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Integrated Air Quality Management in Urban Areas: Simplified Methods

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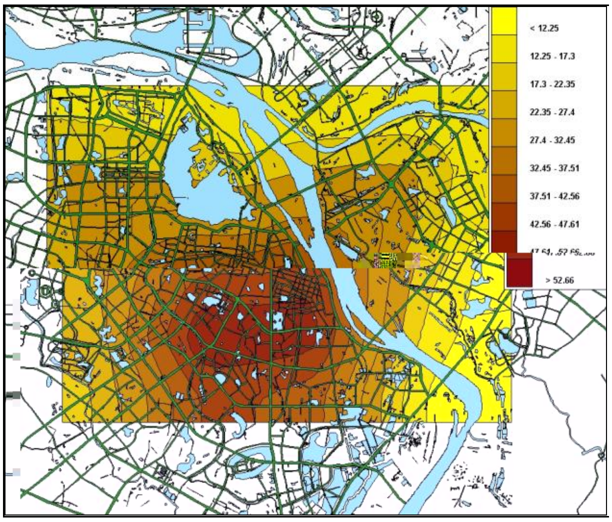

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INTEGRATED AIR QUALITY MANAGEMENT IN URBAN AREAS: SIMPLIFIED METHODS

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Abstract

In order to evaluate alternative actions and policy measures planned for the improvement of air quality, the Norwegian Institute for Air Research (NILU) has tested a combination of simple integrated management models and the NILU developed air quality modelling and planning system AirQUIS. The models have been applied to evaluate traffic solutions in large urban areas.

The models include emissions from traffic and other sources, concentration and exposure estimates and evaluations of health impacts. The model also includes simple mathematical and financial tools in order to list various management options, which aim at improving air quality. The management options are linked to health impacts and costs. It will thus be possible to put priority on the most cost-effective actions. The method has been applied on data from Hanoi, Vietnam. Some results from these evaluations will be presented.

Keywords: Air Pollution in Mega Cities, modelling, Air Quality Management.

1. Introduction

The Norwegian Institute for Air Research (NILU) has developed the powerful AirQUIS GIS based air quality management and dissemination system to perform integrated assessment and planning for improving air quality (AirQUIS, 2003). Information on air quality available in almost any city of the developing world is highly disorganised, poorly quality assured and often inaccessible. A comprehensive management system such as AirQUIS is usually data hungry and requires large specific datasets. They are in some cases time consuming and expensive in comparison to the needs and resources available in developing countries. Therefore, there is a need to develop simple interactive decision support tools to assist local authorities to carry out screening processes aimed at taking appropriate decisions and actions for air quality management.

2. System approach

The concept developed by NILU can be summarised in three stages: estimation of top-down emission inventory, calculation of ambient concentrations using dispersion modelling and evaluation of health effects, management options and related costs.

For estimating emissions for a specific area, NILU uses a similar integrated approach as in the Simple Interactive Model for Better Air Quality (SIM-AIR) presented by the World Bank (Shah and Saikawa, 2005). Where a detailed emission inventory is not available, estimates of emissions are performed as a top down approach. This is achieved using a simple Excel based model. In l n kkm c dhe emission inventory is estimated for a defined gridded domain that spatially covers the area being studied. It takes as well into account area and point sources. The resolution of the emission inventory grid can be adil midbo oc pn mi n)

Following the top down emission inventory, the data is formatted to be directly used in the AirQUIS dispersion modelling system in order to generate ambient air concentrations. The added value in using AirQUIS is its powerful dispersion module based on local meteorological data.

The resulting concentration distributions are then used in Excel spreadsheets based on visual macros that allows the user to evaluate health effects, potential management options and related costs. This Excel platform is currently under development at NILU.

This simple integrated decision support tool meets the requirement of a first screening of air pollution problems in defined areas and requires less computing power than existing advanced air quality management tools including complex dispersion models.

This paper describes the methodology and the required data for the tool to function. It is based on examples from preliminary results generated for Hanoi, Vietnam, where this approach has already been used.

3. System domain

A model domain must be defined prior to any analysis. An example for the city of Hanoi is shown in Figure 1.

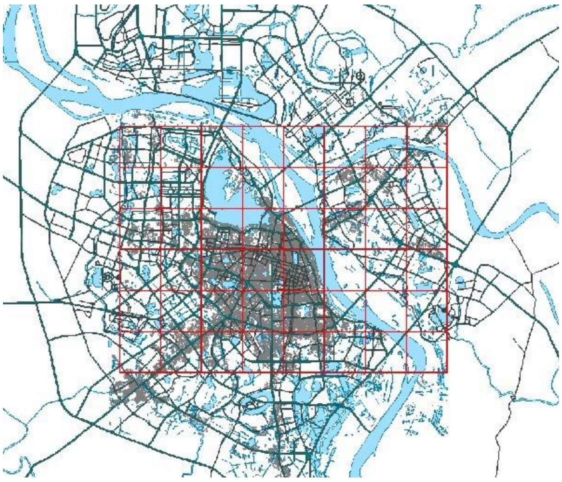

Figure 1: Model domain for the city of Hanoi, Vietnam, based on a GIS platform.

Maps of the area have to be collected in order to define boundaries, grid resolution and important features of the area. If digital maps are available these can be added directly into AirQUIS. The grid will then be transferred into Excel sheet cells.

4. Input data

Input data for the modelling system are collected in an Excel sheet format. These data include:

- Population data
- Meteorological data
- Emission data
- Emission factors for source categories
- Dose response functions
- Cost estimates

4.1 Population data

Information about population statistics must be collected in order to distribute total emissions of pollutants, to evaluate the highest activity areas and to enable exposure estimates. Such data must be distributed over the model domain.

Population data are needed down to the finest resolution available:

- Districts
- Wards
- Kilometre scale

In any cities, information about the population distribution can be collected from local authorities and experts working with area planning and master plans for the area. In the example of Hanoi City, the population census data have been tabulated for the national, regional and provincial levels and separated by urban and rural areas.

4.2 Meteorological data

Meteorological data are important as part of a complete air quality monitoring system.They must be provided as inputs to dispersion models and may also help to visualise the importance and impact of different sources in the area and to understand the air quality measured.

Local meteorological data can be collected from local authorities and national meteorological institutes. Such data should be obtained from monitoring stations operated in the area under study. When no such station is available one alternative is to obtain data from stations operated in a worldwide station network from the World Meteorological Organisation (WMO).

The required meteorological input data should be based on continuous measurement of the most important parameters such as:

- Wind speeds,
- Wind directions,
- Turbulence/stability
- Relative humidity,
- Temperatures or vertical temperature gradients.

Wind and stability statistics including wind roses will have to be generated and will serve as support to the system.

4.3 Emission data

Rough emission inventories are generated based on a top-down approach, or from more advanced bottom-up approaches. A top-down emission inventory is usually carried out for cities where no previous emission study has been made.

Complete emissions inventories require larger resources, in comparison to the needs and resources available in developing countries. As an alternative to this problem, the NILU approach requires the collection of some basic data for a top-down approach.

4.3.1 Top-down emission inventory

Simple top-down emission inventories can easily be carried out. For instance, considering the example of traffic as a main source of air pollution in an area, the following data would be necessary to achieve the top-down inventory:

- Vehicle fleet data (number of vehicles per main vehicle class);
- Fuel use statistics (amount per annum).
- Emission factors (EF, amount of PM, NOx etc. emitted per km driven, per vehicle class). We have used EFs from different sources of information in the Region and in other parts of the World;
- Average kilometres driven per year, per vehicle class has been estimated based on input from local authorities and from other studies;
- Estimate the traffic density flows (vehicles per day) on some main roads.

As another example, when industrial sources need to be included in the evaluation, information would be required concerning:

- A survey of air polluting industries, by type or industrial sector
- Data on products / raw materials / fuels consumed / product output if available
- Period of production (if different from entire year)
- Emission factors (EF) from literature (e.g. EU Corinair, USEPA AP42)

Other sources in the area being studied may be more difficult to estimate. Many of the random area sources are normally not well known. The same is true concerning re-suspended dust from roads and other surfaces.

For refuse burning it is possible to estimate the amount burned per annum e.g. from the number of households and refuse produced per household per day. Associated emission factors can then be taken from the literature. Other area sources and small enterprise activities can be in some cases linked to population distributions.

4.3.2 Emission factors

The emission factors used in different studies in Asia may vary considerably. The numbers selected in the table below represents an average of the vehicle park typically available in Hanoi with a reference to the year 2005.

For the study undertaken in the city of Hanoi, Vietnam, the emission factors (EFs) were collected for each pollutant compound separately including SO_2, NOx, PM (PM_{10} as well as $PM_{2.5}$, if available) and CO_2. Background information from other cities in Asia was used as indicated in Figure 2.

5. Health impact

The Excel based method for evaluation of health impacts as part of the simplified assessment tools is currently being further developed at NILU.

Vehicle type	Fuel	NOx	PM	Ref
MC-2 stroke	Gasoline	0.02	0.30	Shu
MC-4 stroke	Gasoline	0.20	0.10	Khaliquzzaman
Light car	Gasoline	1.5	0.10	Anglo
Heavy car	Gasoline	6.1	0.15	Lentz
Bus	Gasoline	3.2	0.40	Anglo
Truck	Gasoline	7.5	0.24	Anglo
Light car	Diesel	8.5	0.6	Suksod
Heavy car	Diesel	11.0	0.8	USEPA, Anglo
Bus	Diesel	7.6	1.5	Suksod
Truck	Diesel	17.0	1.6	Khaliquzzaman

Figure 2: Emission factors used for estimating emission rates of NOx and PM in Hanoi, Vietnam

Methods for evaluating health impacts have been discussed and are still a debatable issue. The World Bank developed SIM-AIR model takes into account a number of different health related being used in the development of the simplified version of the assessment tool. Costs are being estimated for the control options used in the various scenarios balanced against the reduced costs of health impacts.

7. Concentrations and exposure estimates

The models have used the results of top-down emission estimates together with meteorological statistics to generate concentration distributions for the study area. Figure 3 shows an example of the concentrations of NOx estimated for all sources in Hanoi 2005.

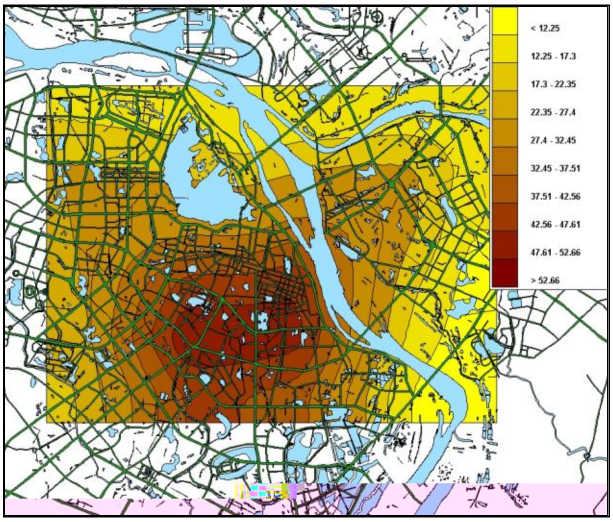

Figure 3: The NOx concentration distribution due to emissions from all types of vehicle units in Hanoi, 2005.

The sources included in the estimates were: motorbikes, petrol and diesel cars, heavy vehicles, trucks and buses.

As a first estimate/surrogate for the total population exposure the estimated concentrations have been used together with the population distributions to estimate the person-weighted concentrations. These results can further be used with dose/response functions to evaluate the health impact. It has also been possible to assess the relative importance of different sources as related to the total population exposure.

8. Relative importance of different sources

The relative contribution from each of the vehicle categories has been estimated for NOx, PM_{10} and SO_2. The NOx contributions are presented in Figure 4 based on the estimated person weighted concentrations.

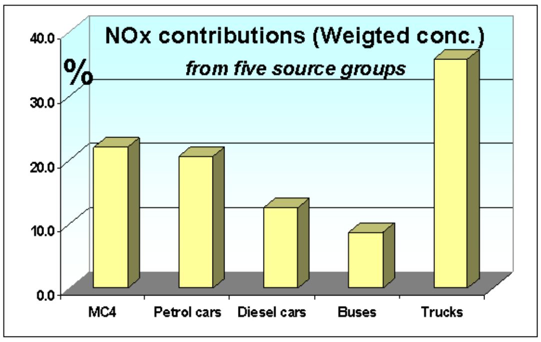

Figure 4: The relative contribution of person weighted average concentrations of NOx in Hanoi from each of five vehicle categories.

These estimates show that NOx exposure due to traffic emissions is caused by: 36% emissions from trucks, motorcycles represented 22%, petrol driven cars about 20%, diesel cars 12% and buses about 8%.

A similar estimate for the PM_{10} contributions indicated that traffic emissions on the annual average contributed to about 23% of the total population exposure in Hanoi. Industrial sources contributed to about 15% and other undetermined sour n d gp db fbmpi i ondpo o about 62% of the exposure.

9. Limitations and advantages

The estimates and methods presented above can only be considered as a first input to air quality assessment and management. In order to reduce uncertainties in such estimates it would be necessary to develop complete emission inventories. The resolution of the models should be increased, and input data should be quality controlled.

However, as a first approach we believe that estimates using this simplified method will support the decision making process to identify and verify the best possible actions needed in order to reduce the air pollution impact.

The simplified method may be used both in situations were no or little information is available and in cases where there is a fair amount of data available already. Simple decision support systems of this kind may also help stakeholders and participants in the generation of air quality management plans or action plans in better assessing the different options.

Acknowledgments

The development of improved simplified management tools is supported by NILU. The first estimates performed for Hanoi was supported by the World Bank and input data were collected in co-ordination with the Hanoi Department of Natural Resources, Environment and Housing.

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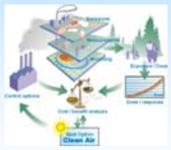

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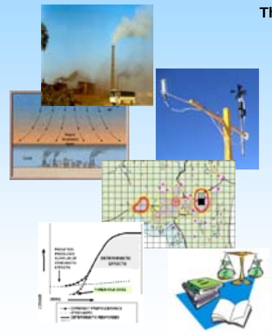
Impact Pathway Approach



The complete integrated analyses

- Identify sources Emission inventory
- Meteorological data Dispersion and turbulence
- Dispersion modelling SO2, NOx, PM +
- Concentrations, Exposure
- Exposure/response functions
- Effect / cost data
- Optimised plan

modelling

Simplify methods

AQMS ➡ Action Plan

cost-effective

AQM tools

- Monitoring /air pollution and meteorology
- Surveys / population, emissions inventory
- Modelling / air quality and exposure
- Guidelines / Regulations
- Impact and Cost Analysis
- Air Quality Information System

⟺ assessment

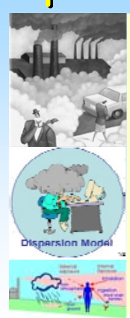
Reduction measures:

- Mobile sources (traffic)
- Stationary sources
- Processes, industries
- Waste handling
- Renewable energy
- Residential sources
- Use of coal

Short term – medium
- long term actions

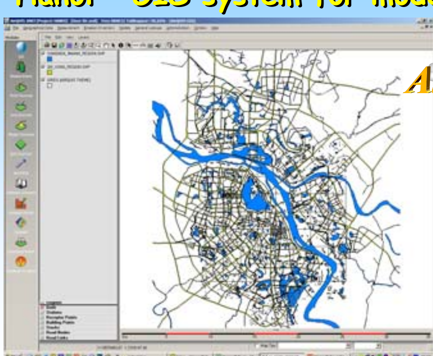
area specific !

Input data



- ✓ Population data
- ✓ Meteorological data
- ✓ Emission data
- ✓ Emission factors for source categories
- ✓ Dose response functions
- ✓ Cost estimates

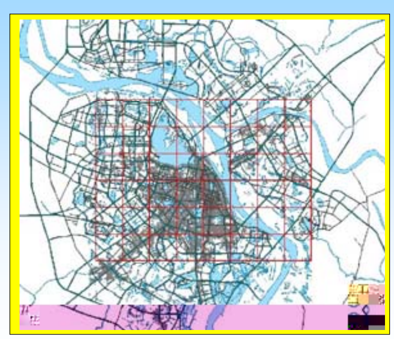
Hanoi - GIS system for modelling



AirQUIS
NILU
⇕
Sim-AIR
Shah et.al.

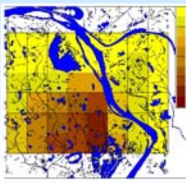
The Hanoi grid system

192 km²
16 x 12 squares
2km x 2km grid



Hanoi gridded information

Population data
Emission data
Concentrations

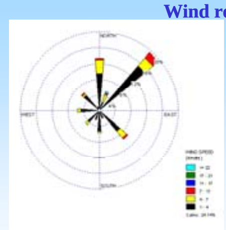


2000	3000	5000	3000	2000	6000	7000	8000
7000	9000	2000	4500	3000	2500	6000	7000
25000	45000	40000	70000	90000	8000	3000	2000
15000	80000	85000	88000	134140	9000	8000	6000
40000	75000	120000	110000	115000	20000	7000	3000
15000	45000	82000	70000	105000	50000	20000	2000

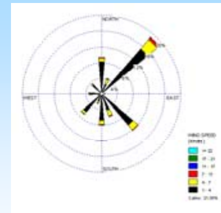
2km x 2km grid

Wind data for Hanoi

Wind roses Hanoi



September 2005



Annual wind

from WMO database

Top-down emission inventory

- **Vehicle fleet data (number of vehicles per main vehicle class);**
- **Fuel use statistics (amount per annum).**
- **Emission factors (EF, amount of PM, NOx etc. emitted per km driven, per vehicle class).** *EFs from the Region and from other parts of the World*;
- **Average kilometres driven per year, per vehicle class has been estimated based on input from local authorities and from other studies;**
- **Estimate the traffic density flows (vehicles per day) on some main roads.**

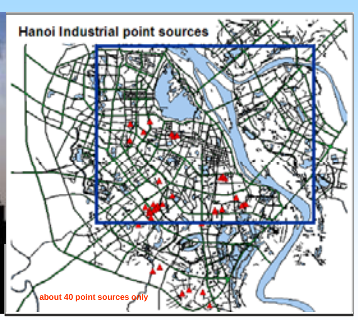
Emission factors

Unit: g/km

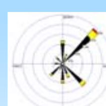
Vehicle type	Fuel	NOx	PM	Ref
MC-2 stroke	Gasoline	0.02	0.30	Shu
MC-4 stroke	Gasoline	0.20	0.10	Khaliquzzaman
Light car	Gasoline	1.5	0.10	Anglo
Heavy car	Gasoline	6.1	0.15	Lentz
Bus	Gasoline	3.2	0.40	Anglo
Truck	Gasoline	7.5	0.24	Anglo
Light car	Diesel	8.5	0.6	Suksod
Heavy car	Diesel	11.0	0.8	USEPA, Anglo
Bus	Diesel	7.6	1.5	Suksod
Truck	Diesel	17.0	1.6	Khaliquzzaman

Point sources in Hanoi

Additional emission data needed for stacks

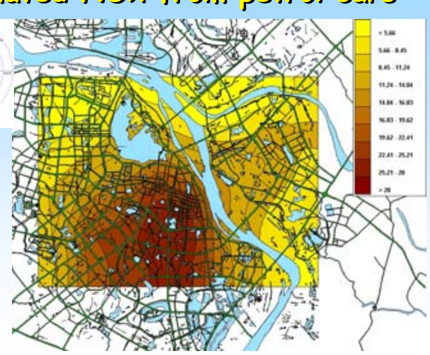


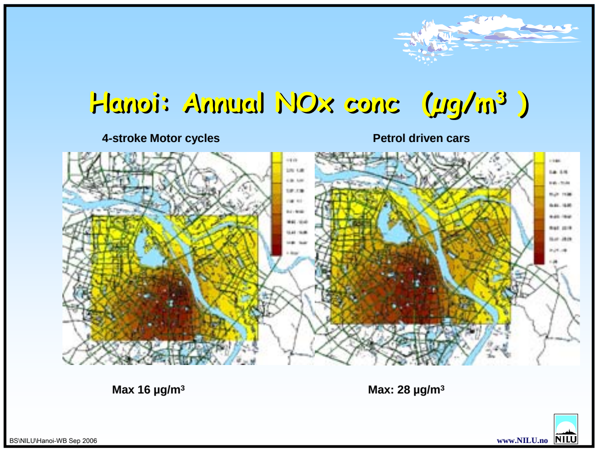
Estimated NOx from petrol cars

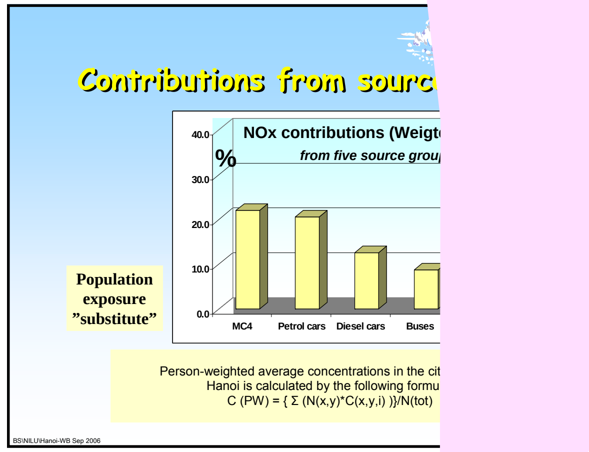


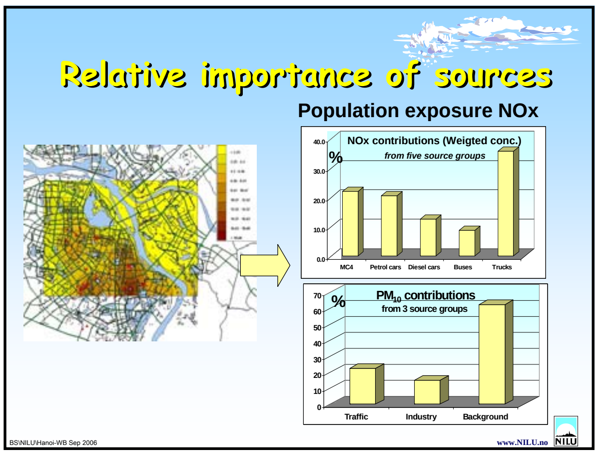
wind direction frequency (windrose)

μg/m3




Hanoi: Annual NOx conc (µg/m3)
4-stroke Motor cycles
Petrol driven cars
Max 16 µg/m3
Max: 28 µg/m3
BS\NILU\Hanoi-WB Sep 2006
www.NILU.no
NILU


Contributions from sourc
NOx contributions (Weigt
from five source grou
%
40.0
30.0
20.0
10.0
0.0
MC4
Petrol cars
Diesel cars
Buses
Population
exposure
"substitute"
Person-weighted average concentrations in the cit
Hanoi is calculated by the following formu
C (PW) = { Σ (N(x,y)*C(x,y,i))}/N(tot)
BS\NILU\Hanoi-WB Sep 2006


Relative importance of sources
Population exposure NOx
NOx contributions (Weigted conc.)
from five source groups
%
MC4
Petrol cars
Diesel cars
Buses
Trucks
PM10 contributions
from 3 source groups
%
Traffic
Industry
Background
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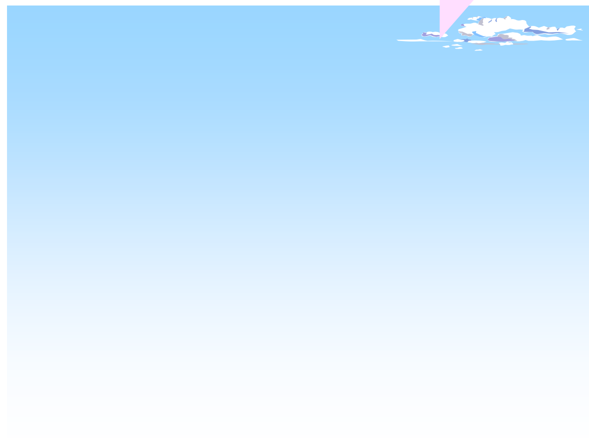
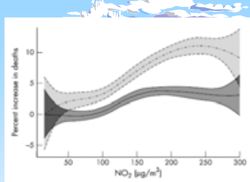


Cost of Reduced Impacts

Dose/response functions →



A large number og health end points and pollutants

- Chronic mortality from PM
- Infant mortality from PM
- Acute mortality from ozone
- Morbidity impacts from PM
- Morbidity impacts from ozone

Costs of effect as estimated in Europe

Mortality	Median value	Mean value
Infant mortality	€1,500,000/death	€4,000,000/death
Value of statistical life	€980,000/death	€2,000,000/death
Value of a life year	€52,000/year	€120,000/year

Morbidity	low	central	high
Chronic bronchitis	€120,000/case	€190,000/case	€250,000/case
Respiratory/cardiac hospital admissions		€2,000/admission	
Primary care consultations		€53/consultation	
Restricted activity day (stay in bed)		€130/day	
Minor restricted activity day		€38/day	
Use of respiratory medication		€1/day	
Symptom days		€38/day	

CAFE CBA 2005

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Cost benefit analysis

A comparison of cost-benefit of various control options for SO_2 and TSP in Taiyuan, China

Cost benefit analysis:

A comparison of cost-benefit of various control options for SO_2 and TSP in Taiyuan

A comparison of cost-benefits of various control options for SO2 in Taiyuan

	Emission Reduction (t)	Concentration reduction (μg/m³)	Cost-benefit ratio	Rank
Natural gas utilization	20400	19.79	-52	2
Desulfuration in power plants	18460	6.47	115	4
Centralized heating	30000	51.89	-424	1
Implementation of productivity policies	9280	5.75	2000	5
Clean coal technology	36600	6.24	-23	3

A comparison of cost-benefits of various control options for TSP in Taiyuan

	Emission Reduction (t)	Concentration reduction (μg/m³)	Cost-benefit ratio	Rank
Natural gas utilization	31900	16.7	-0.489	2
Centralized heating	69400	90.29	-1.601	1
Implementation of productivity policies	17000	18.57	3.711	5
Clean coal technology	47100	93.13	-0.008	3
Dust control		50	1.813	4

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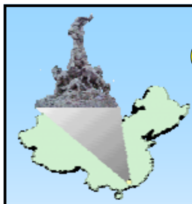
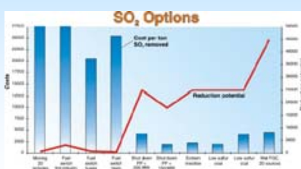
Guangzhou



- A.Q. Assessment
- Health impacts
- Abatement options
- Cost/benefit analyses
- Optimal abatement strategy

Cost effective SO_2 options



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Further work needed for Hanoi

- ✓ Improve input data
- ✓ Emissions from point sources
- ✓ Small industries and area sources?
- ✓ Better meteorology, Stability data?
- ✓ Emission factors for MC, cars, industries etc
- ✓ Complete emission inventory

AQM

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Thank you !

Modelling environmental friendly vehicles !

no engine
no pollution !

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