene. All responsibility for improvement of AQ in Riga is delegated to Riga City Council. Action plan on improvement of AQ in Riga City has been approved in 2004 comprising actions to be carried out until 2009.

Key Words: Air Quality, Air Quality Management System, Riga, Latvia

1. INTRODUCTION

Atmosphere air is one of the most important environmental factors influencing human health. Especially the problems of air quality (AQ) are emerging in large cities and industrial zones.
Latvia during the preparation process to join the European Union (EU) began to incorporate EU requirements for ambient AQ monitoring and related AQ standards into the environmental legislation of Latvia since late 1990-ties, several years before official status of an EU member state from May 1, 2004. These AQ standards and monitoring pattern substantially differs from the previous one implemented during Soviet times and in the first half of 1990-ties after regaining of independence in 1991 (Table 1).

Table 1. Comparison of two AQ standard's, monitoring and legislation systems

System implemented in the former Soviet Union	System implemented in the European Union
Many polluting substances	Prioritized polluting substances
AQ standards in the form of Maximum Permissible Concentration in relation to instantaneously measured and daily averaged concentrations	Broad range of limit values from one-hour to mean annual concentration
Discrete manual sampling	Continuous automated measurements
Quite inflexible monitoring	Flexible monitoring based on amount of population exposed and actual AQ situation
Minimum monitoring requirements not specified	Minimum monitoring requirements specified

Complex AQ management system consists of a number of elements which could be divided into 4 main functional blocks: 1) Data and information generation and gathering; 2) Assessment, reporting and dissemination of information; 3) Decision making and public involvement; 4) Implementation of actions. Accordingly, proper AQ information system is the basic prerequisite for management of AQ. The main elements of the environmental information system are data gathering patterns (monitoring, scientific investigations, statistics, modeling), data processing and storage and reporting (operationally, monthly, annually, etc.) to decision makers and public (Fig. 1).

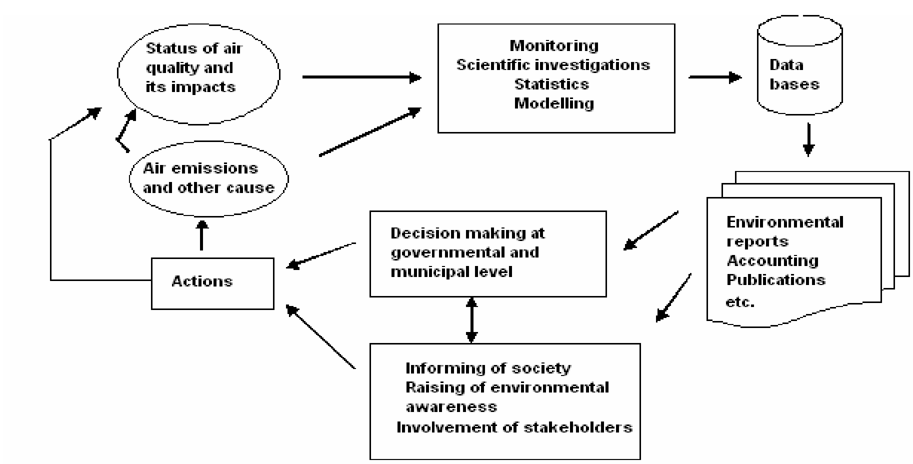

Figure 1. Conceptual AQ management system (Kadikis et al., 2002).

Environmental monitoring plays the key role in supplying environmental information. Besides, AQ modeling plays more and more important role in providing additional information on AQ status.
The paper aims at development of general principles and possible solutions for complex AQ management system in a large city, irrespective of its geographical

location reflecting the development of AQ management system in Riga City, the capital of Latvia.

2. MAIN TEXT

2.1. Brief characterization of Riga City

Riga is the capital of Latvia and the largest city of the Baltic States. It is located on the plain area on the southern shores of the Baltic Sea at the mouth of the Daugava River. The city's crossroads location between Western Europe and huge Eastern markets is one of Riga's attractions for business activities. This favorable location and membership in the Hanseatic League of northern cities has promoted the rapid development of the city since it's founding in 1201.

According to data from the last population census in 2000, Riga has the population of ~764 thousands (~32 % of Latvia's total population) and intensive traffic and economic activities, as well. The maximum number of inhabitants was reached in 1990 – ~ 912 thousands owing to mechanical migration from other parts of former Soviet Union.

Territory of Riga City occupies ~ 307 km^2. 5,7 % cover streets and highways, 5,2 % - industrial areas, 4,3 % - technical services zones (railway, power stations, garages, etc.), 1,7 % - port areas. Nature and greenery takes up of 36,6 % of city territory (CEROI, 2004). It consists of nature areas, nature protection zones, various forms of greenery - parks, gardens, etc. The street and arterial road network in the central part of Riga was developed at least 150 years ago and is not able to accommodate today's increasing traffic.

Riga's climate is determined by prevailing air masses from the Atlantic Ocean. This maritime influence results in mild winters and cool summers as well as high air humidity (80%). Average long period temperature is - 4.9 ^oC in January and + 16.9 ^oC in July. The air temperature is usually 2-3 ^{o} C higher in the center of Riga than in the suburbs. Snow cover during winter is normally sustained for a short period. Autumn is the windiest season but windy days are occurring quite often through the year favoring air circulation.

2.2. History and development of AQ monitoring in Riga

The first AQ assessment performed in Riga dates back to 1913. Regular AQ observations in Riga as pilot observations started in 1965, being the first AQ monitoring observations in Latvia. Permanent observation's program in Riga was launched in 1969 and until 1974 steady AQ monitoring in Latvia was carried out only in Riga covering 3 posts. Total number of AQ monitoring sites within the state monitoring system reached 5 posts until 1997 selected as a frontier zone between industrial and residential areas and in the central part of the city influenced by traffic. The monitoring was based on manual sampling methods (3-4 times per day for SO_2, NO_2, TSP[1], CO, NH_3, phenol, etc. and 1 time per month for Cd, Cu, Pb, Zn in TSP) followed by conventional laboratory analyses and, therefore, often called as wet

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[1] Total suspended particulates

chemistry methods. Before regaining of independence in 1991, observation's network of Latvia was included in the state observational network of the former Soviet Union and unified methods were implemented summarized in the Guidance on control on atmosphere pollution (Anonymous, 1991).

The turning point in the development of state AQ monitoring system in Latvia relates to introduction of automated, continuous measurements performed by means of instruments implying differential optical absorption spectroscopy (DOAS) method. Devices based on DOAS method consist of light emitter and receiver, which are placed at some distance (up to few 100 m) and, therefore, measure average concentration of air pollutants within the particular spatial distance. To some extent, the reason for such preference to choose DOAS equipment as a basic element of state AQ monitoring system was the previously got experience from the first DOAS station operating within municipal observational network in Riga since 1994. On the other hand, DOAS technique seemed to provide advanced and modern opportunities in development of automated AQ monitoring equipment (Leitass, 2000). From 1998 to 2002 the amount of DOAS stations (produced by OPSIS AB, Sweden) operating within the framework of state monitoring network in Riga reached 4 stations (totally, in Latvia operated 13 stations) supplemented by 1 municipal observation station. The standard set of parameters included SO_2, NO_2, O_3, benzene, toluene, and xylenes. Additionally, formaldehyde was determined at one station.

Several other important parameters required by European directives, namely, CO and PM_{10} particulate matter are detected on continuously basis applying different from DOAS techniques - infrared spectrophotometer for measurements of CO and beta ray attenuation method for detection of PM_{10}. Additionally Hg fumes were detected by means of atomic absorption mercury vapor analyzer. In their turn, the combusted PM_{10} samples are used for laboratory analyses on heavy metals (Zn, Cu, Cd, Pb, Ni, As, Mn) with atomic absorption flame spectrophotometer.

Remarkable changes in observational programme occurred in 2003 as two new automatic municipal stations (DOAS station and a "single point" station based on gas chromatography principles and produced by HORIBA, Germany) have been installed in Riga. Since 2004 two DOAS installations are located in the territory of Riga Commercial Free Port responding to rising public concerns about air pollution caused by harbor operations. The mentioned stations are financially maintained by the enterprise itself and provide example of enterprise AQ monitoring.

Summary on main development stages of AQ monitoring in Riga is given in the table 2.

Besides, new possibilities for air quality monitoring have been provided with the development of diffusive sampling methods being some advanced derivation of wet chemistry methods as conventional laboratory analyses are involved. Usually diffusive samplers are placed in smaller towns, which is not possible to equip with expensive automated analyzers or in order to gather additional information on AQ with regard to more detailed distribution of polluting substances. A short time measurement campaign of NO_2 and benzene pollution in Riga was performed in 2003 using diffusive samplers.

As regards 2005, there are 8 automated monitoring stations operating in Riga and representing different institutional framework (Fig. 2, Table 3). 7 of them are DOAS stations and 1 is "point" station, which is based on gas chromatography (street

Valdemāra). Additional analyzers determining a number of supplementary pollutants equip some of the stations. 5 stations belong to Latvian Environment, Geology and Meteorology Agency (LEGMA) – a state agency under the Ministry of Environment. The agency is the main authority responsible for AQ monitoring and assessment in Latvia having skilled technical staff and specialists capable to carry out technical maintenance of monitoring stations and data quality assurance / quality control (QA/QC) (Kadikis et al., 2004). Despite 3 other stations are the property of Riga municipality, technical maintenance as well as data QA/QC is done by LEGMA on contract basis. The same general principles with respect to technical maintenance and QA/QC apply to stations that have been rented to Riga Commercial Free Port and are working at industrial sites. So, neither municipality, nor enterprise is obliged to maintain its own staff capable to ensure reliable measurements within municipal or industrial monitoring network. It should be mentioned that LEGMA is accredited according to EN ISO 9001:2000 standard (introduction of overall quality management system in all operations performed by the agency) since 2004.

Table 2. Summary on AQ monitoring in Riga, 1969 – 2005

Manual methods			Continuous automated methods			
Pollutants	Maximum number of stations sampled during one year (state / municipal / enterprise)	Started-closed	Pollutants	Method	Maximum number of stations in operation during one year (state / municipal / enterprise)	Started-closed
SO_2, NO_2, TSP, CO, NH_3, HCl, formaldehyde, phenol, heavy metals (Cd, Cu, Pb, Zn) in TSP	**5** (5/0/0)	1969 - 1997	SO_2, NO_2, O_3, benzene, toluene, xylenes	DOAS	**7** (4/2/2)	1994[2]
			NO, NO_2, benzene	Gas chromatography	**1** (0/1/0)	2003
			O_3	UV spectrophotometry	**1** (0/1/0)	2003
Heavy metals (Cd, Cu, Pb, Zn, Ni, As, Mn) in PM_{10}	**3** (2/0/1)	2000	PM_{10}	Beta ray attenuation	**4** (2/1/1)	2000
			CO	Infrared spectrophotometry	**1** (1/1/0)	2002
			Hg fumes	Mercury vapor atomic absorption	**1** (1/0/0)	2000-2002

Notes: TSP - Total suspended particulates

[2] As municipal monitoring; state monitoring was launched in 1998

2.3. EnviMan – a complex AQ data storage, management and modeling system

Development of strategical and technical methods for monitoring measurements and data handling manners go hand in hand depending on progress in information technologies. Till 1991 all data were stored on paper sheets only, but since 1991 - digitally and with duplicated reserve copies on paper formats, as the safe maintenance of digital data is not fully ensured yet. The software used were FOXPRO.

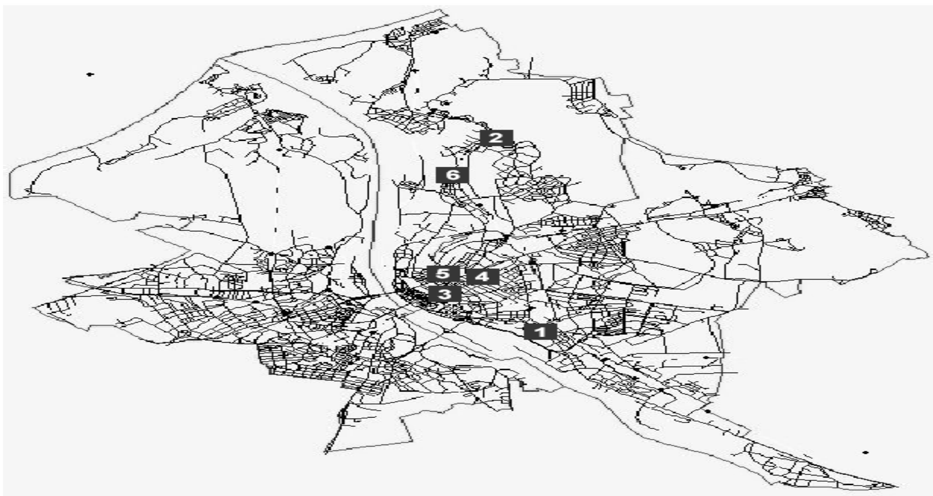

Figure 2. Schematic state and municipal AQ monitoring network in Riga in 2004-2005 (indication of stations corresponds to those given in the Table 3) (Šteinberga et al., 2005).

The newest tool for data management and pollution's dispersion assessment EnviMan, which is coupled with DOAS observation's stations and produced by OPSIS AB Company in Sweden, was obtained in the LEGMA in the late 1990-ties. Initially it was used for processing and storage of data gathered from automatic monitoring stations only. First AQ modeling exercises using EnviMan began in 2000 – 2001 when digital map of Riga City and related GIS databases with regard to emission point sources as well as input meteorology data were prepared. Nowadays AQ modeling with EnviMan is broadly used for permitting purposes to regulate release of air pollutants from industrial installations.

The similar EnviMan system is located in the Air Quality Division of the Environmental Department of RCC. So, the data storage from municipal observation's stations is duplicated both in LEGMA and Riga municipality (Table 3).

2.4. AQ management system: from reliable data to on information based decisions and informed society

Ambient air monitoring system as well as set of AQ standards are established on the basis of relevant EU directives incorporated into the environmental legislation of Latvia. According to legislative provisions and taking into account the results of AQ assessment covering time span 1998-2003, the Ministry of Environment restated 2 zones for AQ management and assessment in Latvia in 2004 - Riga agglomeration and the rest of the country (initially, there were Riga agglomeration and 2 additional zones nominated in 2003).

The main AQ problems in Riga are represented by elevated concentrations of NO_2, PM_{10} and benzene. All responsibility for improvement of AQ in Riga agglomeration is delegated to Riga City Council (RCC). Due to before mentioned AQ problems RCC was obliged to prepare action plan on improvement of AQ in Riga agglomeration. RCC has announced the tender for preparation of related action plan in 2003 and such a plan was elaborated by the Latvian consultancy company "Eiroprojekts".

Table 3. Structure of AQ monitoring system in Riga in 2005

Nr.	Name of station	Type of station	Monitoring system	Financier	Technical maintenance and data QA/QC	Place of data storage	Main pollutants measured
1	Ķengarags	Urban background	State	LEGMA	LEGMA	LEGMA	SO_2, NO_2, O_3
2	Mīlgrāvis	Urban background	State	LEGMA	LEGMA	LEGMA	SO_2, NO_2, O_3, benzene
3	Parks	Urban background	State	LEGMA	LEGMA	LEGMA	SO_2, NO_2, O_3, PM_{10}, heavy metals in PM_{10}
4	Street Brīvības	Traffic	Municipal	RM	LEGMA	LEGMA RM	SO_2, NO_2, O_3, PM_{10}, benzene, heavy metals in PM_{10}
5	Street Valdemāra	Traffic	Municipal	RM	LEGMA	LEGMA RM	NO, NO_2, O_3, PM_{10}, CO, benzene
6	Street Tvaika	Traffic	Municipal	RM	LEGMA	LEGMA RM	SO_2, NO_2, O_3
7.	Port 1	Industrial	Enterprise	RCFP	LEGMA	LEGMA	SO_2, NO_2, PM_{10}, benzene, toluene, xylenes, heavy metals in PM_{10}
8.	Port 2	Industrial	Enterprise	RCFP	LEGMA	LEGMA	SO_2, NO_2, benzene, toluene, xylenes

Notes: 1. LEGMA - Latvian Environment, Geology and Meteorology Agency;
RM – Riga Municipality;
RCFP - Riga Commercial Free Port
2. Heavy metals include Pb, Cd, Cu, Zn, Ni, As, Mn

The action plan is approved by RCC in 2004 and it comprises actions to be carried out until 2009 (Table 4).

Table 4. Action plan on improvement of AQ in Riga agglomeration – summary on planned activities

Nr.	Activity	Description	Time	Expected results
1.	To state AQ as an obligatory criteria for elaboration and review of city development plan as well as for optimization of traffic system in the city.	Riga City Council decision	2004	Effective introduction of AQ action plan
2.	To decrease the amount of traffic in the historical center of the city by 35 % compared to 2002 performing optimization of the traffic.	One of the objectives stressed in the Riga City development plan 2006-2018. Restrictions to traffic, restructuring of traffic flows, avoiding of traffic jams, setting of differentiated starting time for work of authorities and enterprises.	2009	Decrease in NO_2 pollution caused by traffic to the limit value.
3.	Wet cleaning of streets and pavements in the city center during spring-autumn seasons.	Regularly during days without pronounced precipitation.	Steadily since 2005	Gradual decrease in particulate matter pollution caused by traffic. Combination with other measures (see Nr. 1) will lower concentration to the limit value until 2008.
4.	Elaboration of regulations of Riga City Council on zoning of air pollution for development of heat supply in Riga.	Actual and forecasted NO_2 pollution must be taken into account when allowing differentiation of heating systems. All pollution sources including small ones must be enumerated.	2004-2005	Decrease in NO_2 and PM_{10} caused by stationary pollution sources.
5.	Elaboration of new conception on heat supply in Riga for coming 10-15 years.	Modernization of 2 main steam shops supplying heat in Riga (until 2009).	2004-2005	Considerable decrease in air pollution.
		Gradual replacement of coal based small boiling houses to gas or wood burning installations (until 2009).		
6.	Strengthening of AQ monitoring system in Riga.	Expansion of existing monitoring network with 4 stations measuring PM_{10}. Upgrading of benzene analyzers of DOAS monitoring stations within state network.	2005	Proper information gathered and society informed, possibility to assess introduction process of the plan.
7.	Introduction and maintenance of AQ monitoring system in the territory of Riga Free Port.	Possible expansion of the observations network if oil loading terminals will be	Since 2004	Follow-up of air pollution caused by port operations.

Table 4 (continued)

Nr.	Activity	Description	Time	Expected results
		expanded. Installation of meteorological station (2004).		Measures on pollution restriction.
8.	Strengthening of Environmental Department of Riga City Council and establishment of system of supervision and control on air pollution reduction.	Establishment of 4 additional new working places within Environmental Department.	2005	Established system of supervision and control on air pollution reduction.
9.	Involvement of public by establishment of interactive system of information exchange.	Information system about AQ, measures taken and results achieved. Understandable interpretation of information dedicated to public.	2005	Enhanced effectiveness of introduction of AQ action plan.

In order to get the necessary information on AQ, all available information sources have been used – data generated by AQ monitoring, statistics on air emissions gathered by Riga Regional Environmental Board and compiled by LEGMA and Central Statistical Bureau of Latvia and AQ modeling especially in relation to different development scenarios, which could change the air emissions and related AQ situation. Although pollution generated by traffic is evaluated on the basis of amount of cars and pollution factors, routine assessment methods must be refined.

The main objective of the action plan is to lower the elevated air pollution to the level that corresponds to AQ good enough for human health protection as well as to implement preventive measures for places of already satisfactory AQ but of potential risks in the future due to possible development of traffic and industrial activities. Priority targets were defined mainly based on costs - benefits analysis as well as on forecasts of possible changes in AQ taking into account temporal dynamics of air emissions. Additionally, different scenarios were analyzed with respect to social and economical development, potential changes in legislation and residential areas (Steinberga, 2005).

As it was already mentioned, regardless of different property and financing characteristics of the monitoring stations all of them are technically and methodologically (data QA/QC) maintained by LEGMA. More diverse and fully separated are information dissemination patterns including on-line access to information published on Internet homepages both of LEGMA and the Riga City Environment Center "Agenda 21" (www.lvgma.gov.lv and www.agenda21riga.lv, respectively). Both LEGMA and Riga municipality are reporting on-line and monthly AQ information to the public obtained within their own observations network only. However, yearly reports on AQ prepared by LEGMA comprise full analysis on the AQ situation in Riga (Šteinberga, et al., 2005). All kind of reports is freely available on the Internet, though, almost only in Latvian for the moment. It must be emphasized that Riga municipality applies integrated AQ index in order to inform public in an understandable way, however, integrated AQ indexes are not supported by environmental legislation.

3. CONCLUSIONS

3.1. Complex AQ management system consists of a number of elements which could be divided into four main functional blocks: 1) Data and information generation and gathering; 2) Assessment, reporting and dissemination of information; 3) Decision making and public involvement; 4) Implementation of actions.
3.2. Environmental monitoring plays the key role in supplying environmental information useable for management purposes. In order to reach an appropriate coverage in a large city monitoring network must combine networks of different actors – state, municipal, enterprise, etc. The most effective and cheapest way is to centralize the technical and methodological (QA/QC) maintenance of all AQ observations under one authority having skilled and experienced staff.
3.3. The same considerations relate to information dissemination, which must be organized on the integrated basis – the public must have the possibility to obtain all the AQ information at one place what is not a case for Riga City at the moment.
3.4. Successful AQ management in a large city depends on cooperation and networking of all actors involved but it is not easy to avoid no needed competition among authorities and to break institutional barriers.
3.5. Main AQ problems in Riga - the only one agglomeration nominated in Latvia as an AQ management and assessment unit according to EU legislation, are manifested by elevated concentrations of NO_2, PM_{10} and benzene exceeding the related limit values.
3.6. Action plan on improvement of AQ was prepared taking into account monitoring data, results of AQ modeling and different development scenarios associated with different air emissions. Riga City Council approved the action plan in 2004. It foresees more or less concrete measures until 2009. Strengthened AQ monitoring network in Riga must prove success of measures implemented and indicate to targets, which are to be reconsidered.

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ADDING VIRTUAL MEASURING STATIONS TO A NETWORK FOR URBAN AIR POLLUTION MAPPING

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ABSTRACT

Generating maps of pollutants concentration is made by means of interpolating and extrapolating methods. The quality of the results depends mainly of the number of input concentration values issued from the measuring ground network i.e, from the number of stations. This paper deals with a method for the virtual densification of this network. "Virtual measuring stations" are created. They are determined by the means of a classification method combined with hashcoding tools. Discriminating elements are pollutants emission classes, land cover types and urban morphological indicators created to this purpose. A first implementation was done for particulate matter (PM). This method aims at improving the quality of interpolation by increasing the number of concentration data.

Key Words: Pollution Map, Virtual Measuring Station, Morphological Indicators

1. INTRODUCTION

Many large cities in Europe have acquired a measuring network in order to monitor and analyze air quality. Monitoring and studying air pollution are made by agencies created to this aim. Local authorities rely on these studies to take decisions and to inform the population in order to reduce health impact caused by air pollution. European policies in this domain involve space-time knowledge of individual or collective exposure to pollutants. Therefore it is becoming more and more essential to know the spatial distribution of pollutants concentration at any time and any place in the city in order to map pollution at very local scale.

To answer this need, agencies in charge of studying air pollution are using two different methods. Either they map pollutants concentration with numerical models, either they interpolate concentrations values issued from measuring ground network. Combination of both methods may occur. Interpolation methods are mostly used. Modeling pollution variability at local scale involves to solve very complex phenomena and needs many input parameters such as meteorological parameters, emissions parameters, boundary conditions. Many models are used to map pollutants concentrations at larger scale (country scale). Others such as STREET and ADMS can model pollution dispersion at very local scale (street scale); they turn to be insufficient because they are often dedicated to emissions due to traffic and do not represent the background pollution over the whole city. It results that they give no accurate knowledge of the spatial distribution of pollutants over the whole city. Moreover such models require many input parameters to be optimal and parameters are often not available. For all these reasons, practitioners presently generate maps of concentrations by means of interpolation and extrapolation methods. Among those, the most used is the kriging method.

The accuracy of the results of the interpolation depends mainly on the number of known measurements. Majority of cities have a monitoring network composed by an insufficient number of measuring stations. Indeed, according to Stalker & Dickerson (1962), a network of conventional ground measurements requires at least four sampling stations of SO_2 by surface of 2.5 km² to estimate the actual concentration at ± 20 %. For the city of Strasbourg, which is our study area, and whose surface is 306 km², a network of approximately 120 stations instead of the 32 current ones would be needed. Increasing the number of ground measuring stations requires important material means and is extremely expensive. Furthermore, maintenance has a considerable cost.

To overcome these problems, we propose a method for mapping concentrations of pollutants. It consists in a virtual densification of the network. Our study is based on the work of Ung (2003), Ung *et al.* (2001, 2002), who introduced the concept of "virtual stations". The first part of this paper presents the method. In the second part, an application of the methodology to the city of Strasbourg is shown. In the third part, results are discussed. The last section is a conclusion; future work is sketched.

2. METHOD

The starting point of the concept of "virtual station" comes from observations made by agencies in charge of air quality monitoring. These agencies (such as ASPA in Strasbourg) observed that there are places in the city, which present properties similar to those of the measuring stations (Weber *et al*. 2002). From this, we made the assumption that a place having the same morphological features with respect to air flow and belonging to the same emission class than an actual measuring station, will have the same behavior regarding pollutants circulation and therefore, the same concentration.

Accordingly, if we can identify these features in an automatic way, we will identify virtual stations. As features, we selected morphological indicators (Miller and Gravelius), emission register and land cover.

Morphological indicators describe the shape of the space surrounding the station. Individual buildings, their height, orientation and their arrangement influence wind flows and thus spatial distribution of the pollutants (Turbelin 2000). We have selected two indicators to characterize the space surrounding the station.

The Miller indicator $\mathbf{I}_M$ characterizes the circularity of this space. It varies from 0 for a linear shape to 1 for a perfectly circular shape (eq. 1):

$$I_M = \frac{4\pi S}{P^2} \quad (1)$$

where S is the surface of the area and P is the perimeter of the area.
The Gravelius indicator $\mathbf{I}_G$ is an indicator of compacity. It compares the perimeter of the visibility surface to a perimeter of a disk having the same area (eq. 2):

$$I_G = \frac{P}{2\sqrt{\pi S}} \quad (2)$$

The visibility surface S characterizes the open space around the station. It is computed by a rays throw technique by taking into account the buildings position around the station. It is expressed as follow (eq. 3):

$$S = \sum_{i=1}^{N_{rayon}} S_{angle}(i) \quad (3)$$

where $S_{angle}(i)$, is a sector in the direction *i* (eq. 4):

$$S_{angle}(i) = \frac{\pi D_{angle}^2(i)}{N_{angle}} \quad (4)$$

with $D_{angle}(i)$, the visibility distance computed in the direction *i*.

The emission register informs about the quantity of pollutants (in tons) emitted per year per squared kilometer.

The land cover plays an important role in the pollutants dispersion. Changes in land cover (e.g., buildings compared to trees) imply changes in aerodynamic roughness lengh, which in turn modify air flow by creating turbulences (Tennekes & Lumley 1972). The method is made of two steps: determining virtual stations and mapping by an interpolation / extrapolation method.

Prior to the determination of virtual stations and their localizations, the urban area is divided into cells by a regular grid. The cell size defines the spatial resolution. For each cell, the Miller and the Gravelius indicators, the emission class and the land cover type are computed or already known. Each cell containing a measuring station is compared to all others. Only are kept those cells whose features are similar to those of the station; they are “virtual stations” for this measuring station and they are precisely localized in the city. The method uses spectral analysis tools, namely hashcoding tools (Albuisson 1995).

3. APPLICATION TO THE CITY OF STRASBOURG

3.1 Study area

The city of Strasbourg is located in Eastern France, separated from Germany by the Rhine river. Geographical coordinates are: 48.33° and 7.38°. Strasbourg is the permanent seat of the European Parliament. ASPA is the local agency in charge of the air quality measuring network in the city of Strasbourg and vicinity. Fig. 1 displays a map of the measuring network in the city of Strasbourg and vicinity. There are 12 stations, 5 of them measure (PM_{10}, $_{13}$, $_{2.5}$). There is no heavily polluting industries in this area and the local traffic of motor vehicles plays an important role. Wind is blowing mostly from North or South and does not bring significant pollution clouds from abroad (REKLIP 1995).

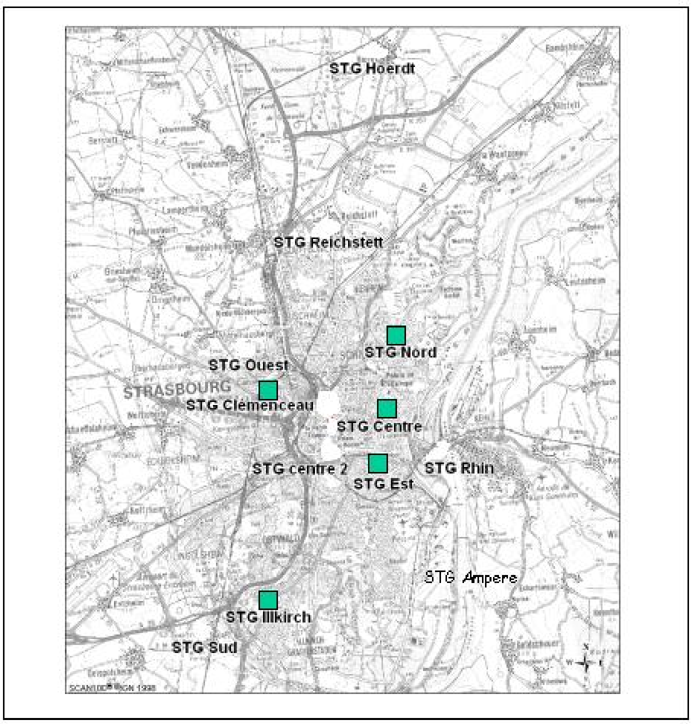

Figure 1. Stations of the air quality measuring network in the city of Strasbourg. Square denoted the stations measuring PM. The width of the map represents a distance of approximately 20 km.

3.2 Data used

The morphological indicators Miller and Gravelius were computed for the whole city of Strasbourg (fig. 2). They are computed from scripts of Arcview 3.2, Geographical Information System (GIS) software applying to a geographical database of the French Institute of Geography (BD TOPO®). The database is georeferenced and contains a 3D description of the city for buildings. Each building is described by a polygon and each polygon has attributes such as height (minimum, maximum, mean), area and perimeter… The computation provides two images of Strasbourg whose pixels contain the values of the Miller and Gravelius indicators. The computing time requested was very large (several days). All data used are input to a GIS. The size of the elementary cell is set to 10 m.

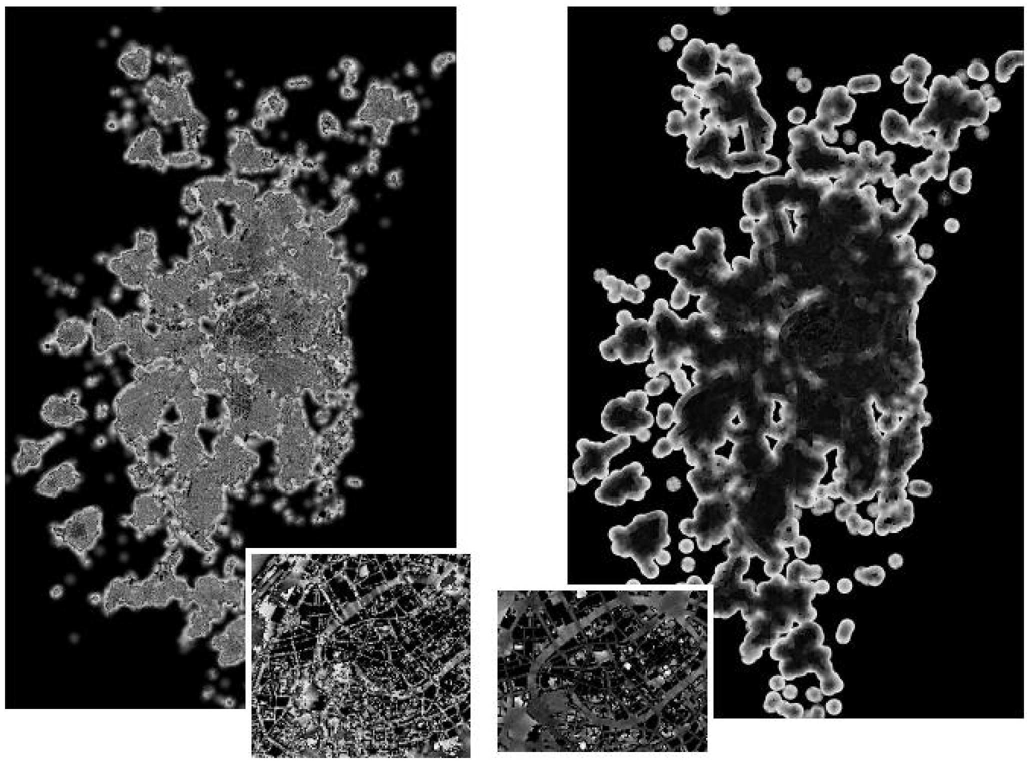

Figure 2. Images of Gravelius (left) and Miller (right) for the city of Strasbourg. Images at bottom, display zooms of the city center for each indicator.

The land cover map is a CORINE Land Cover (2000) with an initial resolution of 100 m. This map contains 44 different types of land cover. It was oversampled to a grid cell of 10 m using a nearest neighbor technique (Fig.3, left). The emission register is a map in a vector format, whose each polygon represents 1 km² area. The quantity of pollutants was recoded into a limited number of classes (10).The map was then oversampled to 10 m using a nearest neighbor technique. A polluting source has an influence over a surrounding area (Hewitt & Jackson 2003). A spatial filter of Gaussian type was applied to take such influence into account. The resulting image is no longer the emission register but more a map of annual background pollution (Fig. 3, right).

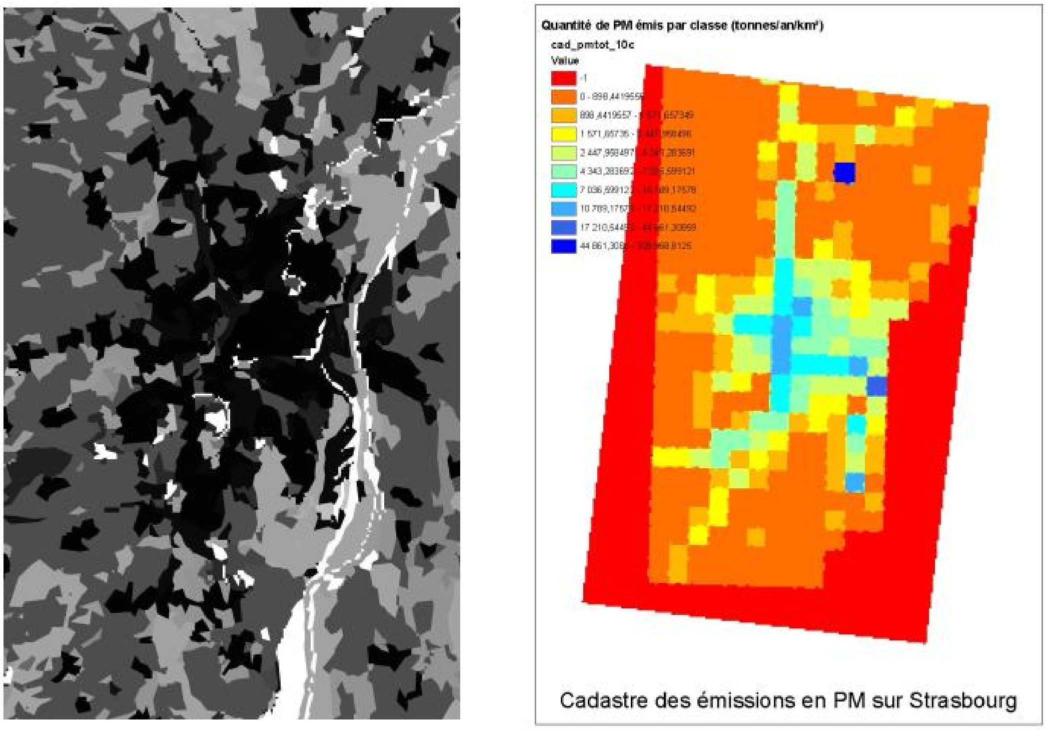

Figure 3. Images of the land cover map (left) and the emission register for PM for 2004 (right).

4. RESULTS AND DISCUSSION

Table 1 reports on the number of virtual stations found for each of the five stations measuring PM. These virtual stations are mapped in Fig. 4.

Table 1. Number of virtual stations for each real measuring station

Real station name	Number of virtual stations
STG Illkirch	361
STG Centre	727
STG Nord	710
STG Clemenceau	16
STG Est	11

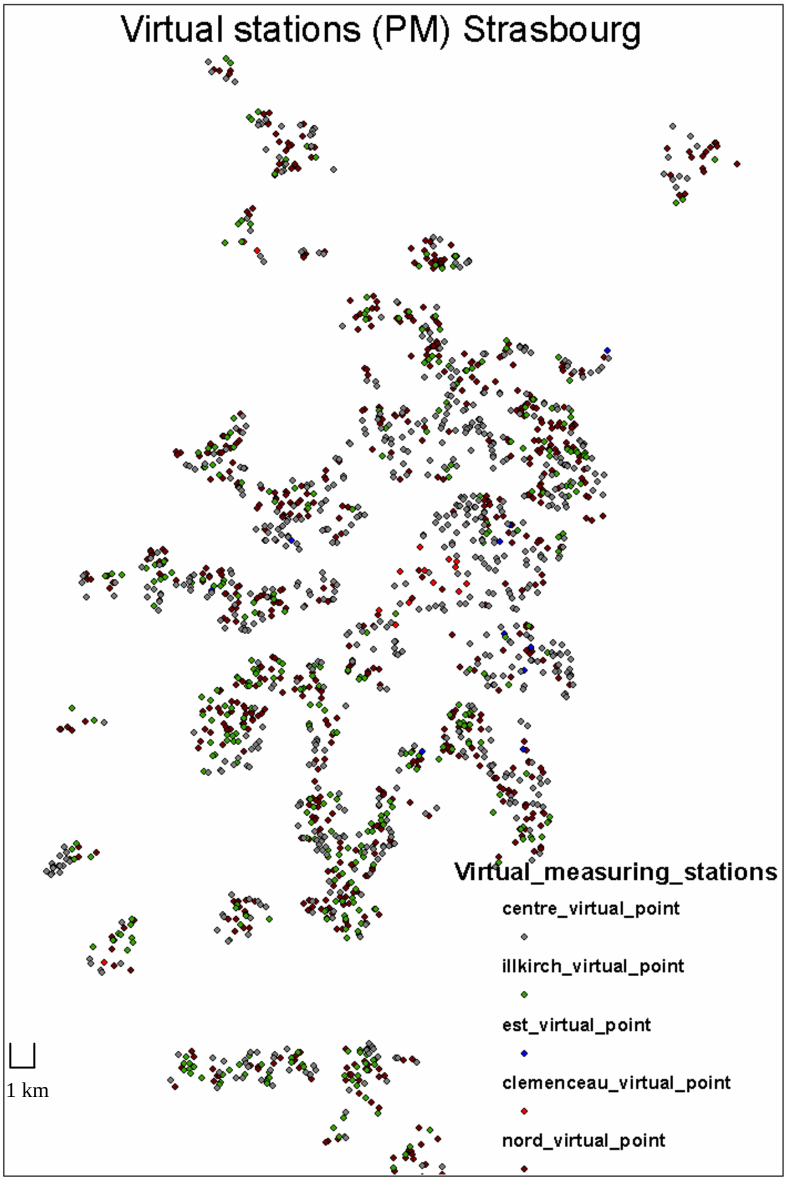

Figure 4. Localization of virtual stations for each real measuring station.

The total number of virtual stations is quite high: 1825. They are scattered all over the city, which is a real advantage for interpolation method. Compared to the initial 5 stations, one may easily understand the benefit of the virtual densification.

However, we are puzzled in this first application of the method by the very large number of virtual stations for the three first stations. It may mean that many places in the city have the same features than the measuring sites. Conversely, the number of virtual stations is quite low for STG Clemenceau and STG Est. It means that the discriminating elements are sufficiently discriminating in the last case and maybe not in the first one. A detailed analysis is underway to assess this hypothesis.

Mapping the PM concentration from this set of virtual stations has not been performed yet. However previous works in our laboratory (Ung *et al.* 2002), show the interest of virtual stations for mapping. The set of virtual stations they used was determined with a different method and different data sets: from satellite images, but the idea is similar. Figure 5 (left) shows a PM_{10} concentration map. It is obtained by the "thin plates spline" method from three actual measuring stations (black dots). The area is approximately 26 x 34 km² with a spatial resolution of 30 m. A map of Strasbourg was laid in the background for better readability.

The low number of measuring points yields to a very uniform pollution map, which does not represent the reality. Figure 5 (right) is a pollution map obtained thanks to virtual stations for the same date. 301 virtual stations were found. Compared to the figure on the left, the map based on virtual stations shows a more realistic pollution distribution. This map has not been fully validated though a measuring campaign in June 2003 indicates that several virtual stations spotted by Ung *et al.* (2002) were actually behaving like the real stations as expected (Ung 2003; Puissant 2003). In a similar approach, in a study on the city of Nantes (France), Basly (2000) found that using virtual stations for the mapping improved result quality. The root mean square error (RMSE) decreased from 80 % (for a map interpolated without virtual stations) to 50 % (for a map interpolated with virtual stations), for the case of black smokes.
2

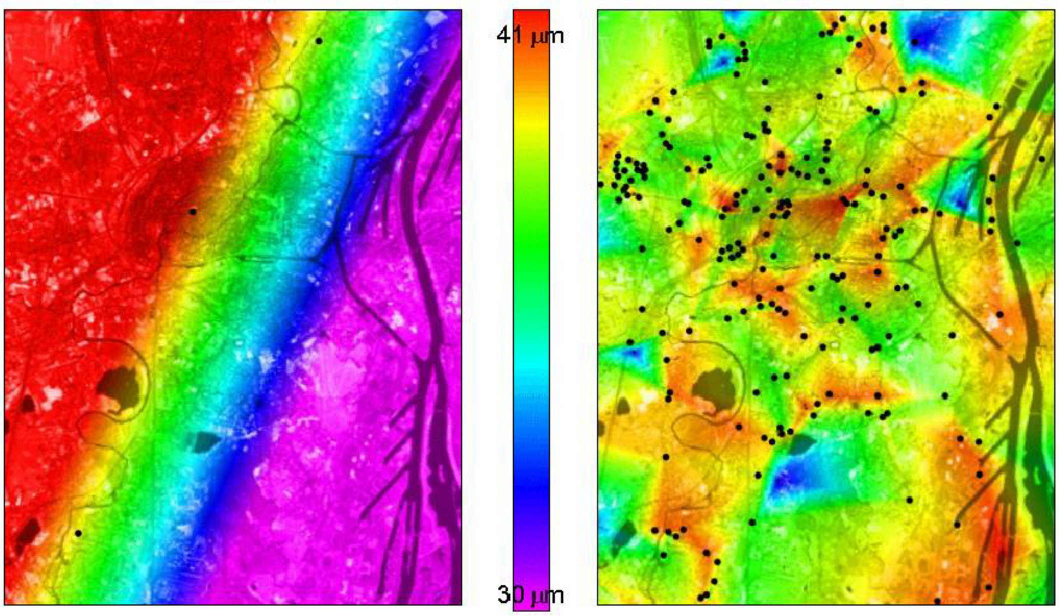

Figure 5. PM_{10} concentration maps over Strasbourg obtained by interpolation of real measuring stations only (left) and of both real and virtual measuring stations (right).

3. CONCLUSION

In this paper, we present a method to make denser the pollution measuring network and thus to increase the concentration measurements in order to improve the pollution mapping by interpolation. Making denser consists in virtually adding new measuring stations. "Virtual stations" are places of a city exhibiting features similar to those of measuring stations. Features are linked to pollution sources (emission register) and aerodynamical properties of the considered place (morphological indicators, land cover). The first implementation of the method was done for particulates (PM) and for the case study of the city of Strasbourg.

From the 5 PM measuring stations initially, we obtained 1825 virtual stations homogeneously spread over the area. Among the virtual stations, several of them are likely to be wrong because the selected features are not discriminating enough. Our further work will consist in finding additional features to improve the determination of virtual stations. It will also consist in validating the virtual stations obtained and then in interpolating estimations to obtain a particulates pollution map.

Technically, the method is easily feasible by practitioners since it involves well-known tools and it uses data they already have. It is promising to map pollution with high accuracy and thus to represent the pollution distribution variability.

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QA/QC PROGRAMME ON AIR QUALITY MONITORING IN THE WHO EUROPEAN REGION (1994 – 2004)

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ABSTRACT

Since early 90ies the WHO Collaborating Centre operates a QA/QC programme on air quality monitoring in the WHO European Region. As main activity between 1994 and 2004 Intercomparison workshops have been carried out for air monitoring network laboratories on a regular basis to harmonise air quality measurements, analysis and calibration techniques. 36 air hygiene laboratories of public health and environmental institutions of 24 countries participated in twelve workshops. The majority of Intercomparisons were carried out for NO, NO_2, SO_2 and O_3. They produced predominantly satisfactory results for automatic methods. Manual methods were mainly in a good, and for several concentration levels partly very good accordance with the data obtained by monitors.

Key Words: Air Monitoring, Quality Assurance and Control, Intercomparison Measurements, Calibrations

1. INTRODUCTION

Already in the 70ies UNEP and WHO established a global programme on air quality monitoring (GEMS-Air) to assist countries in monitoring air pollution to improve the utilization of data for health risk assessment and to promote the exchange of information. In 1990, the WHO European Centre for Environment and Health (WHO/ECEH: until 2000 located in Bilthoven/NL, since 2001 in Bonn/D) was established besides to take over the responsibility for the programme ‘Air Quality and Health (AIQ)’ for the WHO European Region. Part of AIQ is the evaluation of air quality which is important for assessing the nature of population exposure to air pollution. Reliable data are indispensable for any further assessments of air pollution impacts on human health or measures. But problems in the comparability of air quality data have been identified within Europe. Therefore, WHO/Euro recommended quality assurance and control (QA/QC) activities to harmonise air quality measurements and data. Along this the WHO Collaborating Centre for Air Quality Management and Air Pollution Control (WHO/CC, Berlin) at the German Federal Environmental Agency (UBA) supports the efforts of harmonising air pollution measurements to improve comparability and applicability of data, e.g. for an international health impact assessment and in an environment and health information system. In 1994, WHO/CC started the international QA/QC programme 'European Intercomparison Workshop on Air Quality Monitoring' for air monitoring networks of the 52 WHO European Member States to harmonise air quality measurements, analysis and calibration techniques.

The main objective of this programme is to serve as a platform supporting especially laboratories responsible for QA/QC in air monitoring networks, either at the national, regional, or local level, which are not routinely involved in international QA/QC programmes. The workshop offers a sound opportunity to compare the operation and quality of ambient air measurements of continuous and discontinuous methods to be carried out with automated, semi-automated, and/or manual devices (monitors vs. sampling and analysis), to check calibration procedures and standards, and to share acquired experiences and know-how amongst the experts. Test gases (dry and without interfering substances) of inorganic and organic pollutants are generated continuously for different concentration levels during a one week workshop training campaign. The Intercomparison measurements are carried out at a central laboratory facility (sample air manifold at the German reference laboratory for air quality) to determine and evaluate the quality of the measured concentration values. Each participating laboratory has to apply their own complete equiment to measure and to achieve in situ calibration of its analysing method(s) using the national calibration method (reference or transfer standard). Laboratories participate on a voluntary basis. The technical description of the sample air manifold, generation of test gases, calibration procedures, and individual results of all Intercomparison measurements have been published in detail in the WHO/CC series ‘Air Hygiene Report’ (Mücke et al., 1995, 1996, 1999, 2000, 2003).

2. OVERVIEW

Between July 1994 and April 2004 the WHO/CC conducted twelve Intercomparison workshops for inorganic and organic pollutants (oxides of nitrogen, sulphur dioxide, carbon monoxide, ozone, and benzene, toluene, xylene). In total 36 air hygiene laboratories of public health (n=15; 11 national, 3 regional and 1 local) and environmental (n=21; 17 national, 2 regional and 2 local) institutions of 24 countries of the WHO European Region participated (Table 1).

Table 1. Participating laboratories (1994-2004)

Laboratories (n = 36)	Participations (n = 97) n
AEA Technology, National Environmental Technology Centre, Culham/UK	3
Brussels Institute for Management of the Environment, Brussels/B	2
City Centre of Sanitary and Epidemiological Surveillance, Moscow/RF	1
Czech Hydrometeorological Institute, Prague/CZ	3
Environmental Monitoring Centre, Yerevan/AR	1
Environmental Protection Ministry, Joint Reserach Centre, Vilnius/LT	4
Estonian Environmental Research Centre, Tallinn/EST	3
Federal Environmental Agency, Vienna/A	1
Federal Environmental Agency - UBA Pilotstation, Langen/D	10
Federal Environmental Agency - UBA Branch Schauinsland, Kirchzarten/D	4
Hydromet. Institute / Environ. Agency of Slovenia, Ljubljana/SI	6
Institute of Hygiene and Medical Ecology, Kiev/UA	1

Institute of Hydrometeorology, Tirana/AL	3
Institute of Medical Research and Occupational Medicine, Zagreb/HR	5
Institute of Public Health, Rijeka/HR	1
Institute of Public Health, Belgrade/SCG	4
Institute of Public Health, Bucharest/RO	2
Interregional Cell for the Environment, Brussels/B	1
Latvian Hydrometeorological Agency, Riga/LT	1
Main Administration of Hydrometeorology of Uzbekistan, Tashkent/UZ	4
Main Geophysical Observatory, St. Petersburg/RF	4
Ministry of Environment and Nature Resources Protection, Tblissi/GE	1
National Centre of Hygiene, Medical Ecology and Nutrition, Sofia/BG	7
National Environmental Health Centre, Riga/LV	1
National Institute of Hygiene, Budapest/H	5
National Institute of Public Health, Prague/CZ	7
Norwegian Institute for Air Research, Kjeller/N	2
Occupational Medicine Centre - Institute of Hygiene, Vilnius/LT	1
Research Institute of Hygiene and Epidemiology, Tirana/AL	1
Stadtwerke, Düsseldorf/D	1
State Committee of Sanitary and Epidemiological Surveillance, Moscow/RF	1
State Environmental Agency of North Rhine-Westphalia, Essen/D	2
Swiss Federal Laboratory for Material Testing and Research, Dübendorf/CH	1
Wojewodzka Stacja Sanitarno Epidemiologiczna, Katowice/PL	1
Wojewòdzka Stacja Sanitarno Epidemiologiczna, Warsaw/PL	1
YTV Helsinki Metropolitan Area Council, Helsinki/FIN	1

Besides in the 90ies the European Commission's Joint Research Centre, Institute for Environment and Sustainability, European Reference Laboratory of Air Pollution (JRC/IES/ERLAP) in Ispra/I, was nominated as responsible institution in the European Union in order to fulfill the QA/QC requirements within the implementation of the EC air quality directives. The basis for the organisation of Intercomparisons is laid down in Council Directive 96/62/EC, the so-called 'Framework Directive'. National Air Quality Reference Laboratories, representing the EU Member States, are required to participate in these harmonisation activities (Borowiak et al, 2000; http://ies.jrc.cec.eu.int/Units/eh/Projects/Aquila/). This results in an inhomogeneous distribution of laboratories from Western Europe (WE) participating between 1994 and 2004 in the WHO/CC Intercomparisons, while for laboratories from Central and Eastern Europe (CCEE) and Newly Independent States (NIS) the workshops are continuousely on high demand, as Figure 1 shows.

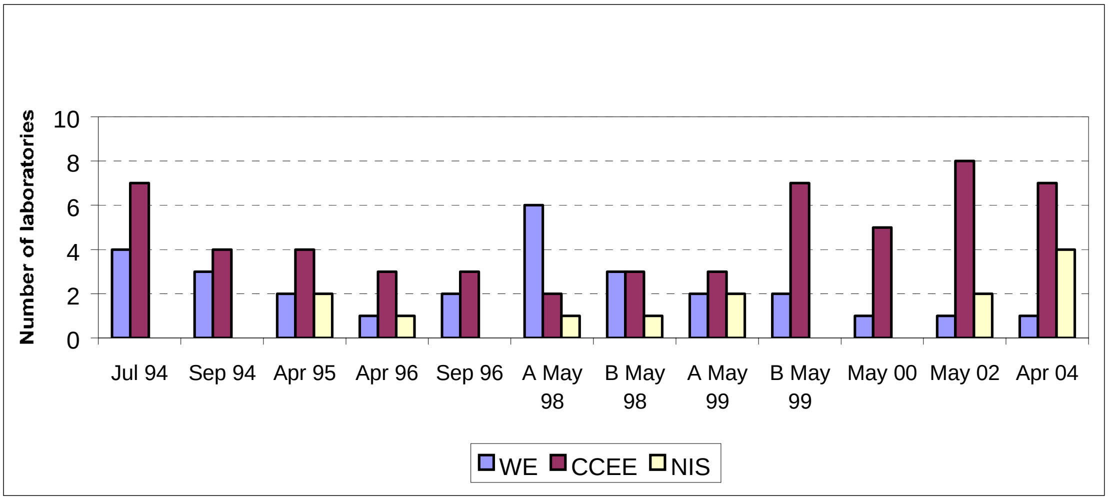

Figure 1. Number and geographical origin of participating laboratories (1994-2004)

3. RESULTS

Between 1994 and 2004 the combination of test gas components to be measured and compared varied slightly. With regard to European air quality regulations Intercomparisons of the inorganic gases NO, NO_2, SO_2 and O_3 were most relevant. Test gases for NO, NO_2 had been offered during eleven, for SO_2 and O_3 in seven workshops. Up to five concentration levels between 20 to 750 ppb for NO, 10 to 250 ppb for NO_2, 5 to 200 ppb for SO_2, and 20 to 220 ppb for O_3 had to be measured. Each concentration was generated for 1.5 hours. The laboratories were requested to report 0.5 hour mean values. Figure 2 depicts the number and proportion of all 0.5 hour mean values determined by manual (sampling and analysis) and automatic (monitors) methods during daytime measurements.

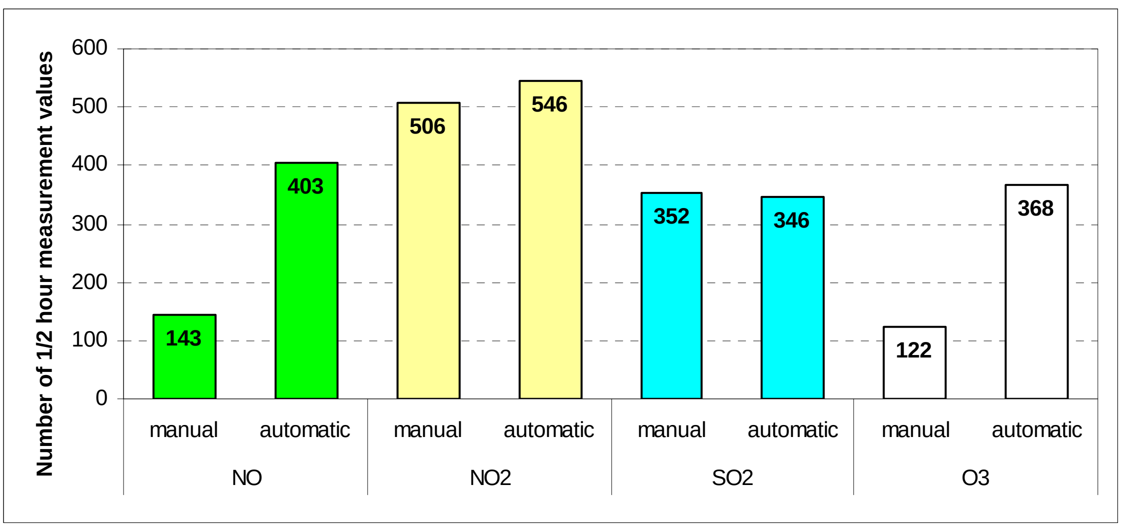

Figure 2.Number and proportion of manual and automatic measurements (1994–2004)

To ensure better and more comparable air quality data across the EU data quality objectives and compilation of results of air quality assessment for NO, NO_2 and SO_2 are set in the European Commission's Council Directive 1999/30/EC, and for O_3 in the Directive 2002/3/EC, the so-called 1st and 3rd 'Daughter Directives' on air quality. As defined, the required accuracy of 15% for continuous (automatic) NO, NO_2, SO_2 and O_3 measurements should be interpreted as being applicable in the region of the appropriate limit value.

During the Intercomparisons volume to volume ratios of test gases were generated by the UBA Pilotstation laboratory. In order to give a point of reference the results of UBA monitors were defined, accepted and used as target values, which is considered to be the most accurate mean for comparison purposes. UBA monitor values are not included in this interpretation. The evaluation of accuracy and uncertainty of the Intercomparisons are not in line with the ISO Guidelines of the 'Daughter Directives', due discontinuous (manual) methods have been applied. Intercomparisons record a momentary measuring situation under laboratory conditions only. Sources of uncertainty during sampling on site could not be considered. Therefore, two tolerance margins (+/-10% from the target value, and a more strict one of +/-5%) were set as a dimension for the interpretation and evaluation of the Intercomparison results. Figure 3 shows the percentage of the beforementioned NO, NO_2, SO_2 and O_3 0.5 hour mean measurement (automatic and manual) values within these margins of tolerance.

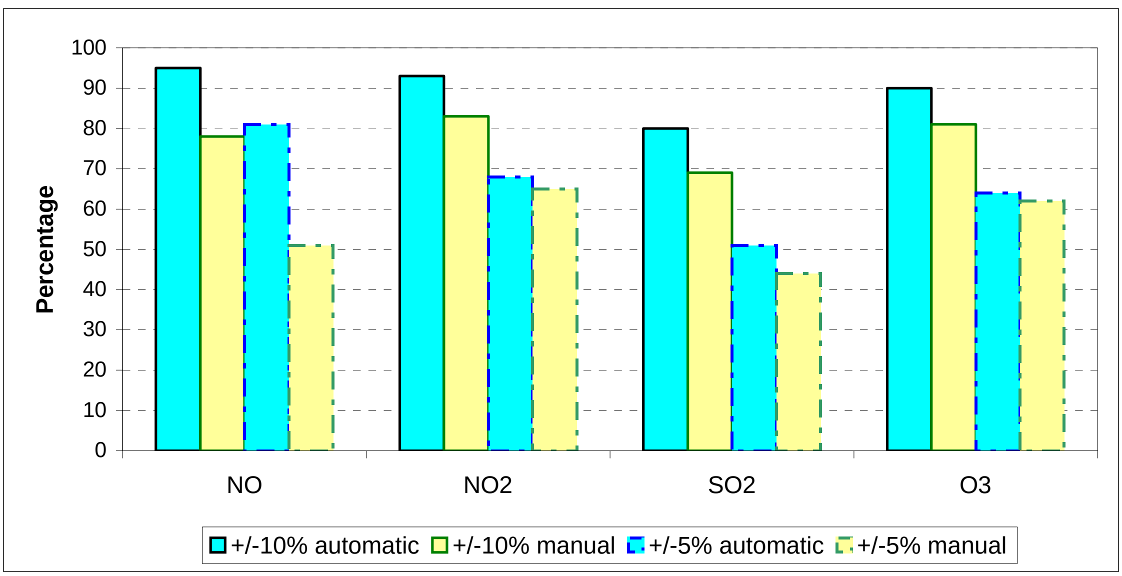

Figure 3. Percentage of manual and automatic daytime measurements within the tolerance margins of +/-10% and +/-5% (1994-2004)

Within the tolerance of +/-10% the values measured by automatic monitors provided satisfactory results agreeing on a high percentage rate with the target value. On average they are about 10% higher than those of manual methods, which is a sound result for discontinuous measurements, too. Regarding the tolerance of +/-5% the results of both methods vary considerably on a lower level, slightly better for automatic ones and with a minor distinction between the methods (except for NO). Both measurement methods show for both levels of accuracy nearly the same proportion for all components, which means about ¾ of values within a tolerance of +/-10% reaching also the margin of +/-5%.

Compared to NO, NO_2 and O_3 surprinsingly the results for SO_2 are not as good for both methods, although SO_2 has been measured for many years and the laboratories are well experienced. Particularely, the Intercomparisons showing problems with the detection of very low SO_2 concentrations (< 10 ppb).

4. CONCLUSIONS

The Intercomparison measurements produced predominantly satisfactory results for automatic methods within a tolerance margin of +/-10% from the target value. Manual methods (still operated in Eastern Europe countries, Caucasus and Central Asia / EECCA) were mainly in a good, and, for several concentration levels partly very good accordance with the data obtained by monitors. Intercomparisons record a momentary measuring situation under laboratory conditions only. More uncertainty sources occur probably under routine monitoring conditions, such as ambient air impact, sampling, drift and maintenance. In some countries calibration standards for automatic devices do not exist. Hence, such monitors had to be calibrated with the standard of the UBA Pilotstation.

The QA/QC programme ‘Intercomparison workshops’ of WHO/CC are to be seen as an important step to provide reliable data measured by automated and manual methods. Such training courses provide an excellent opportunity for laboratory experts to meet and to exchange technical information and experiences. Improvements in the quality of measurements have been identified for laboratories participating more frequently, in particular those from EECCA who switched from manual to automatic methods. Nevertheless, there is an urgent necessity to continue this QA/QC programme in the future in order to check and stabilise the level reached and stress the importance of intensifying the integration process of those countries not yet belonging to EU. The experiences gained during the Intercomparisons should also be disseminated through the participating laboratories to other centres or networks in the Member States.

Recently the WHO Regional Office for Europe and the European Commission strengthened their intention to intensify the cooperation in the broad field of environment and health. Because of the increasing number of EU Member States, which are Member States of the WHO European Region too, ERLAP and WHO/CC are preparing to harmonise their QA/QC activities on air quality for the near future, e.g. planning of joint Intercomparisons.

5. ACKNOWLEDGEMENT

The WHO/CC would like to express their gratitude to the team of German reference laboratory for air quality at the UBA Pilotstation, Federal Environmental Agency, in Langen/D, for their assistance, hospitality and care during the Intercomparison workshops. The QA/QC programme was granted by the German Ministry of Environment, Nature Conservation and Nuclear Safety, Berlin/Bonn, which is gratefully acknowledged.

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AN INTEGRATED STRATEGY FOR URBAN AIR QUALITY MANAGEMENT IN INDIA

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ABSTRACT

An integrated strategy for air quality management (AQM) links anthropogenic emissions and dispersion factors that influence local air quality and consequent impacts are internalized through polluter-pays principle. In India, systemic and resource constraints prevent this comprehensive assessment. The paper addresses this gap through energy-environment modeling and city-studies. Insights are: a) linking development with environment protection, and greenhouse gas mitigation with local AQM, generates co-benefits; b) long-term modeling for local-level policy analysis prevents resource lock-ins; c) purely technological solutions are not suitable and a mix of instruments could achieve technology-equivalent benefits at lower costs; d) a coordinating authority will reduce institutional failures in policy formulation and implementation.

Key Words: Environmentally Sustainable Development; Technology-Push; Emissions Trading; Technology-Equivalent Policy; Institutional Failures

1. INTRODUCTION

Integrated framework for policy assessment and implementation

An integrated approach in policy assessment addresses the issue of air quality management (AQM) in a comprehensive manner. This approach results in effective pollution management, with optimal utilization of resources while minimizing the social costs as well as the transaction costs.

An integrated approach links human activities (that generate emissions), atmospheric conditions such as topographical, meteorological and atmospheric chemistry (that influence dispersion of pollutants in ambient air), air quality (area-specific concentration of pollutants) and impacts (on human health, ecosystems, assets and agriculture). The costs of impacts and adaptation are internalized in the human activities through polluter-pays principle, so that polluters pay for the damages caused and revenues are used to compensate those who bear the impacts. This process of internalization of externalities minimizes the social costs. Figure 1 presents a framework for developing an urban AQM strategy; the policies and measures should be context-specific.

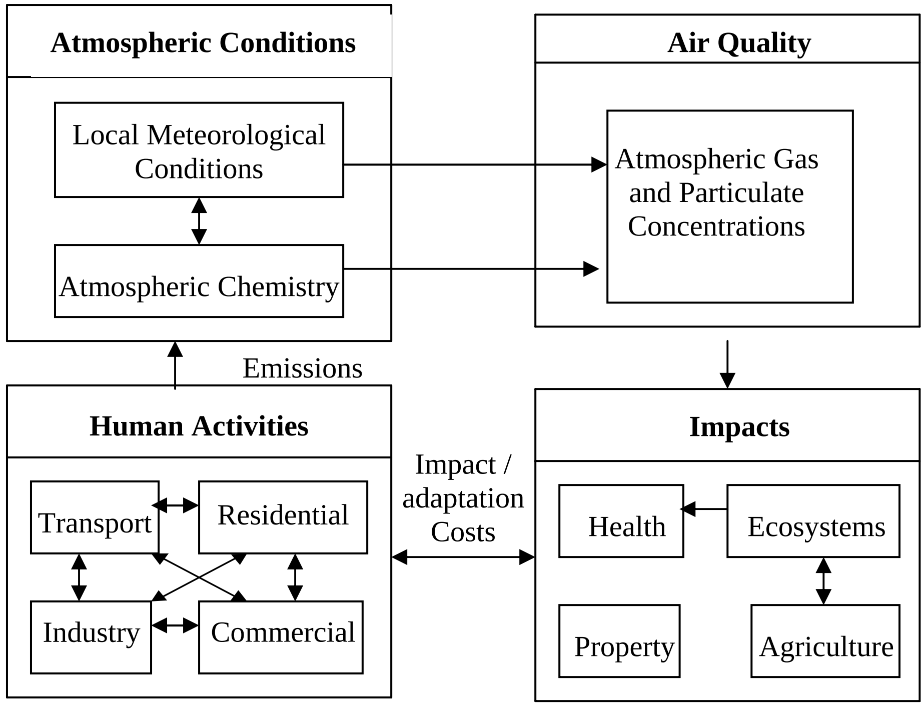

Figure 1. An Integrated Air Quality Policy Assessment Framework

Implementing this framework requires integration at different levels (Table 1).

Table 1. Types of integration

Types	Description	Objective
Spatial	National-level policies are complemented with more stringent local-level policies	Problems are often context-specific; therefore, generic solutions could lead to implementation failures
Sector	Addressing all emission sources	To minimize social costs
Temporal	Need to develop interfaces between short-term, medium-term and long-term policies	Prevents lock-in of resources; Conjoint policies for greenhouse gas (GHG) and AQM has co-benefits
Policy Instruments	A mix of instruments ranging from command-and-control (CAC) to market-based (MBIs)	Effectiveness of a instrument varies with the source, existing institutions, and specificities of the problem
Costs and Benefits	Policies based on the costs and resultant benefits	Understanding the trade-offs of different policy interventions
Policy formulation and implementation	Integrating policies, models, instruments and institutions	Inter-linked in their role in AQM
Media	Regulating the total environment instead of compartmentalizing it by air, water, and land	Fragmentation by media may not achieve effective pollution control; synergies in a single media approach
Sustainable development	Addressing environment and development simultaneously	Minimizes tradeoffs of development and generates co-benefits

Moreover, to prepare a socially optimal and implementable timetable, an integrated assessment of future costs and benefits of emissions mitigation measures, adaptation measures and impacts is required. Such a comprehensive policy analysis requires knowledge from diverse disciplines such as engineering, atmospheric sciences, health, ecology, sociology and economics. It also requires a complete understanding of transaction costs of different processes and the institutions that would minimize these costs. Thus, inter-disciplinary knowledge is required in assessment and implementation.

2. EXISTING APPROACH FOR AQM IN INDIA

In India, economic growth, expanding industrialisation, urbanization, increasing incomes, rapidly rising transport and modernising agriculture, especially in 1990s, has led to rapid growth of energy use and consequent increase in air pollution. Currently, air pollution is widespread in Indian cities where vehicles are major contributors, and in other urban centers with high concentration of industries and thermal power plants (MoEF 2001).

However, economic growth is not only a cause for air pollution; it also provides a solution for improved air quality as is brought out by environmental Kuznets' curve (Kuznets 1955; Grossman and Krueger, 1991). As the economy grows and income levels rise, there are more resources to invest in cleaner technologies and processes and also greater demand for a cleaner environment. This pattern is reflected in India, where since 1990s, urban AQM is the focus of public policymaking. There exists several laws for control and abatement of air pollution; in addition, there are targeted policy interventions (Mashelkar et al., 2002; CPCB, 2003). Implementation mechanisms, in terms of human, resources, are also developing. Public awareness and judicial activism has also grown during this period. As a result, the gap between India and developed countries in the introduction of emission control measures has reduced in many cases even though developed countries faced and addressed the problem as early as 1960s (Menon 2004).

Currently, policies focus on managing emissions and not on the air quality issue as shown in Figure 1. An important reason for this focus is that urban air pollution is relatively new in the hierarchy of environmental problems in India; therefore, systems are gradually developing and resource constraints, in terms of technical, financial and human resources still have to be overcome. Besides, the presence of a multitude of institutions (ministries of central and state government, state departments, municipalities and local authorities, judiciary, environmental NGOs and other stakeholders) with multiple objectives creates co-ordination problems and high transaction costs in policy formulation and implementation. Also, while judicial activism has positive impacts on local air quality, continuous court interventions impede the development of organizations responsible for AQM. These factors often cause institutional failures.

Moreover, given that integration is required at multiple levels, it further adds to the complexities of developing an overall integrated framework of policy assessment. Table 2 highlights the present levels of integration in the Indian AQM strategy.

Table 2. Level of integration in the AQM strategy in India

Types	Existing status
Spatial	Emphasis on national level policies; Few cases of area-specific interventions such as Taj Trapezium Zone in Agra
Sector	Policy focus is on transport sector, with sporadic cases of interventions for industrial and residential sources
Temporal	Emphasis is on short-term policies; Some recent initiatives have been taken, like the roadmap of Euro emission norms proposed for vehicles in cities till 2010;
Policy Instruments	Emphasis is on CAC, primarily emission standards; MBIs not considered in action plans; complementary measures (e.g. traffic management measures) not integrated in the AQM process
Costs and Benefits	Action plans not based on cost-benefit studies; some cases of cost-effective analysis
Policy formulation and implementation	Emphasis is on long-term modeling for national policy analysis and city-level analysis; Weak co-ordination between institutions
Media (air, water, land)	Single media approach not widely considered currently
Environmentally sustainable development	Currently, development path often creates trade- offs with environment since policies address both in a segregated manner

Implications

The existing approach is more curative, than preventive. Policies have often been framed after public interest litigations were filed in the Supreme Court of India, as in the case of Delhi and the Taj Trapezium zone, Agra. Subsequent Court directives resulted in policy implementation. Policies formulated in such circumstances often do not go for feasibility studies. For instance, during formulation of CNG policy in Delhi, issues such as price and future costs of CNG were not addressed and the CNG policy was not linked with health aspects (Environment Pollution Authority for the National Capital Region, 2001).

Also, emphasis on technology-push instruments could lead to higher costs and often not achieve desired results. For instance, there is diminishing marginal benefits, in terms of health costs savings, from advanced Euro emission norms for vehicles (Figure 2).

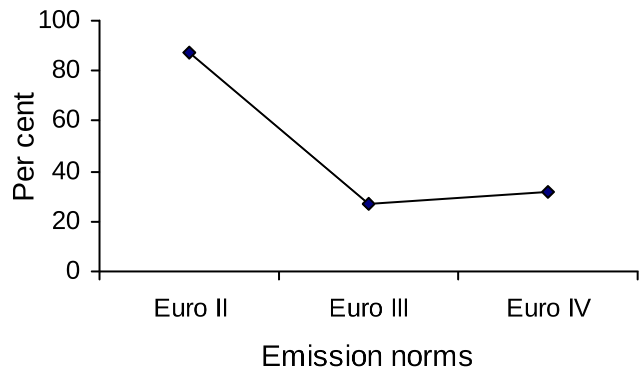

Figure 2. Diminishing marginal benefits of Euro norms in Delhi (% health cost savings)

Short-term policies may lead to resource lock-ins and path dependencies of environmentally harmful policy choices. AQM involves systems such as infrastructure and energy systems that have high inertia for change; thus using long-term models is necessary to generate scenarios of alternate policies that would guide decision-making.

Also, weak coordination between institutions leads to implementation failures, as was seen during CNG policy implementation in Delhi. There were institutional failures due to the opportunistic behavior shown by stakeholders and it led to high transaction costs.

3. DEVELOPING AN INTEGRATED STRATEGY FOR AQM IN INDIA

The paper presents a hierarchical approach for developing integration in AQM in India. To begin with, developmental policies are integrated with environment protection. The next step involves developing conjoint policies for GHG and local pollutant mitigation and ultimately policies and instruments are developed for managing local emissions.

Integrating Development with Air Quality Management

Air quality deterioration is embedded in the development process. Therefore, national level development policies have to be integrated with local policies. Besides, it is also crucial to link urban developmental policies with AQM because urban centers are the focus of developmental policies and enhancing their productivity is central to policies of the Ministry of Urban Development and Poverty Alleviation (http://urbanindia.nic.in).

Policies giving priority to economic growth while moving towards the frontier may not complement environmental goals (Figure 3). There is higher movement along y-axis irrespective of air quality impacts (x-axis); thus, targeted policies are required for AQM. Instead, in a development path where investment flows also adopt environment-friendly technologies, tradeoffs are minimized. Further movement towards a new environment-friendly frontier is brought through innovations and technological leapfrogging.

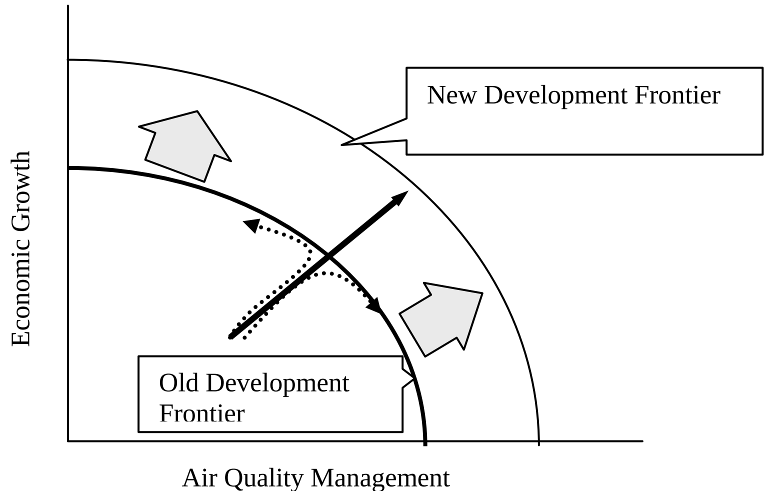

Figure 3. Promoting policies for environmentally-sustainable development

In this context, technology transfers from developed countries (encompassing flow of finance, technology, knowledge and experience) are significant. The development and commercialization of environmentally-sound technologies require huge expenditures, which is possible in these countries due to high government spending on such activities. In India, scarce resources and alternate needs creates constraints in making such investments. Also, there is intense and often contradictory dynamics of development processes. In this atmosphere of uncertainties and tradeoffs, there is a high possibility of adverse selection of policies to minimize risks rather than ensure sustainability.

Conjoint Policies for Local AQM and GHG mitigation

The paper considers the dynamics of policies for SO_2 (local pollutant) and CO_2 (GHG) mitigation since they are often emitted together. The optimum mitigation response actions in separate SO_2 and CO_2 markets are very different in India. Mitigation of local pollution, since its benefits accrue to local constituents, enters the national agenda prior to CO_2 mitigation where the very low per capita emissions [0.98 t-CO_2 as compared to global average of 3.93 t-CO_2 in 2002 (EIA 2004)] provides the moral and practical reasons for delayed national actions in absence of a facilitating global regime. However, a conjoint SO_2 and CO_2 market strategy could provide synergies to align and optimize the actions. We study 82 coal-based power plants that contributed to 50% of CO_2 and 54% of SO_2 emissions in 2000 at all-India level (Menon-Choudhary et al., 2005). Using a long-term, energy-environment optimization model, Asia-Pacific Integrated/Local Model (AIM/Local), we analyze implications of alternate mitigation strategies for SO_2 and CO_2 mitigation. Table 3 presents the co-benefits of a conjoint market.

Table 3. Mitigation strategies for SO_2 and GHG mitigation

Mitigation Regime (from 2005-30)	**Mitigation Cost (2005-30)**	**Direct Benefits (2005-30)**	**Co-benefits (2005-30)**
SO_2 mitigation alone [via technology-push policies in business-as-usual scenario (BAU)	$5.5 billion	-	Little carbon mitigation benefit
SO_2 mitigation alone (with SO_2 Cap and Trade regime for the BAU trajectory)	$3.1 billion	$2.4 billion saving compared to BAU policies	Marginal carbon mitigation benefit
CO_2 mitigation at $5 per ton price	$7.9 billion	$17 billion carbon revenue	Concurrent reduction in SO_2 saves $1.2 billion for SO_2 mitigation in BAU
Conjoint Mitigation: CO_2 mitigation @ $5 per ton and SO_2 Cap and Trade for BAU trajectory	$10.6 billion	$19.6 billion carbon revenue	Cost of conjoint market operations are lower by $0.4 billion

Policies and Instruments for Managing Local Air Quality

The current focus of policies on one sector (transport) or specifying a technology (e.g. CNG in Delhi) reduces sectoral and technical flexibility, respectively, and does not minimize social costs. Therefore, greater emphasis should be placed on industrial and residential sector emissions that can be reduced by inexpensive means, rather than concentrating only on reducing transport sector emissions by expensive means. Once policies are framed, they are to be implemented using tools ranging from CAC instruments to MBIs. Currently, policymakers in India lay emphasis on using technology-based CAC instruments (Dutta et al., 2004). However, the suitability and mitigation flexibility of an instrument varies across sources; thus, it is necessary to look at a mix of instruments, rather than a single instrument for all sources.

We compare alternate instruments for managing source-wise emissions. The paper analyses two instruments, technology-push (where regulations specify the technology) vis-à-vis an emissions trading instrument for SO_2 mitigation from power plants. Both these instruments follow the same trajectory as the BAU (Table 3). This implies that there are equivalent impacts in terms of emissions reduction; therefore, cost implications are studied. Modeling results show that the cost of an emissions cap-and trade system is 44% lower than technology-push instrument for equivalent reductions. This implies an average annual cost-saving of US$ 96 million. We further estimate the cost differences of some of the abatement technology choices under alternate scenarios (Table 4).

Table 4. Costs of mitigation options during 2005-2030 using alternate instruments (US$ billion)

Mitigation measure	Technology-push	Emissions trading
Coal washing	1.3	0.7
Efficiency improvements	0.6	1.0
FGD	3.6	1.4

Similarly, for vehicular emissions too, a technology-equivalent instrument should be considered, where the objective is to achieve the benefits of the technology itself, but at lower costs. Currently, Euro emission norms are being implemented; however, as seen in Figure 2, there is diminishing marginal benefits, in terms of health cost savings, from advanced Euro norms. This is because the health costs savings accrue only when complementary measures required to achieve the benefits of advanced technology exists. For instance, one of the requirements is that all vehicles with pre-Euro specifications have to be phased out. But, in Delhi, there is a low turnover of fleet, and older highly polluting vehicles co-exist with new, efficient ones. Besides, lack of traffic management measures such as synchronized signaling, segregated lanes for non-motorized transport etc reduce the efficiency levels of all vehicles, including those with advanced technology.

We consider a Euro IV equivalent policy; where instead of using the technical requirements of a Euro IV vehicle, the technology of a Euro III vehicle stays, and the consumers are charged an incremental amount (equal to a Euro IV compliant vehicle). This additional amount should be directed to develop the complementary infrastructure that is necessary to achieve the benefits of a Euro IV technology (such as improving infrastructure, traffic management measures, phasing out pre-Euro vehicles through giving financial incentives etc). Once the complementary measures are in place, then policies could leapfrog to more advanced emission norms.

However, developing technology-equivalent policies requires detailed cost-benefit studies to estimate the overall implications of technology policy and equivalent policy. This would include issues such as transaction costs, monitoring and enforcement costs and risks in implementing technology-equivalent policies. Technology-push instruments are usually preferred for their relative ease in implementation, but as seen in the case of power plants they result in higher compliance costs. Thus, policymakers have to evaluate all factors before arriving at a socially optimal decision.

Methodologies and Institutional Requirements for Integrated Assessment

Methodologies and models

An integrated assessment of the policies for AQM requires support from different methodologies and models. Models would help in evaluating different options based on an understanding of the dynamics, and generate scenarios that would guide the policymakers today in making decisions for the long-term (Figure 4).

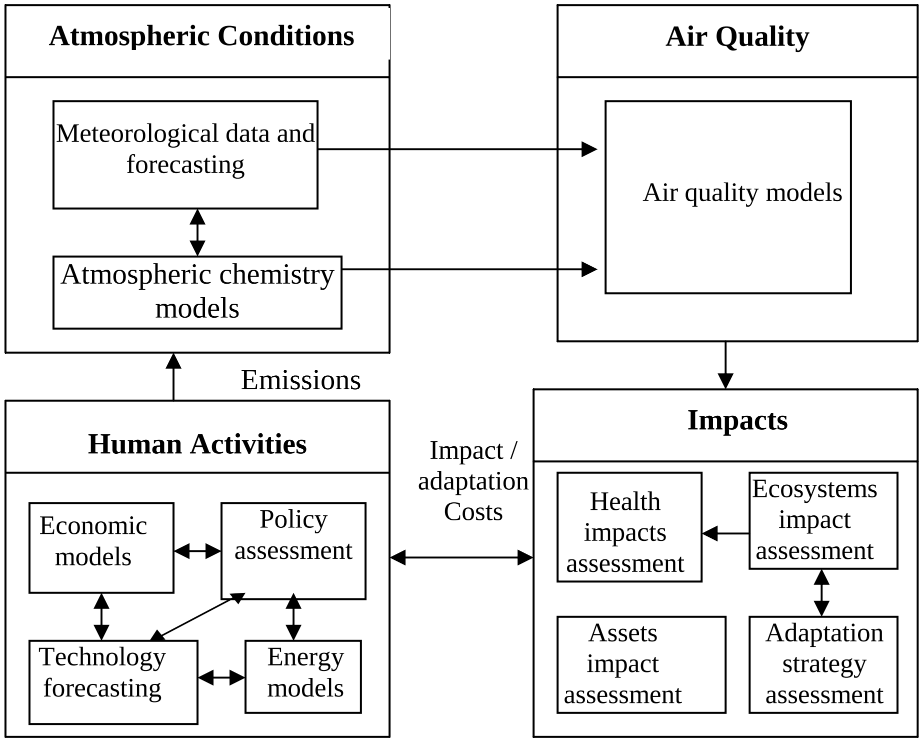

Figure 4. Models and Methods for Integrated Air Quality Policy Assessment

The modeling exercises and impact assessment studies are crucial for understanding the costs and benefits of proposed policies. Inputs for analyzing these issues are required from varied disciplines including engineering, atmospheric sciences, health, ecology, sociology and economics to address the different aspects of the problem. Currently, there are considerable gaps existing in data and information requirements for such a comprehensive assessment in India. Although there are excellent institutions having significant modeling and assessment knowledge in own disciplines, little experience exists on comprehensive modeling that links scientific and technological assessments with socio-economic assessments that is so essential for effective policy making, especially at local level. Therefore, to begin with, there is a need for greater data collection and dissemination in cities, since most of the data required for detailed analysis is either not available at local-level and/or is available in a generalized form. This should be followed by development of relevant databases of these areas that would facilitate setting models specific to the area and analyzing the issues in-depth.

Institutional requirements

Currently, the presence of a multitude of institutions in AQM is leading to institutional failures. This should be overcome by instituting a coordinating authority to manage the overall process. The authority should be supported by experts from varied disciplines as well as technically trained people. The monitoring and enforcement agencies would also come under its purview and should have sufficient manpower as well as the legal authority to enforce policies. They should carry out feasibility studies with a long-term perspective. This authority should work in coordination with the central Ministry of Environment and Forests and related ministries such as power, coal, transport, petroleum and natural gas etc. It also has to coordinate its activities with stakeholders and environmental NGOs that influence the AQM process. Ultimately, they have to work in coordination with the developmental agencies to guide the planning process in a sustainable path. This would promote integration in the policy assessment and implementation process.

4. CONCLUSION

An integrated framework for policy assessment links the emissions from human activities, which coupled with atmospheric chemistry and topographical features that influence dispersion, determine the ambient air quality in an area. The costs of impacts and adaptation are then internalized through the polluter-pays principle. Such a comprehensive assessment of policies is inter-disciplinary and requires a multi-dimensional level of integration. In India, there is still some way to go before such a complex assessment is possible. This is because urban centers in India began tackling the problem of air quality deterioration in 1990s and institutions for policy formulation and implementation are gradually developing. Besides, there are resource constraints.

Yet, the intent to address the problem exists and is reflected in the several policies being implemented currently. This process should move ahead and preventive strategies should be developed based on the integrated framework. To begin with, policy makers should guide developmental policies, at national and local level, in an environmentally-friendly path. Further, conjoint policies should be developed for local AQM and GHG mitigation to derive benefits from the synergies. This process requires using long-term models for generating policy scenarios. Once policies are decided, a suitable mix of instruments should be used so as to achieve a socially optimal solution. The policy formulation and implementation process requires a coordinating authority, so as to reduce institutional failures due to coordination problems between various stakeholders.

Thus, adopting an integrated strategy, rather than focusing on individual issues and preventing deterioration through actions addressing the root causes, rather than seeking remedies is the key to managing urban air quality in India.

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COMPREHENSIVE AIR QUALITY MANAGEMENT OF THE METROPOLITAN AREA OF PORTO

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ABSTRACT
The metropolitan area of Porto, involving several municipalities in the Northern region of Portugal with a total population of more than 1.5 million inhabitants, is one of the Portuguese agglomerations where air quality limit values were surpassed and the assessment and suggestion of strategic measures to improve urban air quality is an urgent issue. This air quality evaluation should not only focus the classical pollutants, like carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen mono and dioxide (NO and NO_2), ozone (O_3) and particulate matter with an aero-dynamical equivalent diameter lesser than 10 μm (PM_{10}), but also cover trace compounds, namely heavy metals, dioxins and furans and polycyclic aromatic hydrocarbons (PAH).

Key Words: Air Quality Management, PM_{10}, O_3, Dioxins and Furans, PAH, Porto

1. INTRODUCTION

Most of industry and traffic is concentrated in urban areas, which are home to almost 80% of the European population. Although emissions from motorised vehicles and large point sources have been reduced through the use of cleaner fuels and technology, urban areas still show increasing signs of air quality degradation (Fenger *et al.*, 1998). In 1996, the European Union (EU) adopted the Framework Directive 96/62/EC on ambient air quality assessment and management. Under this legal framework member states have to control and monitor the concentrations of certain pollutants in the atmosphere. If certain air quality standards are surpassed, member states have the obligation to prepare plans and programs that must indicate measures to improve air quality and to comply with specified limit values.

The main purpose of this paper is to analyse the available air pollutants data in the metropolitan area of Porto towards the contribution to a comprehensive air quality management of this Portuguese agglomeration.

2. AIR QUALITY IN PORTO

During the last 5 years an air quality-monitoring network has been under construction in metropolitan area of Porto. At present, 13 monitoring stations are in regular operation (see Figure 1).

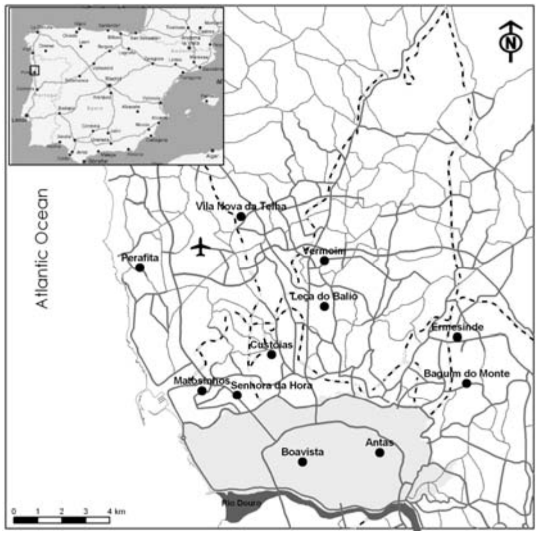

Figure 1. Layout of the air quality-monitoring network of the metropolitan area of Porto. The monitoring stations of Vila do Conde and Espinho are located outside de geographical domain of this map.

Simultaneously, and as a consequence of a monitoring program of a new municipal waste incinerator initiated in 1998, a large database of atmospheric levels of heavy metals (Ni, Cd, As, Hg, Cr, Cu, Mn, Pb and Zn), as well as dioxin and furans has been collected. More recently, regular monitoring of PAHs was initiated.

The existence of this comprehensive data set allows to fully characterizing the air quality *status* in the region of Porto, not being limited by the typical interpretation solely based in regulatory pollutants.

2.1 PM_{10}

The analysis of the data sets of PM_{10} indicates that there is a systematic exceeding of air quality standards for this pollutant, in a significant number of monitoring stations independently from being traffic-oriented or background. These episodes are a combination of several factors dominated by traffic and local emissions, background concentrations and meteorological conditions. The contribution of natural sources is also an important issue, mainly in south-european cities (Rodriguez *et al.*, 2001; Querol *et al.*, 2004) that has to be evaluated.

2.1.1 Natural contribution

The possibility of occurring natural contamination with mineral dust is important to study at larger spatial scale. In fact, one of the most pointed out causes for the occurrence of natural dust particle episodes in southern Europe, and in particular in the Mediterranean basin, has been airborne dust carried from northern Africa (Sahara and Sahel deserts). This scenario might be responsible for extraordinary peak situations. However, an increase of background levels may occur every time air masses are originated form the inner peninsular or northern Africa.

Considering the location of the traffic stations such as Boavista and Antas, it is possible that a decisive factor in measured PM_{10} levels and high number of exceeding situations occurred in 2002 may either be due to dust resuspension from soil due to wind (Chaloulakou *et al*., 2003).

To confirm these assumptions, a study to test dependencies of PM_{10} levels with wind speed and relative humidity was performed (Coutinho *et al*., 2005a). Pollution roses considering 10 m height wind direction were built for each air quality station. As an example, the Senhora da Hora station pollution rose for 2002 is presented in Figure 2. This pollution rose reveals the presence of a marked sector, where higher concentrations characterise the air arriving from the East (99^{th} percentile is 180 $\mu g.m^{-3}$). In average terms, a more marked effect is observed in the presence of East-Southeast winds, where PM_{10} average levels rise to 90 $\mu g.m^{-3}$. This suggests the existence of long-range dust transport, namely Saharan dust.

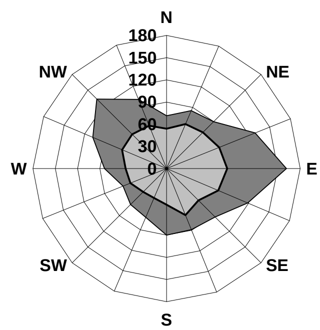

Figure 2. PM_{10} pollution rose (average (light grey) and 99^{th} percentile (dark grey)) for Srª da Hora, with 10 m height wind direction.

The possible contribution of sea spray to the increase of particle levels in the Porto region can equally be assessed with the study of pollution roses. Figure 2 reveals also another marked sector for peak levels with Northwest wind (99^{th} percentile is 120 $\mu g.m^{-3}$). This NW peak clearly corresponds to the presence of sea air masses.

In Portugal, each summer, forest wildfires are another source of PM_{10} to the atmosphere. Backward trajectories analysis (Borrego *et al*., 2005) confirmed that Porto urban area was clearly affected by forest fires emissions, which are one of the main contributors to the high measured levels of this pollutant during summer episodes.

2. 1. 2 Anthropogenic local sources

In urban areas like Porto, PM_{10} emissions are due to combustion associated to residential, industrial and traffic processes. Also turbulence generated by passing traffic generates dust ressuspension (Ketzel *et al*., 2005). Moreover, several monitoring stations in Porto had been under the strong influence of construction works in their proximity throughout 2002.

Stronger winds lead to greater land erosion and consequent scattering of dust accumulated near large construction sites. Although admitting that the existence of a strong correlation with wind speed would be an indication of local sources, this assumption was not confirmed since the assessment of the data revealed that there wasn't any significant correlation with wind velocity.

2. 1. 3 Thermal inversions

Aiming to better understand the PM_{10} sources contribution to the air pollution episodes a phenomenological analysis was developed with a strong incidence on the relation between episodes and thermal inversions (Coutinho *et al*., 2005a).

The innumerable PM_{10} exceeding cases occurred on cold winter days can be associated with the thermal inversion phenomenon, which occurs mainly in large urban centres (Artiñano *et al*., 2003). Figure 3 assesses the correlation between hourly PM_{10} concentrations registered from January to March 2002, at a background station (Leça do Balio) and the temperature gradient for the layer between ground level and an altitude of 200 m, obtained through modelling. The importance of atmospheric stability in episodic PM_{10} contamination phenomenology is quite clear. It is evident that at all situations where concentrations over 150 µg.m^{-3} were observed, occurred in stable circumstances, when temperature gradient was greater then -1ºC/100 m.

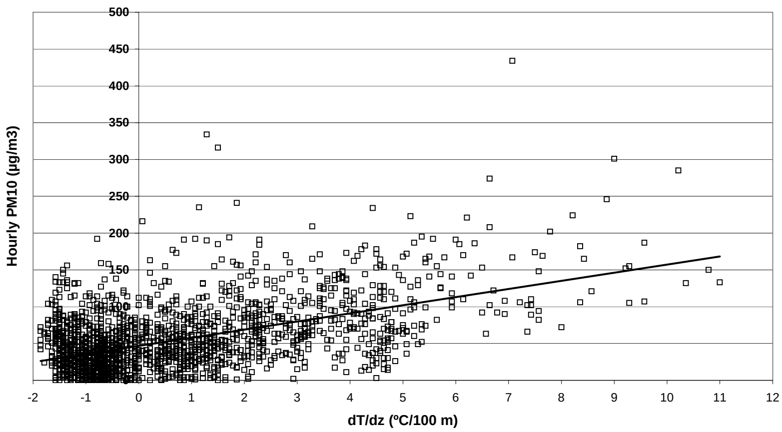

Figure 3. Correlation between atmospheric concentrations of PM_{10} and temperature gradient.

It must be pointed out that this interpretation not only shows the importance of the vertical structure of the low troposphere in the dispersion of atmospheric pollutants, but also the contribution that surface emitting sources, probably of non-industrial origin, are able to have on the degradation of air quality.

2.2 Ozone

Monitoring data obtained in the region of Porto during the last 5 years show that this region is regularly affected by episodes with high levels of tropospheric ozone especially during hot summer days. Geographical patterns follow a typical spatial distribution with lower levels in the urban centre (annual average below 30 µg.m^{-3}) and higher concentrations in the suburbs (annual average close to 50 µg.m^{-3} at 15 to 20 km from downtown).

Figure 4 with the O_3 concentration field estimated by an air quality system of models (Salmim *et al.*, 2005) supports this O_3 spatial pattern.

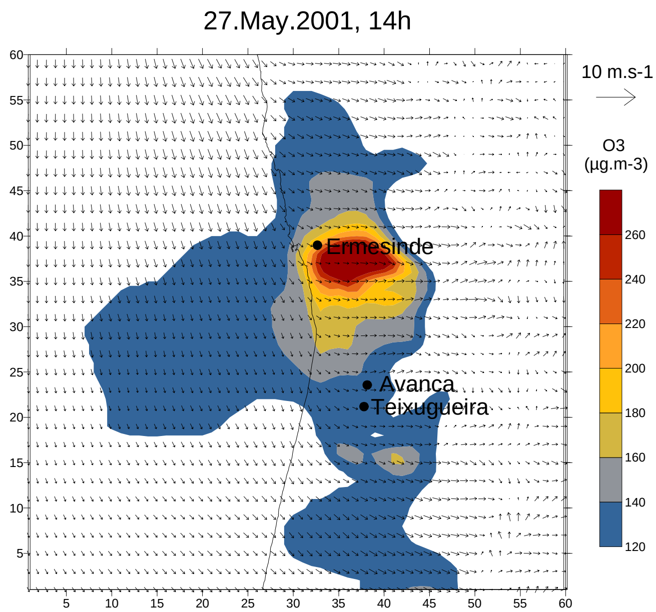

Figure 4: Hourly-averaged O_3 concentration values at 2 pm, for an ozone episode day (Salmim *et al*., 2005).

Application of legal standards included in the EU Directive 2002/3/EC relating to ozone in ambient air reveals that the alert threshold (240 $\mu g.m^{-3}$) was exceeded in 2003 during one hour in three different monitoring stations. Exceeding of the information threshold (180 $\mu g.m^{-3}$) occurs more systematically: 6 monitoring sites were affected by this problem (see Figure 3). The highest number of exceedances occurred in V.N. Telha, a station located 15 km north of the urban centre of Porto. These situations were registered in May, June and August of 2003 and typically happen between 11h00 to 16h00. Standard used as long-term objective for the protection of human health (8 hr average below 120 $\mu g.m^{-3}$) was violated in all of the monitoring stations of the region.

2.3 Dioxins and Furans

The construction of a municipal solid waste (MSW) incinerator in the region of Porto in 1998 led to the development of an external environmental monitoring program (Coutinho *et al*., 2001). This monitoring program includes the regular sampling of dioxins (PCDD) and furans (PCDF) in several matrices such as ambient air, water, sediments, soil, vegetables and diary products. This monitoring program is currently in regular operation. Since the beginning of this program a total of approximately 100 ambient air samples were collected in several sites in the vicinity of the MSW incinerator providing an extensive characterization of dioxins and furans atmospheric levels in the metropolitan area of Porto, as well as information about the temporal trend of the atmospheric concentration of these compounds.

According to Lohmann and Jones (1998), PCDD/F concentrations for the total sum of I-TEQ are typically as follows: remote <10 fg m^{-3}; rural ~20–50 fg m^{-3}; and urban/industrial ~100–400 fg m^{-3}. In Porto, 77% of samples collected are in the 40 to 400 fg I-TEQ m^{-3} range, approximately four times higher than the Lisbon levels (Coutinho *et al*., 2005b). Levels measured in Porto are consistent with data published for Barcelona, on the NE coast of the Iberian Peninsula, where the reported maximum concentrations were in the range of 600 to 800 fg I-TEQ m^{-3} (Abad *et al*., 2004).

In the first trimester of 2001 the emission scenario in Porto experienced a significant reduction in the level of dioxins due to the shutdown of two medical waste incinerators responsible for an important fraction of the dioxin input to the atmosphere. Analysis of this data shows that the improvement of air quality in the region was observed either on the overall level of dioxins and furans as well as in subtle alterations of the homolog pattern of these compounds in the atmosphere (Coutinho *et al*., 2005c).

To determine the existence of a seasonal behaviour of PCDD/F in Porto, two periods were considered, April-September and October-March, referred to as “summer” and “winter” in all figures presented in this paper. Fig. 5 shows the average PCDD/PCDF concentration, expressed in I-TEQ, considering summer and winter periods in the region of Porto.

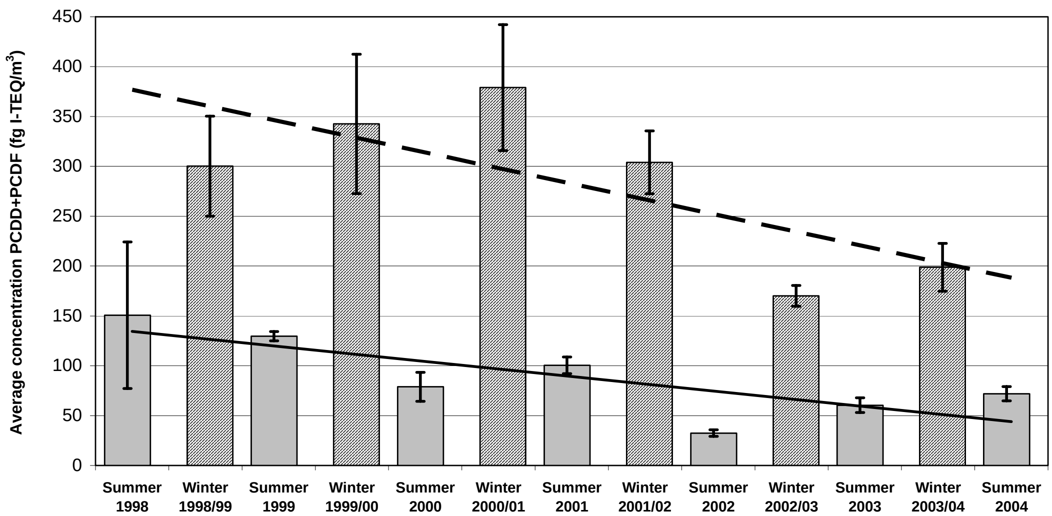

Figure 5. Seasonal average atmospheric levels of PCDD/F in the region of Porto including standard deviation bars and trend line for winter (continuous) and summer (dashed) samples.

Prior to the winter of 2001-02, winter levels in Porto were approximately 3 to 4 times higher than summer levels. After then it is possible to observe a significant decrease of mean concentrations of atmospheric PCDD/PCDF. The mean value (37 fg I-TEQ m^{-3}) and concentration range (13-42 fg I-TEQ m^{-3}) for Summer 2002 are the lowest recorded in this region, followed by Summer 2003 (mean: 50 fg I-TEQ m^{-3}, range: 9,8-172 fg I-TEQ m^{-3}). The decrease of atmospheric concentrations of PCDD/F was

more evident during winter time: PCDD/F levels showed a reduction by a factor of 2, from average levels typically above 300 fg I-TEQ m^{-3} to values between 150 and 200 fg. I-TEQ m^{-3}.
The seasonal pattern can be explained by the intensification of the operation of diverse combustion sources during winter as well as by the more frequent presence of thermal inversion layers at the surface level during winter. These inversions cause a significant increase of atmospheric concentrations when pollutants are emitted at low levels below the thermal inversion layer.

Nevertheless, atmospheric levels of dioxins and furans are still significantly higher than concentrations found in similar airsheds. Probably, ferrous and non-ferrous metal industries located in the region might be partially responsible for these levels.

2.4 Metals

As consequence of the monitoring program designed for the follow-up of the environmental performance of the MSW incinerator, regular measurements of the atmospheric levels of metals (Pb, As, Cd, Ni, Hg, Mn, Cu, Cr and Zn) were performed in the stations of Leça do Balio and V.N. Telha. Samples were taken on a weekly base for all metals except for Lead that was monitored 15 days per month. This field work was initiated in 1998 with sampling of total suspended particles (TSP); starting on the last trimester of 2004 high-volume samplers were adapted for PM_{10}.

Table 1 summarizes data obtained in this monitoring program from 2002 till present. Levels listed as typical correspond to the 90th percentile of each pollutant for that period. Data presented for PM_{10} should be interpreted with additional care due to the limited number of samples (~10) when compared to TSP (>100). Results obtained indicate that there are not exceedances of the EU standard for Pb or for the target value for As, Cd and Ni. At this stage it is significant to mention that the majority of the samples present levels of Ni and Cd below the analytical limit of detection (LD).

Table 1. Typical and maximum levels of metals measured in TSP and PM_{10}.

Concentrations ($ng.m^{-3}$)	TSP typical	TSP maximum	PM_{10} typical	EU standard
Pb	80	420	70	500[§]
As	4	65	4	6[**]
Cd	0.6 (<LD)	8.7	0.6 (<LD)	5[**]
Ni	3 (<LD)	61	3 (<LD)	20[**]
Hg	1	7.2	1	
Mn	45	180	20	
Cu	400	830	120	
Cr	6	20	5	
Zn	1000	2580	700	

[§] Council Directive 1999/30/EC of 22 April 1999 relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air.
[**] EU Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air.

A comparison between levels of metals measured in TSP and PM_{10} suggests that As and Hg appear mostly in the PM_{10} fraction opposed to the distribution of Cu, Mn and Zn which are concentrated in the coarser fraction.

2.5 PAHs

Since October 2004, monitoring activities in Leça do Balio and V.N. Telha include the monthly sampling of polycyclic aromatic hydrocarbons (PAH). Seventeen chemical species are determined through analytical procedures including benzo(a)pyrene (BaP), benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3-C,D)pyrene, dibenzo(ah)anthracene and fluoranthene (FA) as suggested by the EU position paper in PAH (EU, 2001). Analysis of rethene was also included in the analytical procedure with the aim of acting as a tracer of wood combustion.

Measured concentrations reveal a overpassing of the 1 $ng.m^{-3}$ target value for BaP in one third of the samples with a measured maximum of 1.7 $ng.m^{-3}$. Nevertheless, average concentrations of BaP for the total of the samples range between 0.6 and 0.8 $ng.m^{-3}$. Data available up to the moment is not yet sufficient to verify the compliance to the target value recommended by the EU.

A preliminary interpretation of the cross-correlation between the several PAH included in this study suggests the existence of three different categories:

- Naphthalene: common PAH found in numerous petroleum products, cigarette smoke, wood smoke, tar and asphalt (Irwin et al., 1997);
- A group of PAH including rethene, FA, anthracene and fluorene: these compounds occur ubiquitously in products of incomplete combustion and might be associated with wood combustion, either from residential origin in the winter or from forest fires in the summer;
- A complex group of several PAH highly correlated with BaP: most important sources of BaP emissions are small combustion sources (coal and wood), as well as aluminium and coke industrial sources and diesel engines (AEA Technology, 2001).

3. CONCLUSIONS

A comprehensive air quality management of an urban area, as the Porto agglomeration, should encompass different pollutants and different strategies. Not only regulatory pollutants have to be addressed.

There is a trend to attribute all the urban air pollution problems to road traffic exhaust emissions. This could be true for certain pollutants, like CO or NO_x, but PM_{10} or dioxins and furans can be due to small point sources. Data obtained in Porto indicate that minor industrial sources or practices such as residential wood combustion and backyard trash burning might have a key role on local air quality.

These kind of activities emit pollutants near the ground, they are not elevated sources, giving rise to air pollution episodes in thermal inversion conditions. The definition of measures to improve air quality has to seriously address this issue of small sources of air pollutants, distributed by all the urban area.
Moreover, air quality assessment should also consider the seasonal behaviour of air pollutants, which is strongly related to meteorological conditions. Low humidity, high temperatures and solar radiation, which are frequent at summer season, will promote O_3 episodes and also are associated to the occurrence of forest fires that emit O_3 precursors and PM_{10} to the atmosphere. Low humidity and strong winds, from east and south are related too to forest fires and to dust transport.

Surface thermal inversions are more usual at cold winter days/nights avoiding the dispersion of pollutants emitted by the surface sources and contributing to air pollution episodes.

In consequence, meteorological and air quality forecasts should be seen as important and fundamental tools to short-term air quality management. Long-term measures could include actions like (Borrego *et al*., 2005):

- the promotion of the best available technologies in the industries;
- the reduction to a minimum of heavy-duty vehicles circulation in the urban centres;
- the effective control of emissions from the construction activities;
- the replacement of current wood fireplaces by natural gas centralised residential heating;
- the introduction of low-emission urban public transportation vehicles;
- the promotion of the use of these low-emission vehicles.

This scenario indicates that planning an air quality management strategy that includes the correct identification of specific measures to tackle the full problem is not obvious for the “big solution”. Instead, the solution will be the overall sum of many “small measures”, involving a large number of stakeholders. Air quality managers will have to integrate in their plans and programs, knowledge about IPPC best practices on small industries as well as educational measures to change current attitudes of citizens concerning mobility and domestic activities in order to implement a comprehensive air quality management strategy.

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AIR QUALITY MANAGEMNET IN THE AQABA SPECIAL ECONOMIC ZONE (ASEZA), JORDAN

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INTRODUCTION

The Aqaba Special Economic Zone (ASEZ) was created, in 2001, to attract and facilitate investment in the areas of tourism, industry, port development, infrastructure, utilities and services. It is imperative that all such development remains environmentally sustainable in the long term, since the environmental resources of the area are themselves an integral part of its attraction to investment.

As Aqaba embarks on an extensive economic development with tourism as a major focus of its expansion, the need for a pristine environment will be top priority. An enormous project for the development of a tourist village at Tala Bay (15 kilometers to the south of Aqaba city) is presently underway. Another Mega projects are also on underway; the Ayla Oasis and Saraya.

Tala Bay village will be at the edge of the southern Coral Marine Reserve area. What makes it of special concern is that this village will be only ~3 kilometers to the north of the industrial zone. Several hills and mountain ridges will separate the two zones. This tourist village will have dwellings accommodation for 35,000 tourists with three international hotels, an inland marina, golf course and various parks and recreation areas.

For tourism to flourish, the main attractions are good accommodation and recreation, mild weather and pristine environment. The major portions of tourists usually are the elderly and the very young. This sector of society is the most vulnerable sector to environmental pollution. Therefore, preservation of a clean environment will be the main attraction to the region of Aqaba.

THE AQABA SPECIAL ECONOMIC ZONE

An Overview

The Gulf of Aqaba is 180 kilometers long and 14–26 kilometers wide with an average depth of 800 meters. The Gulf is an inland extension of the Red Sea. It contains a unique diversity of fauna and flora that is being threatened by recent urban development including: tourism and industrial expansion, fish farming together with the increase in shipping and overland transportation.

The portion of the Gulf within Jordanian jurisdiction covers the stretch that extends from the extreme northeastern end of the Gulf southward for 26.5 kilometers to the border of Saudi Arabia with the city of Aqaba located at the tip of this stretch. The Jordanian side of the Gulf has witnessed the expansion of the port and storage area, the construction of a large electrical power generation station and the expansion and development of fertilizer production industries at the industrial area (located about 20 Kilometres south of the city of Aqaba). Tourism have also expanded with the necessary construction and planning of new hotels, restaurants, beachside concessions and roads.

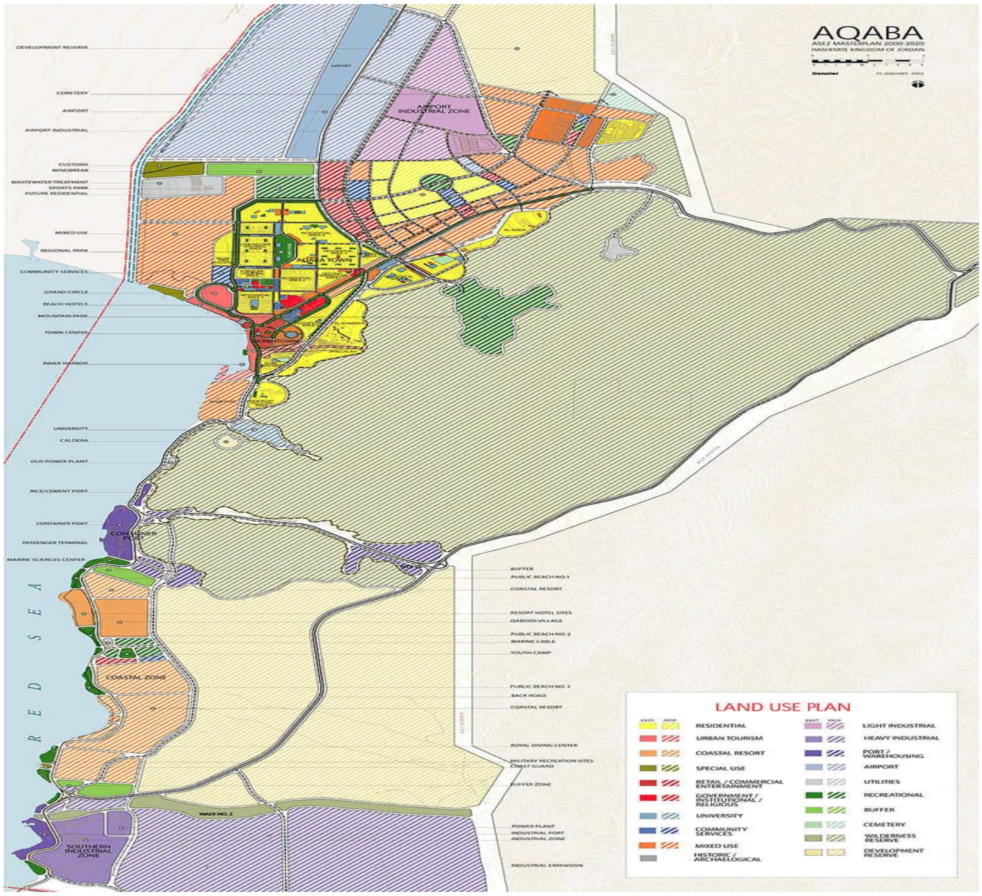
The Port of Aqaba is Jordan's only outlet to the sea. During the last three decades, the Port of Aqaba has witnessed an accelerated growth in population and economic development. Since 1972, the city has expanded from a small urban community of 10,000 inhabitants to more than 85,000. The major reasons for economic growth could be attributed to rapid industrial development, expansion in export-import activities and tourism, which represent the third largest income earner.

These diversified activities have brought with them an increase in various types of overland transportation. This increase included passenger vehicles, and trucks loaded with bulk/cargo shipments from and to Aqaba port. As the industrial activities increase, raw material carried by heavy-duty trucks also increased to meet demands.

Recently, new highways that bypass urban areas were opened for the purposes of diverting the major portion of truck traffics to and from the industrial sector. Trucks, hauling raw materials to and from the industrial sector no longer pass through urban streets. This has resulted in reducing fugitive dusts and air particulates that contributed significantly to contaminating urban atmosphere.

Topography

Mountain ridges cover the region with elevations reaching up to 1600 meters perpendicular to the shoreline and interrupted by a series of intermittent valleys of various widths. This network of valleys acts as wind channels that are eventually responsible for the erratic behaviour of the wind direction in the vicinity of the Gulf shoreline. The coastal areas experience various changes in wind direction and temperature. This topography allows wind channelling from land through valleys to develop and in the afternoon winds with weak gulf breezes will also have some effect on the general circulation. Re-circulation of air due to offshore followed by onshore breezes could develop on occasions.



Map of Aqaba. The map shows the Land use in the Aqaba region.

Climatology

The climate is arid with an average annual rainfall of about 30 millimetres. The mean daily air temperature ranges from 14 ^{o}C in January to more than 35^{o}C in August. On substrate rocky beaches, temperature may reach up to 50 ^{o}C during the summer months. Relative humidity ranges from 30 to 55 percent. The prevailing winds are primarily from the north (81 %) with about 7% originating from the south. Days with calm winds account for 12 % of the time.

Periods of poor dispersion occur during winter and late autumn as a result of slow-moving anticyclones, typified by light winds and low mixing heights. This is a major mechanism for PM-10 events. Air dispersion patterns will be influenced by the Gulf and the surrounding hills.

ENVIRONMENTAL POLICY IN THE ZONE

ASEZA has adopted a number of policies associated with the control, management and protection of the natural environment. The environmental policy requires preservation and protection of the environment and the sustained development of the Zone's natural resources. The water policy requires the protection and management of the groundwater resources , as well as the development of wastewater management and reuse schemes. Water conservation is to be enhanced by managing both supply and demand and efficiency of use. The energy conservation policy promotes the provision of adequate energy to consumers at the least possible cost. A stringent discharge policy of "Zero Discharge" to the sea was also adopted, to preserve the marine environment through the complete elimination of marine pollution. The Gulf of Aqaba is defined as a 'special area' according to the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) signifying that discharges of oil are prohibited from vessels.

The Environmental Protection Regulation (EPR) No. 21 of the year 2001, provides a basis for the environmental policies in the Zone. It lists a number of prohibited acts regarding waste management, use of sea Water, and emission of harmful substances to the environment. The regulation addresses the legal framework for environmental management and monitoring in the Zone including environmental clearance and post-clearance phases of the economic activities in the Zone. The regulation also details appropriate measures to prevent environmental pollution and protect the marine resources, and set out a legal framework for the imposition of penalties for pollution incidents

ASEZA requires that all existing and potential investors within the Zone to comply with the EPR No. 21. This article addresses, particularly the air quality management in the Zone.

AIR QUALITY IN ASEZ

Air Quality Assessment

The major source of air pollution in the region is fossil fuel combustion resulting from industrial activities and other processes. The fuel used contains between 3.5-4% sulfur together with other industrial processes have increased the concentration of SO_2 in the ambient air. The sources for solid particulates in the region are: windblown dust from dry soil; local re-entrained dust emissions from roads together with the combustion of fossil fuels; industrial processes; transporting and handling of phosphate rocks and other raw materials such as potash as well as the photochemical reactions and dry deposition of pollutants in the atmosphere. As vehicular traffic increases, motor vehicles will contribute to various pollutants in the ambient air.

In this regard, the U.S. Agency for International Development (USAID) supported a study on the air quality assessment in the Zone. The survey estimated emissions of some major air pollutants from the existing industries as SO_2, PM, NH_3 & HF. In addition, it showed that data on ambient air quality were few and scattered. Therefore, continuous and reliable source of air pollution measurement is needed for obtaining general trends and achieving any meaningful correlation for long-term predictions.

The assessment was conducted produced by Dr. Fouad Kanbour in the year 2003. The study estimated emissions of some air pollutants from the existing industries as around 72500 ton/yr of SO_2, 48500 ton/yr of PM and 15000 ton/yr of F & HF. This regional load of pollutants has increased when KEMAPCO began production.

Table 1 shows the estimated emission in ton/yr from the various industrial activities in Aqaba. Large increase of NO_x with lesser increase of SO_2 and solid particulate pollutants was observed in the ambient air when production at KEMAPCO commenced. The increase in NO_x concentration will eventually increase the ozone concentration during the summer and fall months.

Table 1. Estimated emissions of the industries in ASEZ

The yr 2000	Power Plant	Industrial Complex					NJFC	Total Ton /y
		H_3PO_4	H_2SO_4	AlF_3	DAP	Utility		
SO_2	67400	-	23	42	1260	3680	130	72500
SO_3	820	-	1.3	0.6	15.3	46	1.5	885
PM	4820	33900	245	15	90	270	9	39500
CO	600	-	-	2.5	11.2	34	1.1	650
NOx	4961	-	-	9.9	149	446	1	5600
VOC	119	-	-	0.1	2.2	6.7	0.01	130
NH_3	-	-	-	-	#2345	-	1225	3600
F, (HF)	-	14805	-	*(3.5)	# 154	-	35	15000

Fuel oil; S = 3.6%; Diesel Oil S = 0.6 %,

▪ Assuming efficient control; # According to actual emission calculation

One must realize sources other than industrial activities will also contribute to the total load of regional pollution. The other anthropogenic sources are motor vehicles, trucks, ships, and planes as well as evaporations from chemical and fuel storage tanks. Natural dust as well as anthropogenic pollutants from neighbouring cities will also contribute to the degradation of air quality in Aqaba.

The study recommended that an ambient air monitoring program to be initiated and implemented as soon as possible by ASEZA in coordination with other regional stakeholders. Monitoring programs will provide scientific basis for the development of policy and strategy and setting objectives, and carrying out compliance measurement and enforcement action against targets. Data collected from monitoring will elucidate urban population exposure to pollutants and the possible threat to the natural ecosystem.

Air Quality Management

In response to the recommendations outlined by the air quality assessment, ASEZA has requested an engineering firm to carry out specialized study to resolve the dust emissions in the port, enforced the industrial stack emissions monitoring program, prioritised the establishments of an ambient air quality monitoring network through the funding agencies as well as the participation in a revision of the national air-quality standards to support the enforcement of the EPR in the Zone. These actions will be discussed further in the following sub-sections.

Alternatives For Resolving The Fugitive Dust Issues At The Aqaba Phosphate Export Terminal

The U.S. Agency for International Development (USAID) to support development of ASEZ funded this study that was conducted by Collins Engineers in 2004.

The study examined the alternatives for cleaning up the fugitive dust problem at the Aqaba Phosphate Rock Export Terminal in the main port of Aqaba. The existing terminal has a problem with too much phosphate dust being discharged to the atmosphere and the marine environment, and this will negatively affect the growth of tourism and the environmental quality of the Gulf of Aqaba. The negative impacts are both aesthetic (the visible cloud of dust) and detrimental to coral growth as a result of siltation and turbidity in coastal waters primarily south of the terminal.

The study addressed two major alternatives: one which involves relocating the entire operation and facilities to the Southern Industrial Zone approximately 15 Km to the south and the second which involves making the capital improvements to the existing facility that would be necessary to clean up the terminal to acceptable levels of fugitive dust. The alternative of making capital improvements to the existing facility was further divided into a series of actions, each of which would result in a recognizable reduction in the fugitive dust escaping the facility.

The alternative of cleaning up the existing facility included such measures as the addition of more vacuum filtration systems, use of fabric hatch covers, expansion and closure of buildings receiving phosphate by truck, paving and cleaning of the site, and improving the existing rail receiving buildings. The study estimated the approximate percentage of dust reduction that could be achieved by each potential, discrete improvement and the probable cost of those improvements.

The estimated cost of relocating the facility to the Southern Industrial Zone is $248 million USD, including the cost for extending rail facilities to the new site. The estimated cost for making all of the improvements needed at the site to bring the dust discharges down to an acceptable level that would be compatible with the continued expansion of tourism would run an estimated $18.3 million USD.

The study recommends that a series of discrete capital and maintenance improvements be undertaken to reduce fugitive dust escaping the existing phosphate export terminal to levels that will not cause problems with the marine environment or tourism development. It also provides estimates of the costs for doing this in a progressive manner, as funds are available. Finally, it addresses means necessary to ensure maintenance is properly done to keep the dust under control.

These findings were communicated to the Aqaba Development Corporation (ADC). ADC was established in 2004 to drive the investment and development in the Zone and currently owns the port. Resolving of the dust issue is being considered in their master plan of the Zone and is being followed closely by ASEZA.

Industries self-Monitoring Program: Stack Emissions

ASEZA identified the various pollutants that are generated from the various industrial activities in Aqaba. Table 2 summarizes these pollutants.

Industries in the zone were engaged in self-monitoring programs on their stack emissions. The results of these programs are reported to ASEZA on a regular basis. ASEZA is working closely with the industries to reduce these emissions and to comply with the Jordanian standards.

In case of violation to the standard and as per the EPR, Corrective- Actions will be send to the industries. They will then propose permanent actions with a time frame to resolve the issues and to fully comply with the standards.

The exercise of self-monitoring, reporting and the compliance wit the Jordanian standard was initiated and followed up closely with each industry during 2004. This has resulted in a better cooperation between the industries and ASEZA as regulator. The data is being used to establish database.

Table 2. Emission of pollutants from the various industries in ASEZ

Industrial Zone	Major Pollutants
Aqaba Thermal Power Plant (APP)	PM, SO_2, SO_3, NO_x, CO, and total organic compounds (TOC).
Jordan Phosphate mining Company (JPMC)	PM, SO_2, SO_3, HF, SiF_4, NH_3, NO_x, CO.
Nippon- Jordan Fertilizer plant (NJFC)	PM, SO_2, SO_3, NO_x, CO HF, NH_3
Arab Potash Storage Plant (APC)	PM
Jordan Safi Salt	PM
Jordan Cement Storage	PM
The Port Authority	PM, NH_3
(KEMAPCO)	PM, SO_2, NO_2, HF, SiF_4, NH_3, CO.

One of the main achievements in the Zone was the introduction of the natural gas through underwater pipeline. ASEZA assisted and facilitated the completion of the gas line and closely follow up the progress of the conversion from heavy fuel oil to gas. ATPP was the first to convert from using heavy fuel oil to the natural gas eliminating the major contribution of SOx to the atmosphere.

Establishment of ASEZA Ambient Air Quality Monitoring Network

ASEZA, with the assistance of the European Union, and as a part of the Institutional Support to the Aqaba Special Economic Zone Authority (IS-ASEZA) program is establishing an air quality-monitoring network as well as purchasing the necessary equipment for the verification of the industrial stack emissions.

One of the major objectives of the program is to provide ASEZA with operational and fully equipped laboratories for the analysis of environmental pollution, certified and accredited to international standards.

ASEZA staff will be trained to operate, maintain and trouble shoot the network as well as able to analyse samples in the environmental laboratory. Staff will also be able to utilize the environmental models and associated software".

The monitoring network is to be operated and maintained by Jordanian experts. The data obtained within the network will be employed in situation assessment, ensuring that accurate information is delivered to the public.

It will enable ASEZA to assess risks for public health from amongst others air pollution, enforce air quality legislation, and to make informed decisions and plans for the improvement of air quality throughout ASEZ. It will also assist the Jordanian authorities in their endeavours to improve air quality/air quality standards throughout ASEZ/Jordan.

One fixed monitoring station will be delivered plus one mobile station. As a matter of principle the parameters, as identified in Annex 1 of the 96/62/EC Directive, will be included in the list of parameters, taking into account the following amendments because of the specific situation in Aqaba.

The fixed station (North of Aqaba) is designated as residential/City Centre type station measuring the impact of traffic and possible industrial emissions reaches the city on ambient air quality.

The mobile station will be used for measurements in the industrial sources, City Centre as well as in residential areas.

Parameter	Continuous measurement?	Remarks
Parameters based on the 96/62/EC directive		
SO_2	Yes	Substantial emissions by local industry south of Aqaba
NO_2	Yes	A possibly important substance emitted by industry and transport and produced in the atmosphere
O_3	Yes	Produced by precursors in combination with sun light, may be relevant
CO	Yes	Substance emitted by industry and transport
PM10 and PM2.5	Yes	PM2.5 is added to the list because since 1996 it appeared that the PM2.5 fraction of dust in air is of special importance for human health. Most EU countries have amended their system, or have the capability, to measure also PM2.5. PM 10 should still be measured because the EU and other international ambient air quality standards are still in terms of PM10. SPM (total dust in air) will not be measured continuously although this is still specified in the above EU directive. However, it will be possible to measure SPM off line with samplers.
VOC	Yes	Emitted by industry and transport
Lead, cadmium, arsenic, nickel, mercury	No, off line	Lead from transport and industry; cadmium from especially the rock phosphate industry south of Aqaba
PAHs	No, off line	Industry and transport are relevant sources
Parameters in addition to the 96/62/EC directive		
Ammonia	Yes	Ammonia processing industry south of Aqaba, also a potential short term risk
Fluoride	Yes	Large local sources from especially the rock phosphate industry south of Aqaba

CONCLUSIONS

Since its establishment, air quality was a major concern to the commission for Environment at ASEZA. The following step were taken to ensure that air quality is being managed in the zone:

- Introducing the necessary regulations to protect the environment

- Assessment of the air quality
- Engaging the industries in the “stack-emissions self-monitoring program”
- Studying alternatives to resolve the phosphate Dust-emission at the port
- Facilitating the introduction of the natural gas in the zone and encouraging industries to convert from the use of heavy fuel oil.
- Establishing air monitoring network to investigate complaints and assess the impact of pollution on man and his environment; obtain continuous and reliable data of regional air pollutants; assures compliance with ambient air quality standards and emission standards as well as the application of dispersion models and carry out prediction for future plans of industrial and tourism expansion. Data collected from monitoring will elucidate urban population exposure to pollutants and the possible threat to the natural ecosystem.

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AIR QUALITY MANAGEMENT IN MEGA-URBAN REGIONS OF SOUTHEAST ASIA

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ABSTRACT

This paper aims to propose an ideal integrated AQM framework for mega-urban regions in Southeast Asia. Based on an assessment of eight frameworks (e.g., Elsom, URBAIR, US-IES, etc.), a proposed integrated approach means: 1) to establish connections with other environmental issues and multiple sectors, such as land use, transportation and industrial sectors; 2) to include socio-cultural aspect besides technological and economical concerns; 3) to incorporate local or regional efforts into a global context; 4) to have strong coordination within and between agencies; and 5) to widen stakeholders participation in the decision-making process.

Key Words: Air Quality Management, Mega-Urban Regions, Southeast Asia.

1. INTRODUCTION

Urbanization is one of the most significant issues facing Asia. In 2001, 36 percent of Asia's 3,500 million inhabitants lived in urban areas, and by 2020 half of the total Asian population will be living in urban areas. There are 12 megacities (10 million or more inhabitants) in Asia: Beijing, Calcutta, Delhi, Dhaka, Jakarta, Karachi, Metro Manila, Mumbai, Osaka, Seoul, Shanghai, and Tokyo (UNEP, 2003). Many of these megacities have expanded as far as 50 km or more from their urban core into peri-urban hinterlands known as mega-urban regions or MURs (McGee and Robinson, 1995). Outdoor (ambient) air pollution is an important issue in these areas due to a growing number of motor vehicles and increasing industrial activities. Most of these cities have exceeded ambient standards limiting the average annual concentration of suspended particulate matter (SPM), particulate matter less than 10μm (PM_{10}), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2) as indicated by the WHO Air Management Information System Database 1990-1999. Air pollution in Asian cities has put lives of millions in vulnerability, approximately 487,000 Asians or 61 percent from a global estimate of 799,000 at risk of premature death because of poor outdoor air (WHO, 2002). Urban governments need to establish an air quality management (AQM) framework that enables them to take measures to promote healthier air quality (Elsom, 1996).

Urban AQM requires an integrated approach that determines which air pollutants are more serious problems; identifies the measures that offer feasible solutions across a range of economic sectors and pollution sources, and builds a consensus among key stakeholders concerning environmental objectives, policies, implementation measures, and responsibilities (World Bank, 1998). International organizations such as the WHO, World Bank, and ADB have already conducted projects to assist developing countries to develop AQM. Still, air pollution continues to be a serious problem in many Asian MURs. The challenges of AQM in Asia range from a lack of government commitment and stakeholder participation, weaknesses in policies, standards and regulation, to deficiencies in data on emissions, air quality and impacts on human health and the environment (APMA and CAI Asia, 2004).

It is realized that in pursuing cost-effectiveness AQM needs to formulate a policy that brings all the stakeholders together in managing better urban air quality. Therefore, this paper aims to propose an integrated AQM framework for MURs that facilitates broader participation from all air quality stakeholders in the context of good governance. Based on a literature review and secondary data, this paper evaluates eight AQM frameworks: 1) Elsom; 2) World Bank-Urban Air Quality Management Strategy (URBAIR); 3) Norwegian Institute for Air Research (NILU); 4) Asian Development Bank (ADB); 5) Air pollution in the Megacities of Asia (APMA) and Clean Air Initiative for Asian Cities (CAI Asia); 6) Europe-United Kingdom (UK); 7) the United States Integrated Environmental strategies (US-IES); and 8) Alabastro on how they address integrated AQM and stakeholders involvement. The paper also identifies the institutional mechanism of air quality governance in MURs of Southeast Asia, specifically Bangkok, Jakarta, Manila, and Ho Chi Minh City (HCMC) in formulating stakeholders involvement in AQM planning and implementation.

2. AIR QUALITY MANAGEMENT FRAMEWORKS

In recent decades, concern about urban air pollution has extended to a scale previously neglected, including smaller scales such as individual households and larger scales such as entire regions. Accompanying this expansion in scales has been an expansion in the nature of negative health impacts that are of concern. Examination of air pollution at smaller scales is necessary because it has become clear that in some cases potential health impacts associated with indoor air quality are not always well predicted by outdoor measurements. Expansion of concern to larger scales has also been required because it has become known that some pollutants can travel large distances over time beyond the emission site, thus resulting in regional and global impacts (Smith and Akbar, 2003).

Table 1 shows the AQM development approaches that are divided into three major periods. Some of the economically more developed regions, such as USA, Europe, and Japan, have step-by-step tackled, more or less, the first period, are well into the second period, and are starting to tackle the third period. Less economically developed regions, such as those in Asia, find themselves, even if progress has been made on the first and second periods, having to tackle all three periods simultaneously. That is an enormous task, which requires developing regions to mobilize a lot of resources (Larssen et al., 2003).

Table 1. Three major periods of AQM development in a region

Period	AQM Development	Focuses
First	Industrial source pollution control	• local and regional scale • SO_2, SPM/TSP, heavy metals • cleaning at stack/improving technologies/moving sources
Second	Urbanization and pollution control	• traffic/urban population exposure • households (space heating, cooking practices)
Third	Co-management of air quality and climate change issues	• benefits on air quality of climate change-driven policies • local emissions control options with a view to their effect on the climate

(Larssen et al., 2003)

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Some examples of frameworks are discussed in this paper can be seen in Figures 1 to 3. Elsom's framework (Figure 1) shows the components of an urban air quality management system that they all form part of an integrated system (Elsom, 1996). He claims that if authorities give inadequate attention to one component, it is likely to result in limitations in the effectiveness of the entire system. Realizing that air pollution is influenced by rapid urbanization and motorization in the city, Elsom suggested to incorporate other air pollution–related aspects such as transportation and land use in the model if an integrated urban AQM framework is really employed.

The APMA and CAI Asia (2004) offer seven key components in the Strategic Framework for AQM in Asia, which are: 1) air quality policies, 2) air quality governance, 3) emissions, 4) air quality modeling, 5) air quality monitoring; 6) health, environmental, and economic risk assessments, and 7) financing of AQM. The AQM as envisioned in this Strategic Framework will enable governmental authorities to collaborate with a broad range of stakeholders. A simplified framework proposed by APMA and CAI Asia (Figure 2) recognizes the importance of emissions standards as well as air quality standards. Apparently, for developing countries, the regulations and implementations of these standards are formed mostly by the economic reasons and prevailing political constellation in the decision-making process. Lack of sufficient political will is a top barrier in AQM development in most of Asian cities (APMA and CAI Asia, 2004).

Dramatic increases in global population and urbanization, and rapid industrialization in many regions of the world may have significant consequences for air quality on a broad regional or even global scale (NRC, 2001). The U.S. Environmental Protection Agency (EPA) has initiated an integrated environmental strategy (IES) program for AQM that links local urban air pollution mitigation to global climate change mitigation – the greenhouse gases reduction (Figures 3). The IES utilizes a country-driven approach where each country tailors the program to best meet its need and priorities. Argentina, Brazil, Chile, China, India, Mexico, South Korea, and Philippines are participating in the IES program (US EPA, 2000).

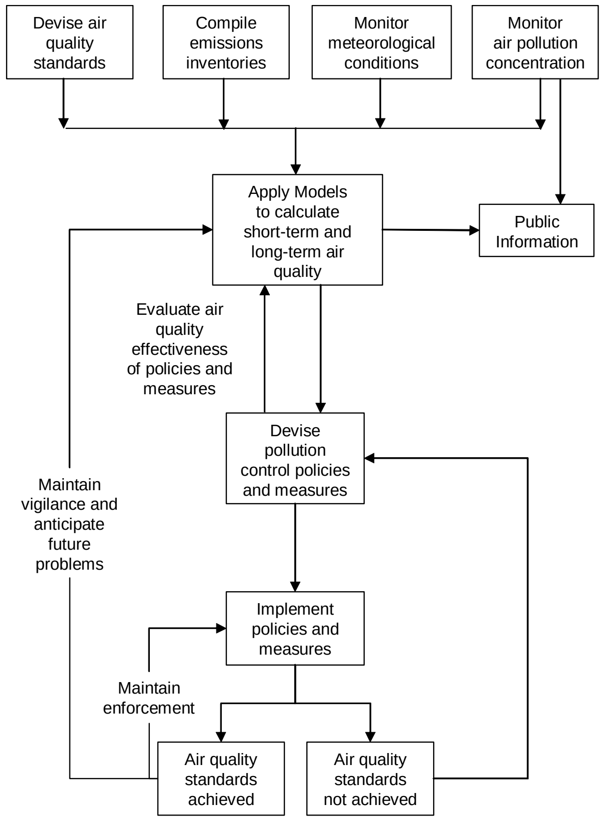

Figure 1. Elsom's framework for air quality management (Elsom, 1996)

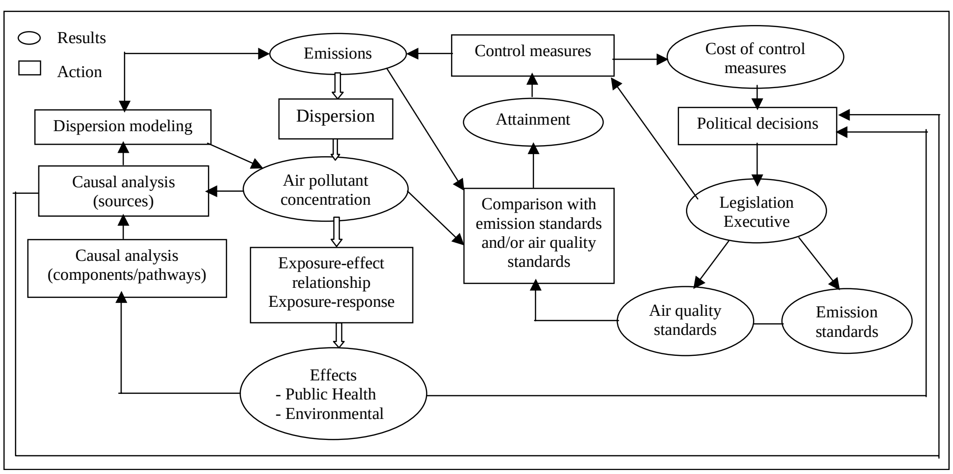

Figure 2. Framework for AQM proposed by APMA and CAI Asia (2004)

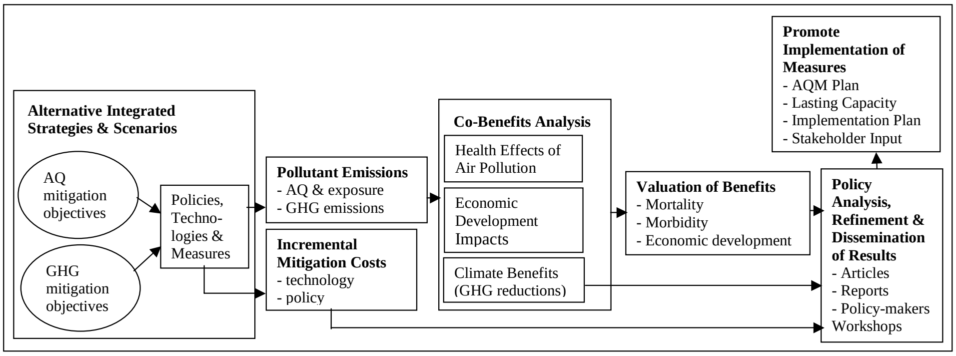

Figure 3. The U.S. Integrated Environmental Strategies (US EPA, 2000)

Since mobile sources contribute over 60-80 percent of air pollution problems in many Asian cities, most AQM frameworks in Asia focus on mobile source. For long term, it is important to consider an overall view of urban air quality rather than to focus on a single-pollutant or isolated problems (Molina and Molina, 2004). Therefore, integration policy with other air pollutant sources, i.e., from industries and households should be carefully managed by MURs in Southeast Asia. In view of the multiple sources, multiple pollutants, and multiple impacts of air pollution, the ideal integrated urban AQM proposed for developing countries should be integrated with other environmental issues; integrated with social/cultural aspects as well as economic and technical aspects; and considering the relation between local, regional, and global air quality issues. The empowerment of local AQM will be an essential foundation for building integrated AQM in MURs of Southeast Asia that are currently experiencing decentralization. Local AQM would acknowledge its local socio-economic conditions, and should have inter-correlation with other local AQMs. Each local AQM should be consistent with national AQM guidelines and policies. On the other hand, the national AQM should acknowledge local socio-economic conditions. National AQM of a country should recognize neighboring countries and should juxtapose with regional and global AQM guidelines and policies.

In developing and implementing AQM policies, locals could also establish collaborations not only with other local or national entities, but also with regional and/or global institutions. Capable institutions are needed to coordinate the multi-sector issue, multi-sector approach, and multiple priorities of stakeholders in achieving better urban air quality. It is necessary that a good integrated urban AQM should have a framework that represents the stakeholders' roles besides the general aspects of AQM. Greater stakeholder involvement is a key in developing an AQM framework and implementing it. Although various AQM frameworks claimed that they pursue an integrated approach, none of the frameworks really fulfill the integrated term as mentioned above. It is difficult to capture local, regional, and global AQM aspects in one perfect framework, and even more difficult for MURs. Table 2 shows the summary findings from the various AQM frameworks.

Table 2. Evaluation summary of AQM frameworks

AQM Framework	Approach	Integrated with other environmental issues or other sectors	Integration between technological, economical and social/cultural, aspects	Integration between local/urban, regional and global issues	Coordination between sector	Stakeholders involvement
1. ELSOM (1996)	Basic AQM	Limited to air pollution issue	More technical	General	Unseen	Public information
2. URBAIR (Shah et al., 1997)	Urban Metropolitan	Limited to air pollution issue	Economical and technical	Unseen	Unseen	Unseen
3. NILU (2003)	Country	Limited to air pollution issue	Economical and technical	Unseen	Unseen	Societal drivers
4. ADB (Huizenga et al., 2003)	Regional	Focus on vehicles emission reduction	Economical and technical	Unseen	Land use, transportation and energy sectors	Considering stakeholders involvement
5. APMA and CAI Asia (2004)	Regional	Focus on harmonization of emission standards	Economical, technical, and political	Unseen	Unseen	Unseen
6. EUROPE/ UK (Beattie et al., 2001)	Local	Transportation issue, Agenda 21	All aspects at local level	Focus on local issue	Between department, local, and national authorities	Local stakeholders
7. US-IES (US EPA, 2000)	Local to Global	Integrated global climate change issue (GHG mitigation)	Economical and technical	Link urban to global	Unseen	Considering stakeholders input
8. ALABASTRO (2002)	Local to Global	Limited to air issues from transportation and industrial sector	Missing economical aspect	Considering international harmonization	Transportation and industrial sectors, institutional building	Stakeholders involvement in legislative and executive

Note: Unseen = not clearly shown in AQM framework.

3. STAKEHOLDERS INVOLVEMENT IN AIR QUALITY MANAGEMENT

It is believed that comprehensive and integrated AQM can be achieved through good air quality governance. Air quality governance is a relatively new discourse along with the democratization process that is underway in most Southeast Asian countries. A concept of governance recognizes that power exists inside and outside the formal authority and institutions of government. Three constituents of governance are government/state, the private sector/corporate economy, and civil society/public (UN Habitat, 2004). Inclusive strategic planning and decision-making processes are the keys to good governance and sustainable cities. Good urban governance is characterized by the universal norms of sustainability, subsidiarity (of authority and resources to the closest appropriate level), equity, efficiency, transparency and accountability, civic engagement and citizenship, and security. These norms are interdependent and mutually reinforcing and can be operationalized (UN Habitat, 2004), and are also applied in term of good urban air quality governance.

If reducing air pollution is not a priority for MURs, it will become a worsening problem. Many developing countries have extensive regulations but often are not applied effectively because of the lack of proper institutions, legal systems, political will, and competent governance. Unfortunately, established political and administrative institutions are usually obsolete for dealing with the problems that occur with the expansion of MURs, particularly where socio-economic conditions are changing rapidly. Political leadership is needed to cut through overlapping and conflicting jurisdictions and short-time horizons (Molina and Molina, 2004).

The most important challenge of air quality governance in Asia involves conflicts that arise because of overlapping responsibilities in AQM (APMA and CAI Asia, 2004). Further, air quality governance in Asia lacks baseline research on awareness-raising among stakeholders; rules and regulations, particularly in neighboring jurisdictions; marketing skills in awareness-raising programs; accountability of agency and staff for inefficient use of funds in AQM; staff with specialized skills; reporting to higher-level management in agencies (e.g. brief to Minister); clear public mechanisms to appeal against new laws and policies; inter-agency communication; and financial resources (APMA and CAI Asia, 2004). Therefore, institutional set-up and mechanisms for stakeholder involvement become important in air quality governance. A major hindrance in environmental decision-making is the lack of collaborative institutional arrangements among principal actors of government, civil society, and private enterprise because each of these actors has different drivers that lead them to manage the environment (Douglass and Ooi, 2000).

The stakeholders who have roles in AQM are the national and local government, implementing national/local agencies, legislators, judiciary, private sector, and civil society including non-governmental organizations (NGOs), media, and academia (APMA and CAI Asia, 2004). Lovei (2003) also includes an international organization (i.e., World Bank) as part of stakeholders. Divergent stakeholders play different roles in formulating and implementing air quality policies.

The impacts of AQM will affect all stakeholders. Hence, stakeholders need an understanding of risk perception that allows the establishment of risk communication strategies to enable the transfer of adequate and reliable information equally among them. Therefore, environmental justice is one crucial dimension of environmental management (Friedmann, 1999) that should be included in an ideal AQM. However, the information of epidemiologic studies of air pollution in Asia is limited. For example, in the period of 1980–2003, there were six studies in Bangkok, two in Jakarta, 16 in Hong Kong, five in Tokyo, and two in Shanghai. Daily time series studies, studies of chronic effects, and integrated capacity building are relatively new types research in Asian cities (PAPA, 2003).

Most of Southeast Asia's governances are in transition. Eeven though there is a trend toward strong environmental laws, the institutions have yet to evolve, especially in expanding role of local governance and people (Roychowdhury, 2003). Douglass and Ooi (2000) emphasized that innovative ways to dramatically raise local capacities for reversing trajectories of environmental deterioration are needed. New mechanism and institutional arrangements are required to widen stakeholders' involvement in the integrated AQM. In Indonesia, programs of the Division of Public Empowerment are still at the level of participation rather than the real empowerment and Jakarta Mega-Urban Region (Jabodetabek) is only a term, not an operationalized concept (World Bank, 2003). Vietnam has started public participation through Strengthening Institutional Capacity for Environmental Information Management (ADB, 2003).

In the Philippines, the operationalization of multisectoral coalitions is co-chaired by NGO, private sector, and government for raising public awareness activities to prepare the public for new policies. A permanent institutional mechanism, the Air Quality Governing Board, is formed to integrate stakeholders' involvement. Citizens can file lawsuits against anyone who is violating the Clean Air Act to ensure law enforcement work well. A comprehensive program to address air pollution in Metro Manila was approved with support funding from ADB (World Bank, 2000).

In 2002, the Government of Thailand announced the new institutional arrangements, the Ministry of Natural Resources and Environment that was created to oversee environmental management, including AQM. It is expected to improve coordination and integration of environmental functions across agencies and enhance service delivery, one of the weakest aspects. A metropolitan government also will be developed to cover four provinces of Bangkok, Thon Buri, Nonthaburi and Samut Prakan (World Bank, 2002).

4. CONCLUSIONS

Based on the assessment of various AQM frameworks, a proposed integrated approach means: 1) to establish connections with other environmental issues and multiple sectors, such as land use, transportation and industrial sectors; 2) to include cultural and social aspects besides technological and economical concerns; 3), to incorporate local or regional efforts into a global context; 4) to have strong coordination within and between agencies; and 5) to widen stakeholder participation in the decision-making process. However, most AQM frameworks do not clearly show how to integrate different tiers of government within MURs.

Air quality governance is a relatively new discourse along with the democratization and decentralization process underway in most countries of Southeast Asia. The implementation of an integrated AQM at the MUR level is challenging as MURs often consist of different tiers of government within different authorities. Inclusion of three constituents of air quality governance —government, civil society, and private sector— in an integrated AQM needs formal legal and institutional set-up to achieve effective AQM implementation for better air quality.

To ensure that an integrated AQM could be implemented appropriately and give the desired results, several key components should be acknowledged: 1) effective communication, collaboration, and consultation between and within stakeholders; 2) functioning working groups (within local authorities and regionally); 3) collaborative processes within and between relevant bodies; 4) collaboration between different tiers of government; 5) although mobile sources are the current main concern for most MURs in Southeast Asia, integration policy with other air pollutant sources, i.e., from industries and households should be carefully managed; 6) ensuring that funding is available and properly allocated; 7) strong political commitment is crucial in developing institutional capacity; and 8) sharing information equally among stakeholders. It is hoped that this paper will contribute to the development of AQM planning, particularly for the MURs in developing countries of Southeast Asia.

5. ACKNOWLEDGEMENTS

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Proceedings of the Third International Symposium on Air Quality Management at Urban, Regional and Global Scales. 26-30 September 2005, Istanbul – Turkey

DIESEL RETROFIT EMISSIONS REDUCTION SYSTEMS: MARKETS, DRIVERS AND COST-EFFECTIVENESS

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Environmental Industries Commission, United Kingdom

Abstract

Many European cities will not meet EU air quality standards in 2010 with "business as usual" vehicle procurement. Therefore, there are many initiatives to enhance the emissions performance of older vehicles and even, perhaps, new vehicles to achieve the targets. There is an emerging mass market opportunity for retrofit emissions reduction systems.

For example, in London there are three such initiatives:

- a London-wide Low Emission Zone with phase 1 in 2007 requiring a minimum engine standard of Euro 2 plus particulate filter and phase 2 in 2010 where the minimum standard will be Euro 3 with particulate filter
- the upgrade of the licensed taxicab fleet to a minimum of Euro 3 standard by 2008
- requirements to add particulate filters to off-highway vehicles from January 2006 for vehicles meeting current emissions standards and past previous emissions standard

The paper addresses the air quality issues including the health effects and concerns regarding atmospheric nitrogen dioxide and particulate matter and the contribution of road transport.

The available NOx and Pm abatement technologies and their effectiveness are detailed with examples of real world chassis dynamometer results. The system flexibility is discussed to cover the modal range from inner city to motorway driving with possible variation in the effectiveness of some technologies. The system requirements for the vehicle, fuel, lubrication oil and maintenance are included.

Examples of national and local government mandates, voluntary schemes, fiscal incentives and system accreditation are given.

Some cost benefit analysis is shown, both with and without co-funding from public bodies, leading to various scenarios regarding payback interval.

The societal costs are also discussed with reference to various studies such as the EU ExternE and compared to the emissions savings and costs of the retrofit technologies.

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DESULFURIZATION OF HYDROCARBON FUELS BY OXIDATION AND SOLVENT EXTRACTION

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ABSTRACT

The oxidation of model sulfur compounds (di-n-butyl sulfide, dimethyl sulfoxide and dibenzothiophene) and heavy gas oils (HGO) derived from Libyan crude oils were conducted with hydrogen peroxide as oxidant and formic acid as catalyst. The effectiveness of sulfur removal is proportional to reaction temperature in the range of 40 to 60 ºC, and maximum 30 ml of formic acid. On the other hand, increasing the amount of hydrogen peroxide leads to reduction in both conversion as well as initial reaction rate. In addition to the oxidative sulfur removal, extraction of unoxidized and oxidized gas oils was also investigated using methanol, dimethylformamide (DMF) and N-methyl pyrrolidone (NMP) as solvents. The removal of sulfur compounds by solvent extraction became more effective for the oxidized samples than for the unoxidized samples. Through oxidation and extraction the sulfur content in heavy gas oils are reduced from 0.1550 to 0.0457 wt % for HGO(A) and from 0.1066 to 0.0148 wt % for HGO(B) by XRF sulfur-in-oil analyzer.

Key Words: Oxidative Desulfurization, Extraction, H_2O_2, HCOOH

1. INTRODUCTION

The removal of sulfur from petroleum products is necessary for both industrial and environmental reasons. Sulfur in petroleum products poisons catalytic converters, corrodes parts of internal combustion engines and refinery facilities because of the formation of oxy-acids of sulfur. Air pollution due to exhausts from diesel is a major concern to the public as well. New fuel regulations call for <50 ppm sulfur in Europe by 2005 and 15 ppm in the US by 2006 (Fairbridge and Ring, 2001). The conventional method for reducing sulfur is catalytic hydrodesulfuraization (HDS). In the HDS method hydrogen and the organic sulfur compounds react together at high temperature and high partial pressure of hydrogen. The effectiveness of HDS process depends on the type of sulfur compounds. The complete removal of sulfur present in petroleum as sulfides, disulfides and mercaptans are relatively easy and an inexpensive process. However, benzothiophenes (BTs) and dibenzothiphenes (DBTs) are difficult to remove by this process. Particularly, the strictly hindered ones, 4-methyldibezothiophene and 4,6-dimethyldibezothiophene are the most resistant compounds in the current HDS processes and they retard the rate of HDS (Otsuki et al., 2000). In order to remove DBTs compounds by HDS, it would require more hydrogen capacity and maintenance of high temperature and pressure for longer contact time. This would increase operating costs and enhance the likelihood that complete saturation of olefins and aromatics will occur resulting in losses of hydrocarbons. Thus, it is likely that HDS processing has reached a stage where increasing temperature and pressure are just not enough to remove the residual sulfur without affecting the yield of diesel fuel from hydrotreatment processes (Yelda et al., 2002). An oxidative desulfurization (ODS) process has the significant advantage over HDS, namely the sulfur compounds that are the most difficult to reduce by HDS are the most reactive by ODS. In effect, the ODS process has the reverse order of reactivity as compared to the HDS process. This effect arises because the reactivity of sulfur compounds for oxidation is augmented with an increase of electron density on the sulfur atom (Otsuki et al., 2000). Many types of oxidants have been used and various consequences of ODS methods have been reported (Wang et al., 2003 and references there in). (Aida and Yamamoto, 1994) reported that peroxyacids such as performic acid, pertrifluoroacetic acid, and a mixture of formic acid or trifluoroacetic acid and H_2O_2 were some of the most positive oxidants for selective oxidation of sulfur compound in fuel oil.

2. EXPERIMENTAL SECTION

2.1. MATERIALS

Three types of model sulfur compounds are selected to evaluate the reactivity of sulfur in an oxidation reaction. Dibutylsulfide, Dimethylsulfoxide and Dibenzothiophene were purchased from Sigma/Aldrich and used without treatment. Hydrogen peroxide (30 wt. % H_2O_2) was used as oxidant. Methanol, N-methyl pyrrolidone (NMP), Di-methyl formamaide (DMF), Dodecane, Decahydronaphthalene (cis and trans-mixture) were used as solvents and supplied by Surechem products Ltd. Formic acid (99 wt.% HCOOH) was used as a catalyst and supplied by British Drug Hose (BDH). Two heavy gas oils were used in the present study (HGO(A) and HGO(B)) which are derived from Libyan crude oils and their properties are shown in Table 1.

Table 1. Properties of heavy gas oils

Property	HGO(A)	HGO(B)	Test Method
Specific gravity at 60/60 ^{0}F	0.8576	0.8810	ASTM D1298
Viscosity (cSt) (50 ^{0}C)	7.06	7.12	ASTM D445
Flash point closed cup, ^{0}C	115	127	ASTM D 93
Sulfur content (wt %)	0.1550	0.1066	ASTM D4294
Pour point (^{0}C)	27	9	ASTM D97
Cetane index	53.4	54.6	ASTM D976

2.2. REACTOR

A 500 ml four necked flask fitted with a mechanical stirrer, a thermocouple and a thermometer was used to carry out the oxidation reaction. The reaction flask was placed in a heating mantel equipped with a temperature controller (within ±2 ^{0}C).

2.3. PROCEDURE OF OXIDATION EXPERIMENTS

A 1.25 ml of hydrogen peroxide is added to 30 ml of solution containing model sulfur compound and solvent in the reactor. The flask is placed into the heating mantel and stirred at 750 rpm. When the required reaction temperature has been reached (approximately 10 minutes) 30 ml of formic acid catalyst was added to the flask to initiate the reaction. This procedure was carried at different temperatures (20, 40, 60 and 80 ^{0}C). Samples from the reactor are taken at 2.5, 5, 7.5, 15, 25 and 35 minutes. The collected samples were left to settle for few minutes after which two layers were formed; the top layer (solvent) and the bottom layer (oxidant-catalyst). The top layer is analyzed by XRF in order to determine the content of sulfur. The same procedure was used for the heavy gas oils using equal volumes of the formic acid and heavy gas oil (30 ml) and half volume of hydrogen peroxide (15 ml) at different reaction temperatures, 40, 60, 80 and 100 ^{0}C. Samples are taken for analysis at different time intervals (5, 15, 25, 35, 70, 90, 180, 270 and 360 minutes). After each run, the mixture is allowed to cool down to the room temperature whereupon two layers are formed. The top layer (oil) was separated, washed successfully with water, 5% aqueous sodium bicarbonate and was finally dried over anhydrous magnesium sulfate, then analyzed by XRF to measure sulfur content.

2.4. PROCEDURE OF EXTRACTION EXPERIMENTS

The extraction of sulfur compounds from the oxidized oil layer and the original HGO were conducted with NMP, DMF and methanol at different solvent/oil ratios. Prior to the extraction, the oxidation of HGO was performed at 60 ^{0}C for 90 minutes. The extraction was done at 25 ^{0}C for HGO(B) and 40 ^{0}C for HGO(A) for two hours. For HGO(A), it was necessary to carry out extraction at 40 ^{o}C in order to dissolve wax formed at ambient condition. The phases are then allowed to separate and their volumes are measured, the hydrocarbon phases were washed with distilled water and then analyzed for their sulfur content.

3. RESULTS AND DISCUSSION

3.1. OXIDATION OF MODEL SULFUR COMOUNDS

Figure 1 shows the effect of reaction time on the conversion of di-n-butylsulfide in the presence of formic acide/H_2O_2 at different reaction temperatures. It is clear from this Figure that the initial reaction rate of oxidation is high and conversion values above 75 % have been obtained within 5 minutes. This Figure also shows that as the reaction temperature increase up to 60 ^{o}C, the initial reaction rate as well as the final conversion increase. But the initial reaction rate and conversion values at 60 and 80 ^{o}C are similar. Figure 2 shows the oxidation of di-methylsulphoxide with H_2O_2 as a function of reaction time over various temperatures. As shown in this Figure the initial rate of oxidation is less than that for di -n-butyl sulfide and the reaction rate strongly increases after 5 minutes, but the reaction does not stop as in the case of di -n-butyl sulfide. Both the initial reaction rate and the final conversion values increase upon increasing the reaction temperature, however above 60 ^{o} C leveling off occurs in the apparent rate of reaction. This is probably due to mass transfer limitation as the kinetic curves fully overlap. The steps between 2.5 and 5 minutes require further investigation. This unusual behavior can be due to (i) product solubility problem, (ii) partial poisoning by the product (product-substrate interaction).

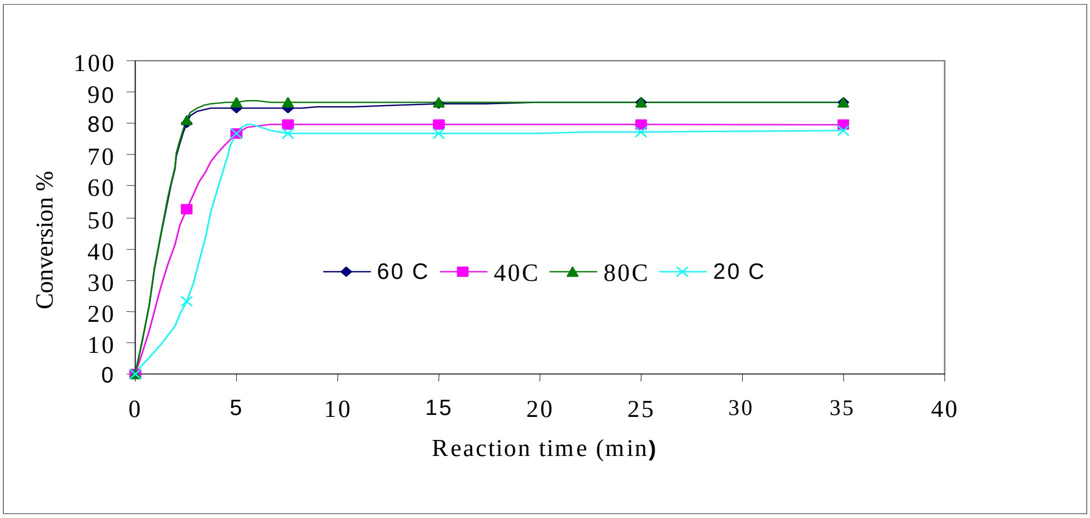

Figure 1. Oxidation of di -n-butyl sulfide in formic acid/ H_2O_2 system at different temperatures

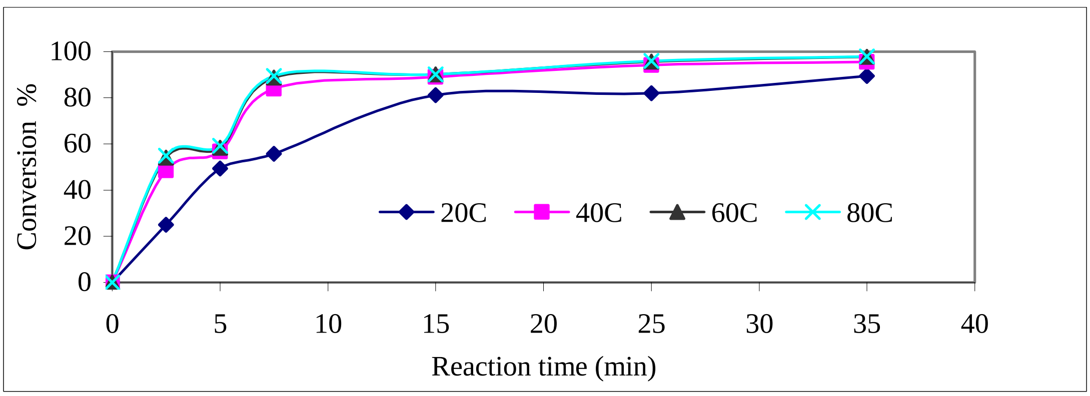

Figure 2. Oxidation of di-methylsulfoxide at different temperatures

Figure 3 shows the results of oxidation of dibenzothiophene with H_2O_2 as a function of reaction time and reaction temperatures. It can be seen that as the reaction temperature increases, the initial reaction rate increase at reaction time below 5 minutes whilst, 98 wt% conversion of DBT has been achieved after 5 minutes for all reaction temperatures. On the other hand when the reaction temperature exceeds 40 ^{o}C and reaction time above 4 minutes, the reaction proceeds with constant conversion, or in other words the operating conditions have no significant influence on the oxidation of DBT.

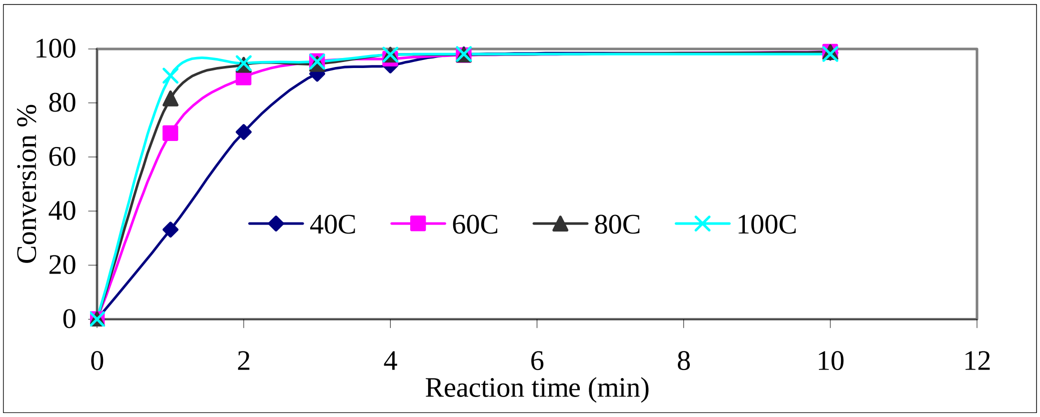

Figure 3. Oxidation of DBT at different reaction temperatures

It is obvious from the comparison of Figure 1 and Figure 3 that the initial rate of oxidation of DBT is faster than in case of the corresponding n-dibutylsulfide. This can be attributed to the fact that DBT has higher electron density than the sulfide and, hence, higher reactivity (Otsuki et al., 2000). The oxidation of DBT with hydrogen peroxide and formic acid has been reported by (Attar and Corcoran, 1978). They postulated that the divalent sulfur of DBT can be oxidized by the electrophilic addition reaction of oxygen atoms to the hexavalent sulfur of DBT sulfone. Hence, the reactivity of oxidation becomes higher for a sulfur atom with a higher electron density.

3.2. OXIDATION OF HEAVY GAS OILS (HGO*)*

Figure 4 shows the oxidation of HGO(A) with H_2O_2 as a function of reaction time over various temperatures. The results indicated that at 40^o C there is a partial poisoning after 5 minutes of reaction but at 60, 80, and 100 ^{o} C the reaction stops after 25 minutes due to the poisoning effect of the reaction products. Figure 5 shows the oxidation of HGO(B) with H_2O_2 as a function of reaction time over various temperatures. As seen from this Figure the results indicated that the oxidation activities increased with the increasing temperature up to 60^0C. Above the reaction temperature of 60 ^{o} C the kinetic curves fully overlap. This could be caused by several reasons such as: (1) Mass transfer limitation (2) Decomposition of H_2O_2 at high temperature (3) High molecular weight sulfones produced owing to reaction temperature above 60 ^{o}C.

3.3. EFFECT OF CATALYST AMOUNT ON THE OXIDATION REACTION

It can be seen from Figure 6 increasing the amount of the catalyst increase both the initial rate and the final conversion. Higher amount of formic acid, gives higher conversion. These results from the fact that probably the products formed are well soluble in formic acid. In this case the probability for the interaction between the product and the initial sulfur compound is decreasing. Addition of more formic acid above 30 cm^3 had no further improvement in the rate of reaction and final conversion.

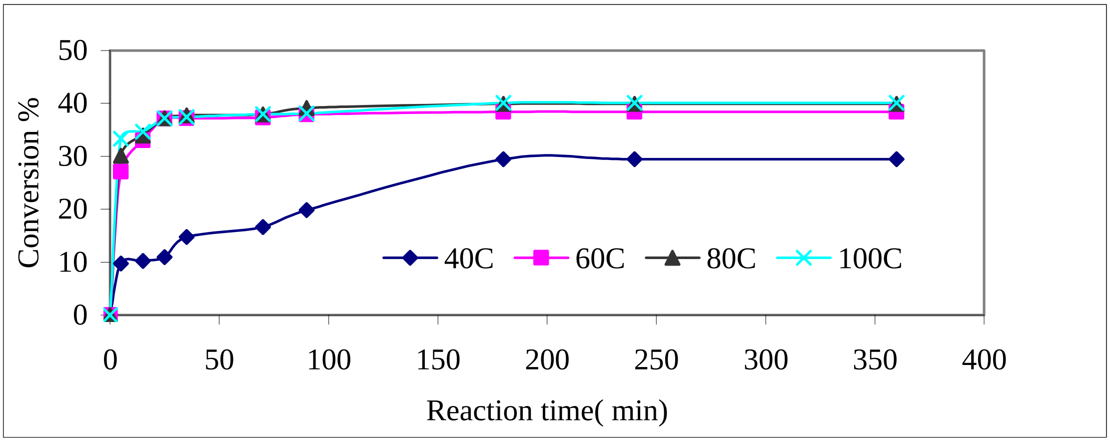

Figure 4. Oxidation of HGO(A) at different reaction temperatures

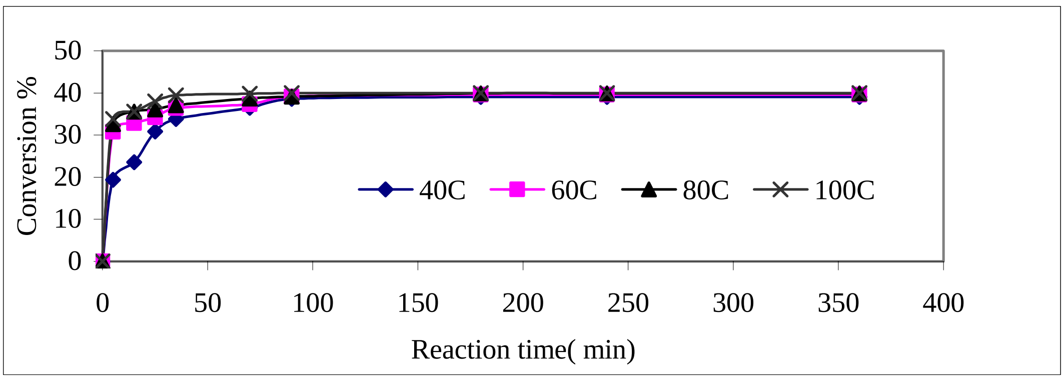

Figure 5. Oxidation of HGO(B) at different reaction temperatures

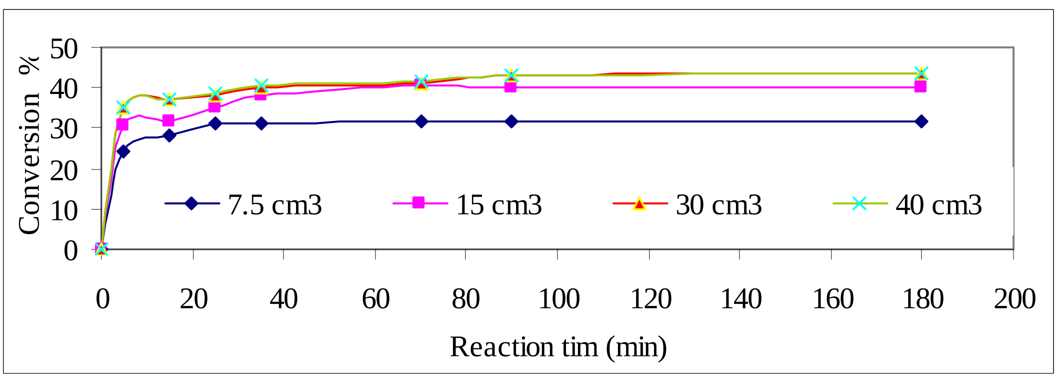

Figure 6. Effect of catalyst amount on the oxidation reaction at 60 ^{0}C

3.4. EFFECT OF OXIDANT AMOUNT ON THE OXIDATION REACTION

As shown in Figure 7, there is a strong negative effect of the oxidant both on the initial rate and the final conversion. The negative effect of H_2O_2 can be attributed to the presence of large amount of water. The higher is the amount of water the lower is the probability for the interaction between the sulfur compound dissolved in the oil phase and H_2O_2 present in the water phase.

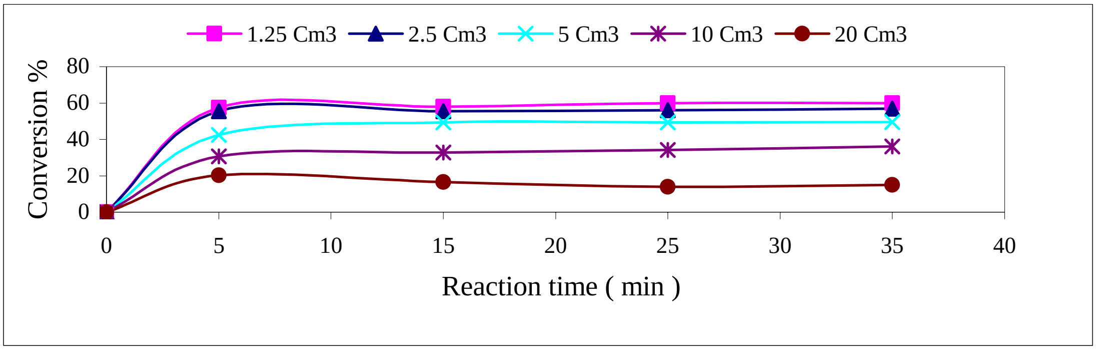

Figure 7. Effect of oxidant amount on the oxidation reaction at 60 ^{0}C

3.5. EXTRACTION

HGO(A) was extracted by using methanol and NMP before and after oxidation. The results are reported in Tables 3 and 4 respectively. As shown in Table 3 the extraction with methanol is more effective after oxidative sulfur removal. However, efficiency of sulfur removal is almost constant above the solvent/HGO ratio of 3. Whereas, the efficiency of sulfur removal using NMP is high as seen in Table 4, HGO(B) was extracted by using methanol, NMP and DMF before and after oxidation. Tables 5-7 show the results. The efficiency of sulfur removal using DMF is higher than both methanol and NMP. It can be observed that methanol is not an effctive solvent in the case of extraction of unoxidized HGO, whereas the NMP and DMF can achive substantial desulfurization albeit relatively low yields (Tables 6 and 7). When the HGO was first oxidized and then treated with various solvents, a further subtantial reduction of sulfur content could be obtained. In this particular case it was found that DMF is as effective as the very polar NMP and methanol in removing sulfur compounds selectively with different solven/HGO(B) ratios. Furthermore DMF give better yields than NMP except at the solvent (DMF)/HGO(B) ratio of 5 for the oxidized HGO(B). Plots of solvent effctiveness (S.E = percent conversion/oil loss) vs solvent/HGO ratio for extraction of unoxidized HGO(B) is shown in Figure 8 and for oxidized HGO(B) are shown in Figures 9 and 10. Figures 8 and 9 give S.E factors for the case when conversion was calculated on the basis of original sulfur content (0.1066 wt %) whereas in Figure 10 conversion is based on oxidized sample sulfur content (0.0609 wt %). Figures 8 and 9 clearly show that methanol is the most effective of these solvents for the case when conversion is based on the original sulfur content. However, when the S.E factor is calculated from conversion based on sulfur concentration after HGO(B) is oxidized, DMF with solvent/ HGO(B) ratio of 1 has been found as the most effective.

Table 3. Extraction of HGO(A) by methanol

Methanol/HGO(A) volume ratio	Unoxidized		Oxidized*	
	S%	Yield%	S%	Yield%
0.5	0.155	99..5	0.093	99
1	0.146	98	0.084	98.5
3	0.117	96	0.057	97
5	0.115	95	0.056	95

Table 4. Extraction of HGO(A) by NMP

NMP/HGO(A) volume ratio	Unoxidized		Oxidized	
	S%	Yield%	S%	Yield%
1	0.1253	93	0.0817	81
3	0.1032	89	0.0543	78
4	0.0981	85	0.0461	75
5	0.0976	83	0.0457	74

*oxidation at 60 ^{0}C, 90 min.(S %= 0.097), amount of H_2O_2:15 cm^3 amount of formic acid: 30 cm^3

Table 5. Extraction of HGO(B) by methanol

Methanol/HGO(B) volume ratio	Unoxidized		Oxidized**	
	S%	Yield%	S%	Yield%
0.5	0.1066	99	0.0607	98
1	0.0982	98	0.0584	97.5
3	0.0903	96	0.0514	97
5	0.0790	95	0.0475	96.5

Table 6. Extraction of HGO(B) by NMP

NMP/HGO(B) volume ratio	Unoxidized		Oxidized	
	S%	Yield%	S%	Yield%
1	0.0733	80	0.0307	78
3	0.0652	79	0.0243	77
4	0.0623	74.5	0.0164	74
5	0.0614	74	0.0155	70

Table 7. Extraction of HGO(B) by DMF

DMF/HGO(B) volume ratio	Unoxidized		Oxidized	
	S%	Yield%	S%	Yield%
0.5	0.0901	97.5	0.0356	95
1	0.0599	82.5	0.0225	90
3	0.0448	80	0.0172	86
5	0.0397	78	0.0148	70

**oxidation at 60 ^{0}C, 90 min.(S %= 0.0609), amount of H_2O_2:15 cm^{3,} amount of formic acid: 30 cm^3

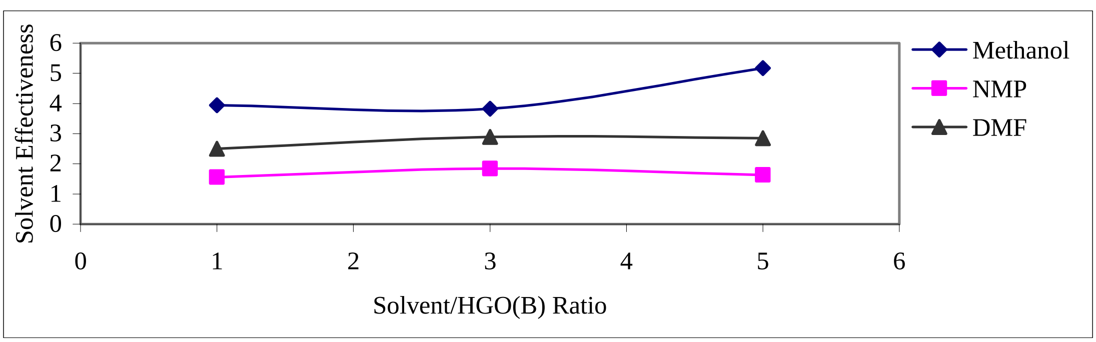

Figure 8.Solvent effectiveness in sulfur removal from unoxidized HGO(B) based on original sulfur content

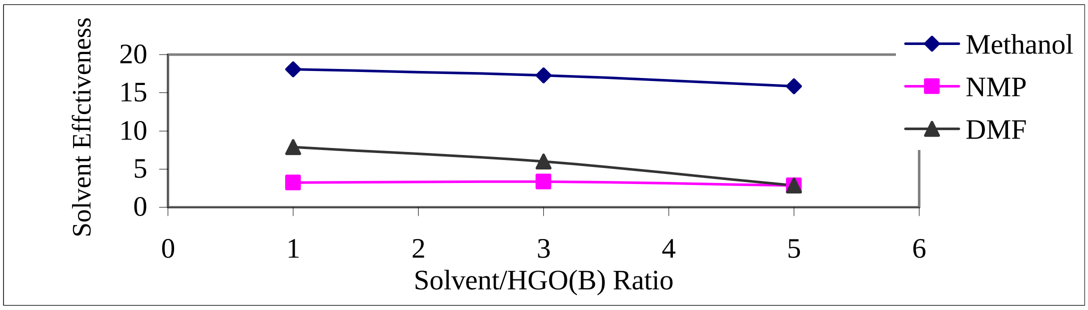

Figure 9.Solvent effectiveness in sulfur removal from oxidized HGO(B) based on original sulfur content

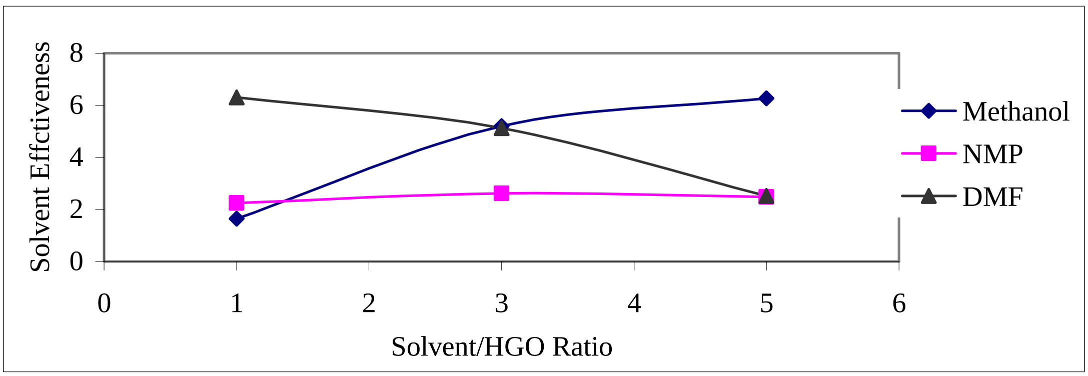

Figure 10.Solvent effectiveness in sulfur removal from oxidized HGO(B)) based on oxidized sulfur content

3.6. EFFECTS OF ODS ON HGO(B) PROPERTIES

The physical properties of the original HGO(B) and desulfurized HGO(B) are listed in Table 8. As shown in this Table the oxidation and extraction processes lead to the removal of a substantial portion of the sulfur and nitrogen that are originally present without any negative effects on the other properties of fuel. In fact, improtant properties as cetane number has improved by at least 3 points. Furthermore, undesirable aromatics and poly nuclear aromatic (PNA) compounds had been reduced.

Table 8. Effects of oxidation and extraction on HGO(B) properties

Physical property			Extraction	
	Original	*Oxidized	Methanol 1:5	NMP 1:3
API	29.1	30	31.1	32.5
Cetane number	53.7	56.8	56.9	59.7
Cetane index	54.6	55.2	56.9	59.4
Total aromatic wt%	16.2	14.4	12.5	6.3
PNA wt%	4.6	3.8	3	1.8
N_2 PPM	176	39	19	-----
S PPM	1066	609	475	244

***** Oxidation at 60 ^{0}C, 90 min.(S %= 0.0609), amount of H_2O_2:15 cm^{3,} amount of formic acid: 30 cm^{3}

4. CONCLUSION

The oxidation of sulfur compounds followed by their extraction is an effective method for reducing these species. The effectiveness of sulfur removal is proportional to reaction temperature in the range of 40 to 60 ºC, and maximum 30 ml of formic acid. On the other hand, increasing the amount of hydrogen peroxide leads to reduction in both conversion as well as initial reaction rate. Through oxidation, the sulfur content in HGO(B) and HGO(A) are reduced from 0.1066 to 0.0609 wt % and from 0.1550 to 0.0970 wt% respectively. DMF was found as the most efficient solvent able to reduce the total sulfur content from 0.0609 to 0.0148 wt% for HGO(B). However, combining sulfur removal efficiency and oil yield, methanol was found to be the most attractive with solvent effectiveness factor of 15.83 compared to 2.87 for DMF. It is important to mention that when sulfur conversion is based on the concentration of sulfur in oxidized HGO rather than the original sulfur, DMF with solvent/HGO ratio of (1:1) is more effective than other solvents. Final solvent selection should be based on economic and environmental considerations. It is confirmed that the oxidation and extraction processes lead to the removal of a substantial portion of the sulfur and nitrogen that are originally present without any negative effects on other fuel properties.

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