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An initial implementation of the RAINS model to assess emission of air pollutants in Egypt

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About the author

Mahmoud A. Hassanien is Assistant Professor at the Air Research and Pollution Control Department of the National Research Center, Cairo, Egypt. His work addresses the assessment, monitoring and regulation of air quality parameters, application of multimedia partitions models, environmental and health impacts assessment, emission of pollutants, costs of emission reduction, field experiments, applications and abatement policies.

1 Introduction

Egypt's rapidly growing economy is accompanied by increasing levels of air pollution, particular in its urban areas. As in many other countries, the major sources of air pollution in Egypt are road transport, stationary combustion of fossil fuels and open burning of waste. Energy consumption has increased by more than 170 percent over the last 20 years.

However, there is limited experience in quantifying the sources of air pollution of Egypt and in designing efficient strategies to keep pollution at levels that do not cause serious impacts on human health. As a first attempt, this study applies the Regional Air Pollution INformation and Simulation (RAINS) model developed at the International Institute for Applied Systems Analysis (IIASA) to estimate emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter (PM) in Egypt. In further steps, the work could be extended to obtaining a more complete set of emission data to explore strategies that reduce the impact of air pollution on the environment while not hampering economic development.

The study, carried out during the Young Scientists Summer Program (YSSP) at the International Institute for Applied System Analysis (IIASA), Laxenburg, Austria, aimed at a draft implementation of the RAINS model for Egypt. In absence of more specific information, the study used default emission factors contained in the RAINS model and applied them to activity levels derived from international energy and commodity statistics. The study attempted to construct a projection of future emissions in Egypt based on information of the IPCC SRES B2 energy scenario (Nakicenovic *et al.,* 2001).

A methodology has been developed to estimate emission control costs of standard technologies under the specific conditions characteristic for Egypt. Based on the assumption of the general availability of control technologies with equal technical properties and costs, a number of country-specific circumstances (level of technological advancement, installation size distribution, labour costs, etc.) are used to estimate the costs for the actual operation of pollution control equipment.

2 Background

Low air quality is a major problem in most cities around the world. It has been observed that current concentrations of pollutants in urban air have impacts in inhabitants' health. The situation is most serious in developing countries.

Since the 1960s, Egypt has witnessed rapid development and industrialization, a by-product of which has been the generation of large amounts of air pollutants. As a result, air quality has decreased drastically in Egypt. This is particularly evident in the two major cities of Cairo and Alexandria, where more than 80 percent of industrial activities take place (JICA, 2002).

Egypt is located in northern Africa, bordering the Mediterranean Sea between Libya and the Gaza Strip. To the south, it shares a border with Sudan. The country has a total area of 1,001,450 sq km, with 3,500 km of coastline facing the Mediterranean in the north and the Red Sea in the east (Fig. 1). The delta and the narrow valley of the Nile comprise 5.5 percent of the area of Egypt, but have over 95 percent of its people and its agriculture. With the exception of small areas of cultivated land in the oases of the western desert, the coastlands west of the delta, and in Northern Sinai, the rest of Egypt is desert (EEAA, 1999).

Figure 2.1: Map of Egypt

Egypt is the second most populous country in Africa. The population of Egypt was 55 million in 1990, the baseline date for this study. It increased to around 65 million by 1998. Almost fifty percent of the population lives in the urban areas and the rest in compact rural settlements surrounded by intensively cultivated irrigated land. This growing urban population has exerted a lot of pressure on both demand and supply for electricity, water and waste management.

2.1 Air Pollution in Egypt

Air pollution in Egypt arises from natural and anthropogenic sources. As an example, Cairo's topography, its proximity to the desert, and meteorological conditions (low precipitation rates), make it particularly susceptible to natural air pollution, especially from airborne dust. However, the most important sources of air pollution are anthropogenic. These sources include industrial facilities, thermal power stations, illegal open burning of municipal solid waste and other hazardous waste, in addition to serious pollution caused by vehicles exhaust. Among the most common air pollutants in Egypt are sulphur dioxide (SO_2), suspended particulate matter.

Average daily emissions of primary pollutants in Egypt, such as hydrocarbon, nitrogen oxides, carbon monoxide, and others are among the largest in the world. The sources of pollution are distributed all over Egypt and range from point sources using fossil fuel over open waste burning to diesel vehicles running day and night in the streets. To control the negative impacts of air pollution and other environmental problems, the Egyptian Parliament set up a law 4/1994 to protect the environment in Egypt.

Table 2.1 presents the Ambient Air Quality limit values as given by law No. 4 for Egypt and compare them to the World Health Organisation (WHO) Air Quality guideline values.

Table 2.1: Ambient Air Quality Limit Values as given by Law No. 4 for Egypt (1994) compared to the World Health Organization (WHO) Air Quality Guidelines

Pollutant	Averaging time	Maximum limit value (µg/m^3) Egypt	WHO
Sulphur dioxide (SO_2)	1 hour	350	500 (10 min)
	24 hours	150	125
	Year	60	50
Carbon monoxide (CO)	1 hour	30 000	30 000
	8 hours	10 000	10 000
Nitrogen dioxide (NO_2)	1 hour	400	200
	24 hours	150	-
	Year		40 – 50
Ozone (O_3)	1 hour	200	150 – 200
	8 hours	120	120
Total suspended particulate (TSP)	24 hour	230	-
	Year	90	-
Suspended particulate measured as smoke black	24 hours	150	50 *
	Year	60	-
Particulate < 10 µm (PM10)	24 hours	70	70 **
Lead (Pb)	Year	1	0.5 – 1,0

* Together with SO_2 ** Norwegian Air Quality Limit value

Air pollutants are transported in the atmosphere over long distances. Their concentrations in the air and depositions depend not only on the emissions from local sources but also on the emission levels and meteorological conditions (wind patterns, precipitation) over large areas. Once emitted, pollutants undergo complex processes of transformation and interact with each other. When primary pollutants are exposed to sunshine, they undergo chemical reactions and yield variety of secondary pollutants, ozone being the most important one (Elramsisi *et al.,* 2001).

Sulphur dioxide (SO_2) is generated from burning fossil fuels in electrical power stations and transport vehicles. Sulphur dioxide is also generated from different industrial processes such as chemical industries, coke and fertilizer production, petroleum production and metallurgical processes. The concentration levels for sulphur dioxide have been observed to exceed the annual average of the Egyptian Air Quality Limit (60 µg/ m^3), particularly in the main industrial areas of Cairo, and in some occasions in other major cities (Law 4/1994).

Nitrogen dioxide (NO_2) is a poisonous gas formed when nitric oxide combines with hydrocarbons and sunlight, producing a photochemical reaction. These conditions occur in both natural and anthropogenic activities. NO_2 is emitted with combustion of fuels and biomass, motor vehicles and industrial activities as well as from bacteria, nitrogenous fertilizers, aerobic decomposition of organic matter in oceans and soils.

Egypt experiences comparably high levels of emissions of Total Suspended Particulate (TSP). The sources include natural airborne dust from the desert as well as anthropogenic sources, such as motor vehicle exhaust and various industrial processes. PM10 is among major air pollutants in Egypt. Its concentration in some sampling sites can reach a daily average of more than 400 $\mu g/m^3$, which is six times above the Air Quality Limit value for Egypt (70 $\mu g/m^3$). These high concentrations are observed near the areas of cement and brick industries, as well as crowded, and traffic-congested roads and streets.

The impacts of these large particles can be observed and seen without sensors or tracing equipments. Damage occurring to properties and possessions, darkening of the sky, soiling of surfaces, limiting the visibility, annoyance to the senses of people, and finally the direct damage to health, all are other forms of impacts resulting from air pollution generated from the industrial process.

Recent studies in the United States have shown that those living in less polluted cities live longer than those living in more polluted cities. After adjustments for other factors, an association remained between ambient concentrations of fine particles and shorter life expectancy (Pope *et al.,* 2002).

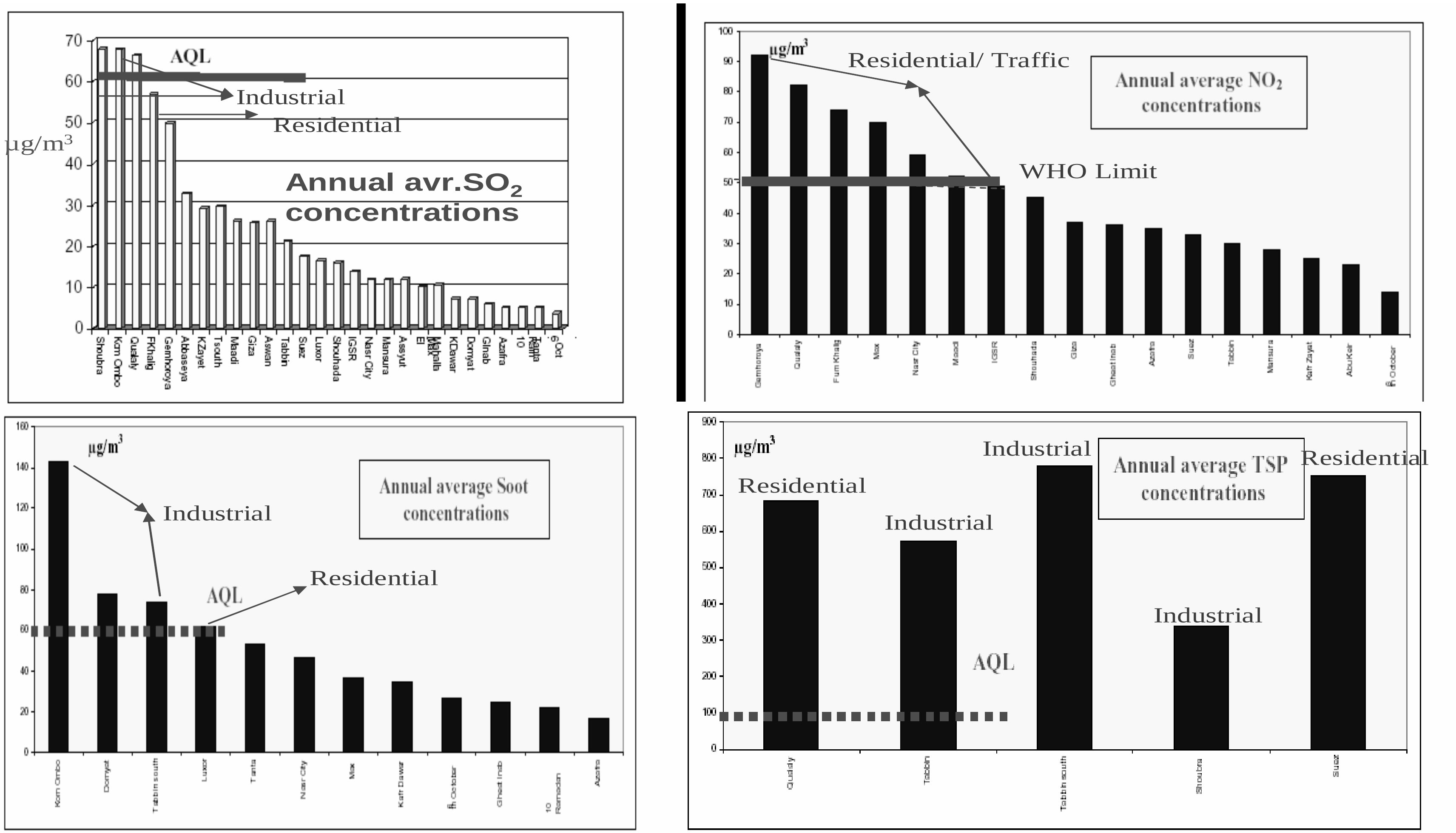
While these recent scientific findings put a focus on smaller particles (PM10 and less) that penetrate deeply into the lungs, other theories are concerned about airborne particles that are important carriers of metals, certain of which possess toxic properties and commonly are present in excess of natural levels. Consequently, it has been proposed that the toxic properties of particles in part may be due to the biochemical activity of metals (e.g., Smith and Aust, 1997; Lighty *et al.,* 2000). Larger particles that can be inhaled and may be an important source of bio-chemically active metals in the guts. Larger metal-containing particles are also of ecotoxicological concern due their more rapid deposition to soils and surface waters.

2.2 Ambient air quality in Egypt in the year 2000

The ambient air quality in Egypt during 2000 is summarized in Figure 2.2. It shows the annual average concentrations of SO_2 for the year 2000. From the figure, we can see that the annual Air Quality Limit value of 60 $\mu g/m^3$ for SO_2 has been exceeded at three of the 28 sites in 2000 (at Shoubra, Komombo and Qualaly). At Fum khalig the annual average has reached 57 $\mu g/m^3$. It is important to note that two of the three sites that exceeded the Air Quality Limit value are industrial surrounded with residential areas.

The annual Air Quality Limit value for Black Smoke (BS) of 60 µg/m^3 has been exceeded at four sites in 2000 (at Komombo, Domyat, Tabbin south and Luxor). BS annual average is presented in Figure 2.2. Although there is no annual limit for NO_2 in the Environmental Law No.4 of Egypt, the World Health Organization air quality guideline value is set at 40-50 µg/m^3. This value has been exceeded at six sites (Gomhoryia, Qualaly, Fum Khalig, El Max, Nasr city and Maadi). Most of these sites are traffic areas impacted by emissions from motor vehicle cars.

Egypt experiences high concentrations of particulates during most of the year. There is no annual limit for PM10 concentrations in the Egyptian law of Environment. El Mahalla and Kafr Zayat station have very high concentrations on an annually basis (369 and 251 µg/m^3 respectively). It can be concluded also from other studies that the annual average TSP concentrations in all measurement sites during 2000 were ranging between four to eight times above the Air Quality Limit values (Hassanien, 2002 & 2001; Hassanien *et al.*, 2001 and Hassanien and Shakour, 1999).



Source: Egyptian Environmental Affairs Agency (EEAA); Air Quality in Egypt, 2000

Guideline value for NO_2 WHO: Air quality guidelines value is shown. For some locations, preliminary source contributions are shown (residential, industrial, and traffic).

Figure 2.2: Annual average concentration of pollutants in Egypt during 2000 at selected locations

2.3 Emission standards in Egypt

The protection of the atmospheric environment from pollution presents one of the primary lines of action of the Ministry of State for Environmental Affairs (MSEA) and the Egyptian Environmental Affairs Agency (EEAA), reflected by the long-term commitment to this issue as expressed by the five year action plan (2002 – 2007). This is in line with the continuous efforts in enforcing existing environmental legislation, as air quality is one of the principal issues addressed in Law (4/1994) for the Environment (see Table 2.2 and Table 2.3).

Table 2.2: The maximum permissible limits of overall particles (TSP) emissions from industrial installations

S. No.	Kind of Activity	Maximum limit for emissions (mg/m^3 from exhaust)
1.	Carbon Industry	50
2.	Coke Industry	50
3.	Phosphates Industry	50
4.	Casting and extraction of lead, zinc, copper, and other non-ferrous metallurgical industries.	100
5.	Ferrous Industries	200 Existing 100 New
6.	Cement Industry	500 Existing 200 New
7.	Synthetic woods and fibres	150
8.	Petroleum and Oil Refining Industries.	100
9.	Other Industries	200

Source: Law 4/1994 for the Environment

Table 2.3: The maximum permissible limits of gas and fumes emissions from industrial installations

	Pollutant	Maximum limit for emissions (mg/m^3 from exhaust)
*	Aldehydes (measured as Formaldehyde)	20
*	Antimony	20
*	Carbon Monoxide (CO)	500 Existing 250 New
*	Sulphur Dioxide (SO_2)	
	Burning Coke and Petroleum	4000 Existing 2500 New
	Non-ferrous Industries	3000
	Sulphuric Acid Industry & other sources	1500
*	Sulphur trioxide in addition to sulphuric acid	150
*	Nitric Acid	
*	Nitric Acid Industry	2000
*	Hydrochloric Acid (Hydrogen Chloride)	100
*	Hydrofluoric Acid (Hydrogen Fluoride)	15
*	Lead	20
*	Mercury	15
*	Arsenic	20
*	Heavy elements (total)	25
*	Silicon Fluoride	10
*	Fluorine	20
*	Tar	
	Graphite Electrodes Industry	50
*	Cadmium	10
*	Hydrogen Sulphide	10
*	Chlorine	20
*	Carbon	
	Garbage Burning	50
	Electrodes Industry	250
*	Organic Compounds	
	Burning of organic liquids	50 0.04% of crude (oil refining)
*	Copper	20
*	Nickel	20
	Nitrogen Oxides	
	Nitric Acid Industry	3000 Existing 400 New
	Other sources	300

Source: Law 4/1994 for the Environment

To further improve air quality in Egypt, studies should be carried out to identify the most appropriate actions that achieve acceptable levels of air quality while not impeding the economic development. Strategies for controlling emissions have to take into account the different sources and address the control potentials for the various sources in a targeted way. To strike a balance among control measures for various pollutants in different economic sectors is a demanding task, and a large body of information needs to be considered (EEAA, 2000; EIMP, 2000; MSEA/EEAA, 2000).

In urban areas, road traffic is recognized as an important source of both particles and certain elements (e.g., Kowalczyk *et al.,* 1982; Gertler *et al.,* 2000; Wrobel *et al.*, 2000; Pakkanen *et al.,* 2001). Understanding emissions from traffic includes identification of the sources, which is also crucial for designing control measures. Road traffic involves numerous potential sources of metals, e.g., combustion products from fuel and oil, wear products from tires, brake linings, bearings, coach and road construction materials, and re-suspension of soil and road dust. Therefore, emission measurements in conventional dynamometric tests alone are not sufficient to fully address this problem. In order to do so, studies need to be performed under realistic driving conditions.

In a further step, the maximum acceptable limits of pollutants emissions should be reviewed. Standards should be defined unambiguously and should refer to specific processes. The present standards do not include important activities (e.g., power plants) that emit the greatest amount of SO_2 to the atmosphere. Therefore, when revising these standards, i) the gaps should be filled to be in agreement with the requirements of future clean air; ii) the types of pollutants should be clearly specified (instead of reporting e.g., organic compounds) iii) the types of industries should be more specifically listed (e.g., “other industries”); and iv) the different options for controlling the emissions in each industrial sector should be clearly specified.

3 The RAINS model

The Regional Air Pollution INformation and Simulation (RAINS) model developed at the International Institute for Applied Systems Analysis (IIASA, Laxenburg, Austria) provides a consistent framework for the analysis of emission reduction strategies, focusing on acidification, eutrophication and tropospheric ozone. The complete description of RAINS model is reported by Amann *et al*. (1999) and see also the RAINS web site: http://www.iiasa.ac.at/rains/index.html.

Briefly, RAINS comprises modules for emission generation (with databases on current and future economic activities, energy consumption levels, fuel characteristics, etc.), for emission control options and costs, for atmospheric dispersion of pollutants and for environmental sensitivities (i.e., databases on critical loads and levels). The model considers emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3), volatile organic compounds (VOC) and fine particulate matter. Thus, it simultaneously addresses four environmental problems: damage to human health, acidification, eutrophication and tropospheric ozone. A description of the general approach used by the RAINS model was reported by Alcamo et al. (1990). More information about the current multi-pollutant, multi-effect version of the model can be found in Amann et al. (1999). A schematic diagram of the RAINS model is displayed in Figure 3.1.

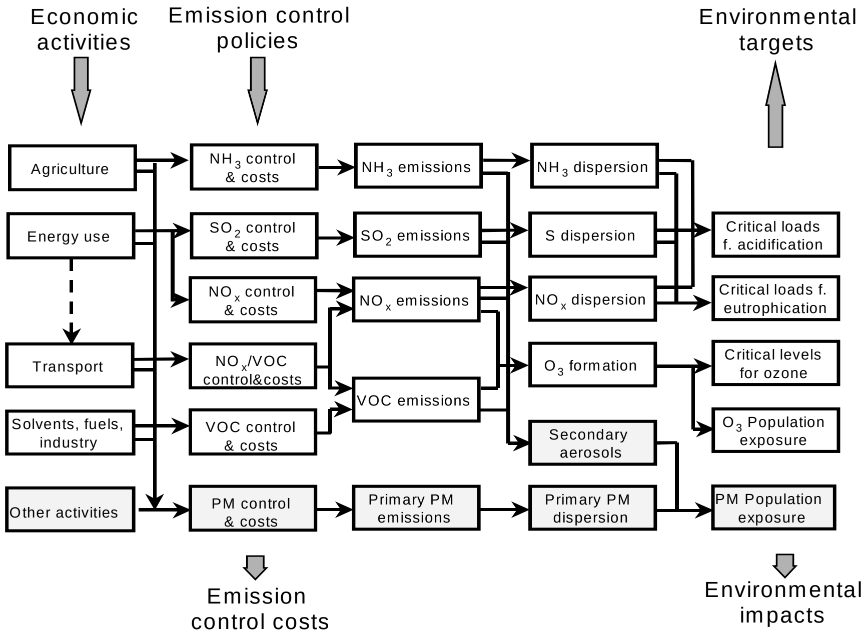


Figure 3.1: A schematic diagram of the information flow in the RAINS model

The RAINS model can be operated in the 'scenario analysis' mode, i.e., following the pathways of the emissions from their sources to their environmental impacts. In this case, the model provides estimates of regional costs and environmental benefits of alternative emission control strategies. Alternatively, an 'optimisation mode' is available to identify cost-optimal allocations of emission reductions in order to achieve specified deposition and concentration targets. This mode of the RAINS model was used for preparation of European environmental policy agreements.

3.1 Methodology for emission estimates

In this section, a brief overview of the principal methods for estimating emissions of SO_2, NO_x and PM employed in the RAINS is provided. More detailed information can be found in Klimont *et al.*, 2002; Cofala and Syri 1998a and 1998b and the Internet version of the RAINS PM module (available at http://www.iiasa.ac.at/rains/Rains-online.html).

3.1.1 Sulphur dioxide and nitrogen oxides

Emissions of SO_2 and NO_x are estimated according to the following formula:

$$E_{i,y} = \sum_{j,k,m} E_{i,j,k,m,y} = \sum_{j,k,m} A_{i,j,k} ef_{i,j,k,y} (1 - eff_{m,y}) X_{i,j,k,m,y} \quad (1)$$

where:

i,j,k,m Country, sector, fuel, abatement technology;

Y Pollutant (SO_2 or NO_x)

$E_{i,y}$ Emissions of pollutant y in country i;

A Activity in a given sector, e.g. coal consumption in power plants;

ef Uncontrolled emission factor, for SO_2 derived for stationary sources depending on fuel parameters (see equation 2);

$eff_{m,y}$ Reduction efficiency of the abatement option m for pollutant y, and;

X Actual implementation rate of the considered abatement, e.g., percent of total coal used in power plants that are equipped with electrostatic precipitators.

If no emission controls are applied, the abatement efficiency equals zero ($eff_{m,y} = 0$) and the application rate is one (X = 1). In that case, the emission calculation is reduced to simple multiplication of activity rate by the uncontrolled emission factor.

While a number of SO_2 and NO_x emission factors is derived from the literature, the SO2 *ef* is derived based on the information on region (regional data are preferable to national average values when such data are available), fuel and sector specific sulphur content, calorific value are to be specific for all fuels, sulphur retention in ash for the solid fuels; see Equation 2 for SO_2 and Equation 3 for NO_x .

$$\mathbf{ef_{SO2} = sc/hv * (1 - sr)} \quad (2)$$

- where the sulphur content (sc), the heat value (hv) of fuels and the sulphur retention in ash (sr) are considered.

$$\boldsymbol{e}\mathbf{(NOx)} = \boldsymbol{e}\mathbf{(fuel\text{-}}\boldsymbol{N}\mathbf{)} + \boldsymbol{e}\mathbf{(thermal\text{-}}\boldsymbol{N}\mathbf{)} + \boldsymbol{e}\mathbf{\ (prompt\text{-}}\boldsymbol{N}\mathbf{)} \quad (3)$$

– where e(NOx) is the total NO_x emission factor, e(fuel-N) is a function of the fuel and firing mode, e(thermal-N) is a function of the combustion temperature, residence time, and stoichiometry, and e (prompt-N) is negligible (Alcamo *et al.*, 1990).

3.1.2 Particulate matter

In the RAINS model the emissions of particulate matter (PM) are calculated for three different size classes:

- fine fraction ($PM_{2.5}$),
- coarse fraction (PM_{10} - $PM_{2.5}$) and
- large particles (PM_>10 µm).

Thereby, PM_{10} is calculated as the sum of fine and coarse fractions and total suspended particles (TSP) as the sum of fine, coarse and PM_>10 fractions.

The methodology includes the following three steps:

- In a first step, country-, sector- and fuel-specific "raw gas" emission factors for total suspended particles (TSP) are derived:
  - For solid fuels (excluding biomass and use of solid fuels in small residential installations) the mass balance approach is used where ash content (ac) and heat value (hv) of fuels and ash retention in boilers (ar) are considered:

$$\mathbf{ef_{TSP} = ac/hv * (1 - ar)} \qquad (4)$$

  - For liquid fuels, biomass, solid fuels used in small residential installations, industrial processes, mining, storage and handling of bulk materials, waste incineration, agriculture[1], and transport, TSP emission factors are taken from the literature.

- In a second step, "raw gas" emission factors for each of the size fractions are estimated. This is done based on size fraction profiles reported in the literature for a variety of installations. They are typically given for PM_{10} and $PM_{2.5}$ and are fuel- and installation (sector)-specific. The typical profiles are applied to the country-, fuel- and sector-specific "raw gas" TSP emission rates (see first step) to derive the size-specific emission factors used in RAINS.

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[1] For livestock, literature emission factors refer typically to housing period. Therefore, information on the length of this period (available from the RAINS NH_3 module) was considered to derive annual animal- and country-specific values.

- In a third step, actual PM emissions are calculated for the three size fractions. For a given country (i), PM emissions of size fraction (y) are calculated by applying a general formula across every fuel (activity) and sector, taking into account the application rates of control technologies and size fraction specific emission removal efficiencies,

$$E_{i,y} = \sum_{j,k,m} E_{i,j,k,m,y} = \sum_{j,k,m} A_{i,j,k} ef_{i,j,k,y} (1 - eff_{m,y}) X_{i,j,k,m} \quad (5)$$

where:

i,j,k,m	Country, sector, fuel, abatement technology;
Y	Size fraction, i.e. fine, coarse, PM_>10;
$E_{i,y}$	Emissions of PM in country i for size fraction y;
A	Activity in a given sector, e.g. coal consumption in power plants;
Ef	"Raw gas" emission factor;
$eff_{m,y}$	Reduction efficiency of the abatement option m for size class y, and;
X	Actual implementation rate of the considered abatement, e.g., percent of total coal used in power plants that are equipped with electrostatic precipitators.

If no emission controls are applied, the abatement efficiency equals zero ($eff_{m,y} = 0$) and the application rate is one (X = 1). In that case, the emission calculation is reduced to simple multiplication of activity rate by the "raw gas" emission factor. For details see Klimont et al. (2002).

3.2 Activity data in RAINS

Activity data includes for example, consumption of hard coal in power plants, kilometers driven by heavy-duty trucks, production of cement, numbers of animals, etc. These data are stored in activity pathways. These are sets of data files that include country- and sector-specific data on energy consumption (energy pathway), agricultural activities (agricultural pathway), etc. It is possible to have several alternative development pathways for either single countries or groups of countries that can be used in the subsequent calculations.

3.2.1 Aggregation of emission sources

Pollutants are released from a large variety of sources with significant technical and economic differences. Conventional emission inventory systems, such as the CORINAIR inventory of the European Environmental Agency, distinguish more than 300 different processes causing various types of emissions.

For the RAINS module, an attempt was made to aggregate the emission producing processes into a reasonable number of groups with similar technical and economic properties. Considering the intended purposes of integrated assessment, the major criteria for aggregation were:

- The importance of the emission source. It was decided to target source categories with a contribution of at least 0.5 percent to the total anthropogenic emissions in a particular country.
- The possibility of defining uniform activity rates and emission factors.
- The possibility of constructing plausible forecasts of future activity levels. Since the emphasis of the cost estimates in the RAINS model is on future years, it is crucial that reasonable projections of the activity rates can be constructed or derived.
- The availability and applicability of "similar" control technologies.
- The availability of relevant data. Successful implementation of the module will only be possible if the required data are available.

It is important to carefully define the appropriate activity units. They must be detailed enough to provide meaningful surrogate indicators for the actual operation of a variety of different technical processes, and aggregated enough to allow a meaningful projection of their future development with a reasonable set of general assumptions. As explained later in the text, some of the RAINS sectors contain a number of pollutant emitting processes. It is often the case that for such aggregated sectors some emission control options are not necessarily applicable to all processes (emission sources) that are represented by the activity.

The fuel categories distinguished in RAINS are shown in Table 3.1. RAINS considers the major energy flows for 17 categories of fuels. For solid fuels (hard coal, lignite) the model offers an opportunity to distinguish - within each sector - different quality parameters (grades) such as calorific value, sulphur content or sulphur retained in ash. This increases the accuracy of estimates of emissions and emission control costs. However, if for a specific country, only the average fuel quality parameter is known, only one category is used.

Table 3.1: Fuel categories distinguished in the RAINS module

Fuel type	RAINS code
Brown coal/lignite, grade 1	BC1
Brown coal/lignite, grade 2	BC2
Hard coal, grade 1	HC1
Hard coal, grade 2	HC2
Hard coal, grade 3	HC3
Derived coal (coke, briquettes)	DC
Heavy fuel oil	HF
Medium distillates (diesel, light fuel oil)	MD
Unleaded gasoline, kerosene, naphtha	GSL
Leaded gasoline	LFL
Liquefied petroleum gas	LPG
Methanol	MTH
Ethanol	ETH
Hydrogen	H2
Natural gas	GAS
Wood, biomass	OS1
High sulphur waste	OS2

The major sectors included in the RAINS model are presented in Table 3.2 to Table 3.5. The RAINS model distinguishes ten emission categories for mobile sources and three for stationary combustion sources that are split by relevant fuels, and 17 other sectors. Some categories are further disaggregated to distinguish, for example, between existing and new instillations in power plants, or between tire and brake wear for non-exhaust emissions from transport.

Table 3.2: RAINS sectors related to stationary sources with energy combustion

RAINS sector	RAINS code
Centralized power plants and district heating	
New power plants	PP_NEW
New power plants, grate combustion	PP_NEW1
New power plants, fluidised bed combustion	PP_NEW2
New power plants, pulverized fuel combustion	PP_NEW3
Existing plants [(1)], wet bottom boilers	PP_EX_WB
Existing plants [(1)], other types (of boilers)	PP_EX_OTH
Other types, grate combustion	PP_EX_OTH1
Other types, fluidised bed combustion	PP_EX_OTH2
Other types, pulverized fuel combustion	PP_EX_OTH3
Fuel conversion	
Energy consumed in fuel conversion process	CON_COMB
Fuel conversion, grate combustion	CON_COMB1
Fuel conversion, fluidised bed combustion	CON_COMB2
Fuel conversion, pulverized fuel combustion	CON_COMB3
Residential, commercial, institutional, agricultural use	
Combustion of liquid fuels	DOM
Fireplaces	DOM_FPLACE
Stoves	DOM_STOVE
Single house boilers (<50 kW) - manual	DOM_SHB_M
Single house boilers (<50 kW) - automatic	DOM_SHB_A
Medium boilers (<1 MW) – manual	DOM_MB_M
Medium boilers (<50 MW) - automatic	DOM_MB_A
Fuel combustion in industrial boilers	
Combustion in boilers	IN_BO
Combustion in boilers, grate combustion	IN_BO1
Comb. in boilers, fluidised bed combustion	IN_BO2
Comb. in boilers, pulverized fuel combustion	IN_BO3
Other combustion	IN_OC
Other combustion, grate combustion	IN_OC1
Other combustion, fluidised bed combustion	IN_OC2
Other combustion, pulverized fuel combustion	IN_OC3

[(1)] Refers to all sources that came on line before or in 1990.

Table 3.3: RAINS sectors for other stationary sources of emissions.

RAINS sector	RAINS code
Iron and steel industry	
Coke production	PR_COKE
Pig iron production	PR_PIGI
Pig iron production (fugitive)	PR_PIGI_F
Pelletizing plants	PR_PELL
Sinter plants	PR_SINT
Sinter plants (fugitive)	PR_SINT_F
Open heart furnace	PR_HEARTH
Basic oxygen furnace	PR_BAOX
Electric arc furnace	PR_EARC
Iron and steel foundries	PR_CAST
Iron and steel foundries (fugitive)	PR_CAST_F
Non-ferrous metal industry	
Primary aluminum	PR_ALPRIM
Secondary aluminum	PR_ALSEC
Other non-ferrous metals (lead, nickel, zinc, copper)	PR_OT_NFME
Other industrial processes	
Coal briquettes production	PR_BRIQ
Cement production	PR_CEM
Lime production	PR_LIME
Glass production	PR_GLASS
Petroleum refining	PR_REF
Carbon black production	PR_CBLACK
Fertilizer production	PR_FERT
Other production (glass fiber, PVC, gypsum, other)	PR_OTHER
Small industrial plants, fugitive	PR_SMIND_F
Mining	
Brown coal mining	MINE_BC
Hard coal mining	MINE_HC
Other (bauxite, copper, iron ore, etc.)	MINE_OTH
Agriculture	
Livestock – poultry	AGR_POULT
Livestock – pigs	AGR_PIG
Livestock – dairy cattle	AGR_COWS
Livestock – other cattle	AGR_BEEF
Livestock – other animals	AGR_OTANI
Ploughing, tilling, harvesting	AGR_ARABLE
Other	AGR_OTHER
Waste	
Flaring in gas and oil industry	WASTE_FLR
Open burning of agricultural waste	WASTE_AGR
Open burning of residential waste	WASTE_RES
Storage and handling of bulk materials	
Coal	STH_COAL
Iron ore	STH_FEORE
N, P, K fertilizers	STH_NPK
Other industrial products (cement, coke, etc.)	STH_OTH_IN
Agricultural products (crops)	STH_AGR
Other sources	
Construction activities	CONSTRUCT
Meat frying, food preparation, BBQ	RES_BBQ
Cigarette smoking	RES_CIGAR
Fireworks	RES_FIREW
Other	OTHER

Table 3.4: Categories of PM exhaust emissions from mobile sources considered in RAINS

RAINS sector	RAINS code
Road transport	
Heavy duty vehicles (trucks, buses and others)	TRA_RD_HD
Motorcycles, four-stroke	TRA_RD_M4
Motorcycles and mopeds (also cars), two-stroke	TRA_RD_LD2
Light duty cars and vans, four-stroke	TRA_RD_LD4
Light duty cars, four-stroke, gasoline direct injection	TRA_RDXLD4
Off-road transport	
Two-stroke engines	TRA_OT_LD2
Construction machinery	TRA_OT_CNS
Agricultural machinery	TRA_OT_AGR
Rail	TRA_OT_RAI
Inland waterways	TRA_OT_INW
Air traffic (LTO)	TRA_OT_AIR
Other; four-stroke (military, households, etc.)	TRA_OT_LB
Maritime activities, ships	
Medium vessels	TRA_OTS_M
Large vessels	TRA_OTS_L

Table 3.5: RAINS sectors related to non-exhaust PM emissions

RAINS sector	RAINS code
Road transport, tire wear	
Heavy duty vehicles (trucks, buses and others)	TRT_RD_HD
Motorcycles, four-stroke	TRT_RD_M4
Motorcycles and mopeds (also cars), two-stroke	TRT_RD_LD2
Light duty cars and vans, four-stroke	TRT_RD_LD4
Light duty cars, four-stroke, gasoline direct injection	TRT_RDXLD4
Road transport, brake wear	
Heavy duty vehicles (trucks, buses and others)	TRB_RD_HD
Motorcycles, four-stroke	TRB_RD_M4
Motorcycles and mopeds (also cars), two-stroke	TRB_RD_LD2
Light duty cars and vans, four-stroke	TRB_RD_LD4
Light duty cars, four-stroke, gasoline direct injection	TRB_RDXLD4
Road transport, abrasion of paved roads	
Heavy duty vehicles (trucks, buses and others)	TRD_RD_HD
Motorcycles, four-stroke	TRD_RD_M4
Motorcycles and mopeds (also cars), two-stroke	TRD_RD_LD2
Light duty cars and vans, four-stroke	TRD_RD_LD4
Light duty cars, four-stroke, gasoline direct injection	TRD_RDXLD4

3.3 Emission factors

Emission factors are key to accurately assess emission quantities for the various pollutants. For the present study it has been decided to identify, as far as possible, the main factors that could lead, for a given source category, to justified differences in emission factors across countries. The aim has been to collect country-specific information to quantify such justifiable deviations from values reported in the general literature. When this was not possible or when a source category makes only a minor contribution to total emissions, emission factors from the literature were used.

3.3.1 Emission factors for stationary sources

Due to the large overall contribution of the stationary combustion of solid fuels to total PM emissions (varying between 50 and 65 percent for PM2.5 and TSP), an attempt has been made to derive country-specific emission factors for power plants, industrial boilers, waste processing plants and domestic ovens. Emission factors have been computed by applying a mass balance approach: Country-specific information on the ash contents of different fuels (IEA, 1998), heat values (from the RAINS database), and the fraction of ash retained in the respective boiler type was used (e.g., Kakareka *et al.*, 1999; EPA, 1998) (compare Equation 6). Emission factors for total suspended particulate matter (TSP) are estimated in a first step:

$$efTSP = ac/hv * (1 - ar)*10 \qquad (6)$$

where:

ef	unabated emission factor [g/MJ],
ac	ash content [%],
hv	lower heat value [GJ/t],
ar	fraction of ash retained in boiler .

In a second step, the emissions of fine particulate matter (for two size fractions: PM10 and PM2.5) were calculated from the TSP estimates by using typical size profiles available in the literature (Ahuja *et al.*, 1989; Houck *et al.*, 1989). The order of magnitude of the emission factors obtained with this method was checked against values reported in the literature, summarized by Dreiseidler *et al*. (1999). For PM emissions from the combustion of liquid fuels (gasoline, diesel, heavy fuel oil) and natural gas), emission factors from the literature have been used.

3.3.2 Emission factors for mobile sources

For mobile sources, the emission factors used in RAINS for the various vehicle categories are based on the full range of country specific factors such as driving pattern, fleet composition, climatic conditions, etc. For the RAINS assessment, fuel-related emission factors were obtained by dividing the volume of PM emissions by the respective fuel consumption. Non-exhaust emission factors for road transport were extracted from various literature sources. Since such emission factors are usually reported in grams per kilometer (g/km), the fuel-efficiencies of the various vehicle categories have been used to convert them into the fuel-related emission factors. Although highly uncertain, the RAINS model treats emissions from tire lining wear, brake wear and abrasion of paved roads as separate sources.

3.3.3 Emission factors for other sources

In the RAINS model emission factors for industrial non-combustion emissions cover all contributions from a given sector. Emission factors used in this study are mainly based on U.S. data (EPA, 1998), reviewed by Passant et al. (2000).

3.4 Options for controlling emissions

The RAINS model considers the full range of practically applicable emission control options (Table 3.6).

Table 3.6: Options for controlling SO_2, NO_x, and PM emissions from stationary sources and technologies for the mobile source sector

Control options for SO_2 emissions
- Low sulphur coal, coke
- Low sulphur heavy fuel oil
- Low sulphur gas oil
- Limestone injection/Fluidized bed combustion
- Flue gas desulphurization (FGD)
- Advanced flue gas desulphurization
- Control of industrial process emissions (three stages)

Control options for NO_x emissions from stationary sources:
- Combustion modifications - Low NO_x burners, exhaust gas re-circulation, staged combustion, etc.
- Selective catalytic reduction (SCR) for large boilers
- Non-selective catalytic reduction (SNCR) for medium and large boilers
- Control of industrial process emissions (three stages)

Control options for NO_x emissions from mobile sources:
- Gasoline cars: Euro-I to Euro-IV (post 2005) standards
- Diesel cars : Euro-I to Euro-IV (post 2005) standards
- Diesel heavy duty vehicles: Euro-I to Euro-IV (post 2005) standards
- Off-road machinery: Standards equivalent to Euro-I to Euro-IV

Control options for PM emissions:
- Cyclones
- Wet scrubbers
- Electrostatic precipitators (three stages, i.e., one field, two fields, and more than two fields)
- Wet electrostatic precipitators
- Fabric filters
- Regular maintenance of oil fired industrial boilers
- Two stages (low and high efficiency) of fugitive emissions control measures
- Regular maintenance of oil fired boilers
- New type of boiler, e.g., pellets or wood chips

4 A preliminary implementation of the RAINS model for Egypt

To form a basis for a rational analysis of the most appropriate emission control strategies in Egypt, the RAINS model has been implemented to assess present emissions in Egypt and their possible development in the future and to explore the potential for cost-effective emission control measures.

The main objectives of this preliminary implementation are:

(a) To estimate the amount of emitted pollutants from different sectoral activities which are included in RAINS model,

(b) to use the RAINS model to analyse abatement policies and programs,

(c) to develop recommendations for further action in Egypt to reduce the pollution from different activities. This catalogue is to be evaluated to investigate the effects of each individual action and a combination of actions in the form of scenarios.

For this purpose, selected parts of the RAINS model have been implemented for Egypt describing emissions and emission control costs for SO_2, NO_x and PM. Additional modules will be necessary to capture primary emissions, control potential and control costs for fine particles, the dispersion of the fine particles in the atmosphere and the formation of secondary aerosols from the “conventional" precursor emissions. Ultimately, a module should be developed to assess the health benefits resulting from a certain emission control strategy.

4.1 Activity data for Egypt

In the RAINS model, energy consumption and fuel-specific emission rates should be country specific whenever possible (for the available details see the appendix). If such specific data are available, they should be used, otherwise international data can be used as default assumptions (Hassan and Attalah, 1999).

For the past years, activity data on energy consumption were retrieved from the national energy statistics (see http://www.eia.doe.gov/emeu/world/country/cntry_EG.html). According to the official published statistics, the transport sector is the largest consumer of primary energy in Egypt (37.4 % in 1995).

A number of energy forecasting studies have been undertaken in Egypt using several international models. In the year 2000, natural gas production was estimated at 15 Mt, increasing to 23 Mt in 2010 and to 27 Mt in 2020. Oil production was also assumed to increase. According to the current forecasts of the National Committee of Egypt for Energy, nuclear energy is not considered among the energy sources in the base scenario, but renewable energy assumed to play an important role. By the year 2020 renewable energy should produce roughly as much energy as hydropower. Coal, on the other hand, was introduced to limit a fast growth in oil consumption (El Mahgary *et al.,* 1994).

Another study "Assessment of Scenario Development for the Energy Sector in Egypt" aimed at estimating the future potential reduction in the level of emissions from energy-related activities for the next four National Plans until the year 2017. Based on the base line scenario for energy and emissions, the study tried to identify and assess a number of measures /technology for mitigating emissions. These selected measures and technologies were classified into the following scenarios:

- Fuel substitution Scenario, FSS
- Use of Renewable Energy in Electricity Production Scenario, RES
- Energy Efficiency Scenario, EES

Reported available national data are presented in the appendix. In addition, collecting other necessary ones will be used then updating and modify the model for the Egypt as whole and regionalization will be done further.

4.2 Emission factors for Egypt

Unfortunately, only few studies were conducted on specific emission estimates for SO_2, NO_x and PM in Egypt. Table 4.1 lists results from a study on emissions from Egyptian Buses of the GCBC's (Greater Cairo Bus Company).

Table 4.1: Emission of major pollutants from diesel buses in Egypt

Average bus daily driving distance	290 km
Fuel economy	
Conversion efficiency of fuel oil production from crude	90%
SO_2	1.2 g/km
NO_x	13 g/km
CO	18 g/km
HC	2.9 g/km
Particulates	0.8 g/km

For Egypt, to reflect the characteristic emission rates of different fuels and different energy-consuming sectors, the RAINS database has been divided into different fuel types, energy sources and economic sectors. It is based on the organization of the available energy statistics (see appendix for available details). Since the current work failed to find studies related to national total or regional emission estimates and emission factors for the concerned pollutants, the default emission factors contained in the

RAINS model have been used for the initial analyses. Thereby, the approach is in line with other regional- and global scale assessments, which use uniform default emission factors and often neglect country-specific differences.

In the RAINS model, default emission factors are based on the CORINAIR 90/94 emission inventory databases and guidebook (EEA, 1996). Actual emission factors differ because of differences in:

- the type and efficiency of the emission control device used,
- the concentration of pollutant in the raw material, and
- the production technology employed in the emitting industry (Pirrone *et al.*, 1999).

Further work is necessary to identify emission factors that are more appropriate for the Egyptian conditions.

4.3 Current legislation and future plans for controlling emissions in Egypt

As a further determinant of present and future emissions, the RAINS model requires information on emission control legislation. The following regulations that are presently in force have been considered for this study:

- Egyptian authorities have required electrostatic precipitators at some but not all of the local cement plants (average cost $9 per ton of PM reduction) and have begun vehicle inspection and maintenance as well as old taxi scrapping programs (average cost well over $5 000 per ton of PM and other pollutants) (Anderson, 2002).

- Measures to mitigate the negative effects of pollution may focus on separating pollution sources and receptors, reducing the polluting activity, reducing its pollution characteristics, and controlling emissions with filtering devices (EEAA, 1999).

- Converting high-use vehicles to cleaner fuels (for example, converting buses to natural gas); improving vehicle maintenance; increasing the share of less polluting traffic modes; using more fuel-efficient vehicles and installing catalytic control devices.

- The Government of Egypt's Lead Smelter Action Plan addresses the high emissions from the smelters by promoting the use of more environmentally friendly technology in the smelting industry, and by supporting the relocation of all lead smelting activities away from densely populated areas. In this respect, plans of 2001/2002 entail the building of the first prototype bag house filter in Egypt (EEAA, 2000a).

- The conversion of the power plants in most Egyptian regions from the use of fossil fuels to natural gas was successfully carried out, thereby reducing ambient concentrations of sulphur dioxide (EEAA, 2000).
- The Egyptian Environmental Initiatives Fund will provide technical and financial assistance for the further upgrading of 50 factories in the area of Arab Abu Saed, encompassing the conversion of their combustion processes to the use of natural gas. This initiative started in 2001/2002.

A number of options for further reducing air pollutants emissions are presently under consideration in Egypt:

- The reduction of road transport emissions and the consequent improvement in air quality has mainly been achieved through technological development. In principle further improvements can be expected from:
  - technological development;
  - control activities;
  - demand and traffic management.
- According to EEAA reports, hydrogen is an ideal energy carrier for the foreseeable future. It can be used for any application in which fossil fuels are being used today. It can fuel furnaces, turbines and jet engines even more efficiency than fossil fuel. Automobile, buses, ships, submarines, airplanes and rockets can run on hydrogen. It can be converted to electricity by fuel cells. Combustion of hydrogen with oxygen results in pure steam, which has many application in industrial process and space heating.
- For industrial activities there are some plans to reduce pollution. Improved burner design, switching heavy fuel oil to natural gas and installing low cost wet scrubbers with waste water treatment are the most acceptable option to reduce TSP emissions.
- In addition, the following areas of research were identified in the Egyptian Action Plan:
  - Research projects for energy efficient buildings that use renewable energy technologies
  - Research to improve automobile and freight transportation fuel efficiency.
  - Research on electric and solar cars.
  - Research on traffic management and practices.
  - Research and demonstration projects on the production of energy from sewage and solid wastes (EEAA, 1999).

5 Preliminary results

The RAINS model has been used to produce preliminary estimates of present and future emissions of Egypt. Because only few Egyptian and national studies are become available, one should stress that these emission estimates are highly uncertain and more work is needed to narrow down this uncertainty. Thus, all numbers presented in this section should be considered as preliminary and subject to future revision.

It is also important to stress that emissions are not evenly distributed in Egypt and thus the analysis should distinguish heavy polluted regions. However, because of the lack of regional data, the current scenarios concentrate on Egypt as a whole. In the future a split into several regions would be necessary.

5.1 Emissions of particulate matter

Because, within the given time, it was not possible for the author to accurately determine the actual extent of application of emission control measures in Egypt, two alternative estimates have been conducted. A conservative estimate assumes no control measures applied to reduce TSP emissions in Egypt, while the other case assumes the Hungarian emission standards and environmental legislation to be fully applied in Egypt. As shown in Table 5.1 to Table 5.2 as well as in Figure 5.1 and Figure 5.2, emission estimates depend critically on the assumptions on implemented emission control measures. While both cases are considered as inapplicable to the real Egyptian situation, further work is necessary to accurately determine the actual implementation of emission control laws in Egypt in order to reduce the uncertainties in the emission estimates.

Table 5.1: Emissions (kt) by aggregated sectors: PM TSP, assuming no control of TSP emissions

Aggregated.sector/year	1990	1995	2000	2010	2020	2030
Conversion, combustion	0.34	0.36	0.3	0.39	0.54	0.51
Domestic combustion	4.95	5.36	5.54	4.05	3.52	3.43
Industrial combustion	6.38	6.94	9.13	0.95	0.44	0.27
Power plants	2.85	1.65	1.71	1.04	0.67	0.44
Road – HDV	4.35	5.96	14.98	16.62	19.47	26.36
Road – LDV	1.98	1.72	1.84	0.79	0.93	1.25
Off-road	16.09	19.2	15.33	17.02	19.93	26.98
Shipping	0	0	0	0	0	0
Road non-exhaust	6.75	8.03	17.32	21.61	26.91	38.64
Off-road non-exhaust	0	0	0	0	0	0
Industrial Process	1963.74	2048.35	2231.65	2372.65	2528.45	2749.17
Mining	0	0	0	0	0	0
Waste	0	0	0	0	0	0
Mat. handling	0	0	0	0	0	0
Agriculture	2.19	2.49	2.66	2.66	2.66	2.66
Other	6.07	6.07	6.07	6.07	6.07	6.07
Non-energy	0	0	0	0	0	0
SUM	2015.7	2106.13	2306.53	2443.85	2609.58	2855.77

Table 5.2: Emissions (kt) by aggregated sectors: PM TSP, RAINS calculation assuming the emission controls of Hungary applied to Egypt

Aggregated sector\year	1990	1995	2000	2010	2020	2030
Conversion.combustion	0.29	0.3	0.26	0.33	0.46	0.43
Domestic combustion	4.95	5.36	5.54	3.97	3.45	3.36
Industrial combustion	3.11	1.89	2.27	0.67	0.28	0.19
Power plants	2.19	1.4	1.46	0.9	0.59	0.4
Road – HDV	4.35	5.96	14.98	16.62	19.47	26.36
Road – LDV	1.98	1.72	1.84	0.76	0.89	1.2
Off-road	16.09	19.2	15.33	17.02	19.93	26.98
Shipping	0	0	0	0	0	0
Road non-exhaust	6.75	8.03	17.32	21.61	26.91	38.64
Off-road non-exhaust	0	0	0	0	0	0
Industrial Process	216.9	80.43	77.52	68.26	71.16	75.27
Mining	0	0	0	0	0	0
Waste	0	0	0	0	0	0
Mat. handling	0	0	0	0	0	0
Agriculture	2.19	2.49	2.66	2.66	2.66	2.66
Other	6.07	6.07	6.07	6.07	6.07	6.07
Non-energy	0	0	0	0	0	0
SUM	264.88	132.86	145.25	138.86	151.87	181.57

Table 5.3: Emissions of PM10 (kt) by aggregated sectors, assuming no emission control measures

Aggregated sector\year	1990	1995	2000	2010	2020	2030
Conversion.comb	0.28	0.29	0.25	0.3	0.42	0.39
Domestic comb.	4.64	5.02	5.2	3.81	3.31	3.23
Industrial comb	5.62	6.13	8.02	0.8	0.37	0.23
Power plants	2.24	1.4	1.46	0.9	0.59	0.4
Road - HDV	4.3	5.89	14.78	16.41	19.22	26.02
Road - LDV	1.9	1.65	1.76	0.75	0.88	1.2
Off-road	15.28	18.24	14.56	16.17	18.93	25.63
Shipping	0	0	0	0	0	0
Road non-exhst.	1.36	1.61	3.44	4.3	5.35	7.69
Off-road non-ex	0	0	0	0	0	0
Ind. Process	834.73	850.74	918.96	977.62	1041.89	1132.94
Mining	0	0	0	0	0	0
Waste	0	0	0	0	0	0
Mat. handling	0	0	0	0	0	0
Agriculture	0.54	0.68	0.75	0.75	0.75	0.75
Other	6.07	6.07	6.07	6.07	6.07	6.07
Nonenergy	0	0	0	0	0	0
SUM	876.97	897.72	975.25	1027.89	1097.78	1204.54

Table 5.4: Emissions of PM10 (kt) by sectors, assuming application of Hungarian emission control legislation to Egypt

Aggregated sector\year	1990	1995	2000	2010	2020	2030
Conversion.comb	0.24	0.25	0.21	0.26	0.36	0.33
Domestic comb.	4.64	5.02	5.2	3.74	3.25	3.16
Industrial comb	2.94	1.78	1.97	0.57	0.24	0.17
Power plants	1.85	1.2	1.25	0.78	0.52	0.37
Road - HDV	4.3	5.89	14.78	16.41	19.22	26.02
Road - LDV	1.9	1.65	1.76	0.72	0.85	1.15
Off-road	15.28	18.24	14.56	16.17	18.93	25.63
Shipping	0	0	0	0	0	0
Road non-exhst.	1.36	1.61	3.44	4.3	5.35	7.69
Off-road non-ex	0	0	0	0	0	0
Ind. Process	127.94	51.25	48.5	43.77	46.14	49.5
Mining	0	0	0	0	0	0
Waste	0	0	0	0	0	0
Mat. handling	0	0	0	0	0	0
Agriculture	0.54	0.68	0.75	0.75	0.75	0.75
Other	6.07	6.07	6.07	6.07	6.07	6.07
Nonenergy	0	0	0	0	0	0
SUM	167.07	93.63	98.5	93.53	101.68	120.83

Table 5.5: Emissions of PM2.5 (kt) by aggregated sectors, assuming no emission control measures

Aggregated.sector\year	1990	1995	2000	2010	2020	2030
Conversion.comb	0.19	0.2	0.17	0.2	0.27	0.24
Domestic comb.	4.36	4.71	4.87	3.6	3.12	3.04
Industrial comb	4.69	5.17	6.59	0.55	0.25	0.16
Power plants	1.56	1	1.04	0.66	0.45	0.34
Road - HDV	4.22	5.78	14.51	16.11	18.87	25.54
Road - LDV	1.79	1.55	1.66	0.71	0.84	1.13
Off-road	14.48	17.28	13.8	15.32	17.94	24.28
Shipping	0	0	0	0	0	0
Road non-exhst.	0.43	0.49	1.01	1.27	1.59	2.29
Off-road non-ex	0	0	0	0	0	0
Ind. Process	369.81	374.88	402.64	428.83	457.04	497.01
Mining	0	0	0	0	0	0
Waste	0	0	0	0	0	0
Mat. handling	0	0	0	0	0	0
Agriculture	0.1	0.13	0.15	0.15	0.15	0.15
Other	6.07	6.07	6.07	6.07	6.07	6.07
Nonenergy	0	0	0	0	0	0
SUM	407.7	417.27	452.51	473.47	506.58	560.26

Table 5.6: Emissions of $PM_{2.5}$ (kt) by sectors, assuming application of Hungarian emission control legislation to Egypt

Aggregated sector\year	1990	1995	2000	2010	2020	2030
Conversion.comb	0.17	0.17	0.15	0.17	0.23	0.21
Domestic comb.	4.36	4.71	4.87	3.53	3.06	2.98
Industrial comb	2.59	1.55	1.47	0.41	0.18	0.13
Power plants	1.31	0.85	0.89	0.57	0.4	0.31
Road - HDV	4.22	5.78	14.51	16.11	18.87	25.54
Road - LDV	1.79	1.55	1.66	0.69	0.8	1.09
Off-road	14.48	17.28	13.8	15.32	17.94	24.28
Shipping	0	0	0	0	0	0
Road non-exhst.	0.43	0.49	1.01	1.27	1.59	2.29
Off-road non-ex	0	0	0	0	0	0
Ind. Process	75.75	35.83	33.35	30.1	31.92	34.5
Mining	0	0	0	0	0	0
Waste	0	0	0	0	0	0
Mat. handling	0	0	0	0	0	0
Agriculture	0.1	0.13	0.15	0.15	0.15	0.15
Other	6.07	6.07	6.07	6.07	6.07	6.07
Nonenergy	0	0	0	0	0	0
SUM	111.25	74.43	77.93	74.38	81.2	97.55

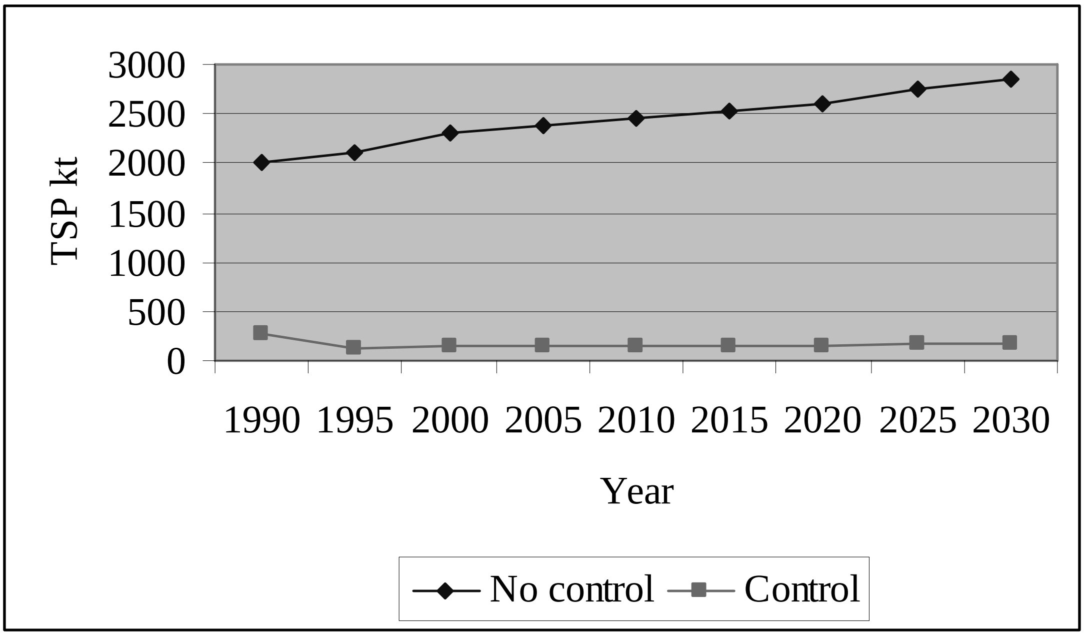

Figure 5.1: TSP emission estimates for Egypt for the two scenarios (no control, application of Hungarian legislation to Egypt)

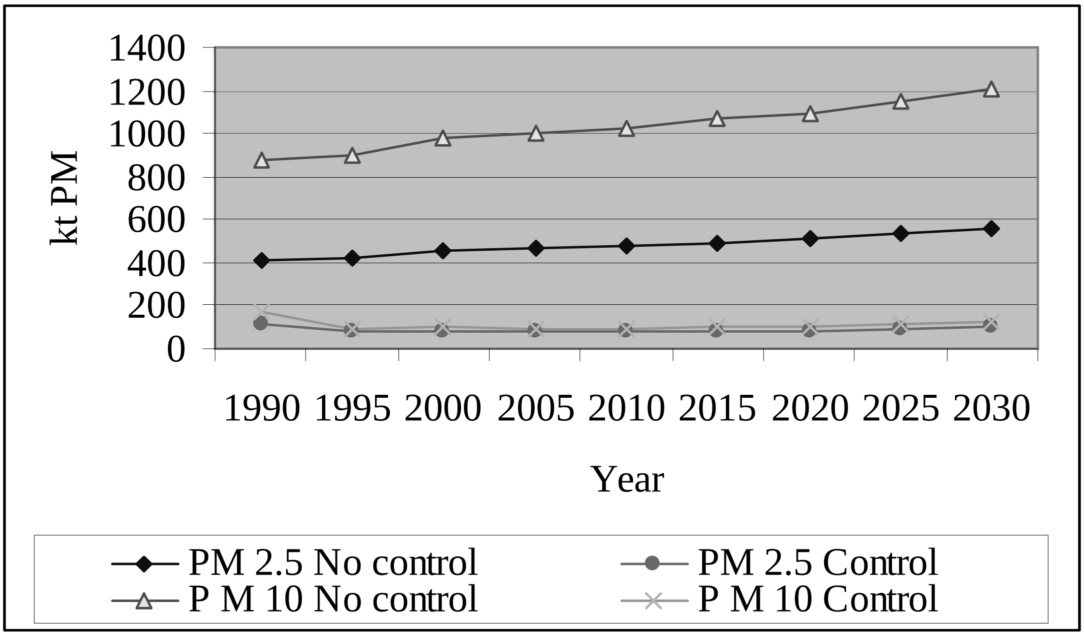

Figure 5.2: PM_{10} and _$PM_{2.5}$ emission estimates for Egypt for the two scenarios (no control, application of Hungarian legislation to Egypt)

5.2 Emissions of SO_2 and NO_x

Similar calculations were carried out for SO_2 and NO_x emissions, contrasting the hypothetical cases if no emission control measures were applied with the application of Hungarian emission control legislation (Table 5.7 to Table 5.10 and Figure 5.3 to Figure 5.4).

Fuel combustion still represents the major emission source of SO_2 and NO_x emissions in the urban environment; however its contribution to the regional atmospheric budget is following a downward trend. The level of NO_x emissions from mobile sources indicates pressure on urban air quality in Egypt according to the estimates by RAINS-Egypt. These indicators reflect pressure coming mainly from the transport sector.

Table 5.7: Emissions of NO_x (kt) by sector, assuming no emission control measures

Sector\year	1990	1995	2000	2010	2020	2030
CON	5.58	7.14	7.97	9.91	10.97	10.33
IN_BO	0	0	0	0	0	0
IN_OC	17.17	13.14	34.21	20.02	14.25	15.51
DOM	9.32	9.74	10.64	20.51	13.18	7.4
TRA_RD	172.31	196.62	394.73	438.15	513.15	694.73
TRA_OT	125.42	149.7	119.5	132.65	155.35	210.33
TRA_OTS	0	0	0	0	0	0
PP_EX_WB	0	0	0	0	0	0
PP_EX_OTH	57.87	41.6	38.04	18.47	0	0
PP_NEW	0	6.56	15.43	39.51	63.02	88.03
PROC	32.91	35.46	38.22	40.63	43.35	47.2
OTHER	1	0.8	0.9	0.9	0.9	0.9
SUM	421.56	460.76	659.65	720.75	814.19	1074.43

Table 5.8: Emissions of NO_x (kt) by sectors, assuming application of Hungarian emission control legislation to Egypt

Sector\year	1990	1995	2000	2010	2020	2030
CON	5.58	7.14	7.53	8.46	9.34	8.85
IN_BO	0	0	0	0	0	0
IN_OC	17.17	13.14	31.73	16.5	12.18	13.51
DOM	9.32	9.74	10.64	20.51	13.18	7.4
TRA_RD	172.31	189.38	317.61	180.36	66.38	89.87
TRA_OT	125.42	149.7	113.84	102.08	119.55	161.86
TRA_OTS	0	0	0	0	0	0
PP_EX_WB	0	0	0	0	0	0
PP_EX_OTH	57.87	41.6	35.94	15.41	0	0
PP_NEW	0	6.56	15.43	39.51	63.02	88.03
PROC	32.91	35.46	38.22	40.63	43.35	47.2
OTHER	1	0.8	0.9	0.9	0.9	0.9
SUM	421.56	453.52	571.86	424.37	327.91	417.62

Table 5.9: Emissions of SO_2 (kt) by sector, assuming no emission control measures

Sector\year	1990	1995	2000	2010	2020	2030
CON	27.57	28.34	24.24	33.66	47.65	45.59
IN_BO	0	0	0	0	0	0
IN_OC	70.89	45.52	166.09	56.51	22.86	15.03
DOM	1.42	1.4	1.62	2.32	1.57	1.06
TRA_RD	32.51	44.34	110.87	123.06	144.13	195.12
TRA_OT	50.88	60.73	48.48	53.81	63.03	85.33
TRA_OTS	0	0	0	0	0	0
PP_EX_WB	0	0	0	0	0	0
PP_EX_OTH	213.87	135.88	140.25	68.16	0	0
PP_NEW	0	0	0	12.47	46.48	22.87
PROC	38.84	43.76	44.92	47.79	50.99	55.52
OTHER	0	0	0	0	0	0
SUM	435.98	359.97	536.46	397.79	376.71	420.52

Table 5.10: Emissions of SO_2 (kt) by sector, assuming application of Hungarian emission control legislation to Egypt

Sector\year	1990	1995	2000	2010	2020	2030
CON	27.57	28.34	21.28	24.25	33.14	30.32
IN_BO	0	0	0	0	0	0
IN_OC	70.89	45.52	166.09	26.22	10.65	7.01
DOM	1.42	1.4	1.62	2.32	1.57	1.06
TRA_RD	32.51	44.34	5.42	0.87	1.01	1.37
TRA_OT	50.88	60.73	9.7	2.42	2.84	3.84
TRA_OTS	0	0	0	0	0	0
PP_EX_WB	0	0	0	0	0	0
PP_EX_OTH	213.87	135.88	139.93	26.15	0	0
PP_NEW	0	0	0	0.62	2.33	1.15
PROC	38.84	43.76	44.92	47.79	50.99	55.52
OTHER	0	0	0	0	0	0
SUM	435.98	359.97	388.95	130.65	102.54	100.27

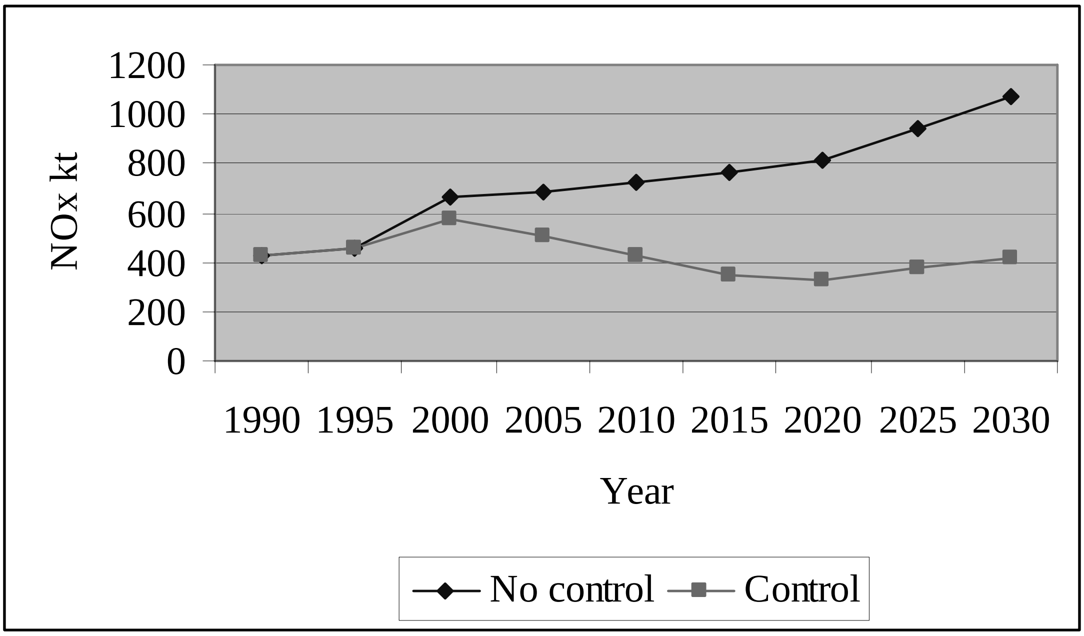

Figure 5.3: NO_x emission estimates for Egypt by two different scenarios

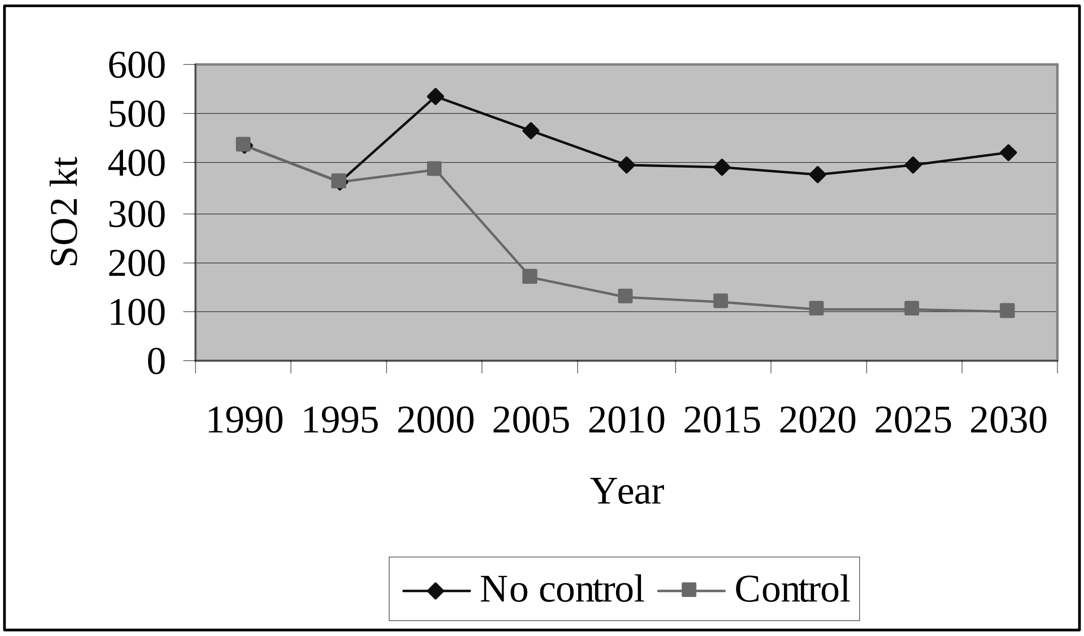

Figure 5.4: SO_2 emission estimates for Egypt for two different scenarios

A comparison has been made between the emission estimates for SO_2 and NO_x of the RAINS-Egypt model and the global EDGAR estimates. In general, the output results were within a ± 10-20 percent range (Figure 5.5). The difference might be attributed to the fact that data collected by EDGAR were extracted from global statistics and not from local ones (). EDGAR estimates was done by using; a) international statistics as activity data, since these are comparable between countries in definition and units; b) emission factors from the scientific literature, also common across countries when judged comparable (EDGAR 3.2 database and data source see; http://www.rivm.nl/env/int/coredata/edgar/index.html/.

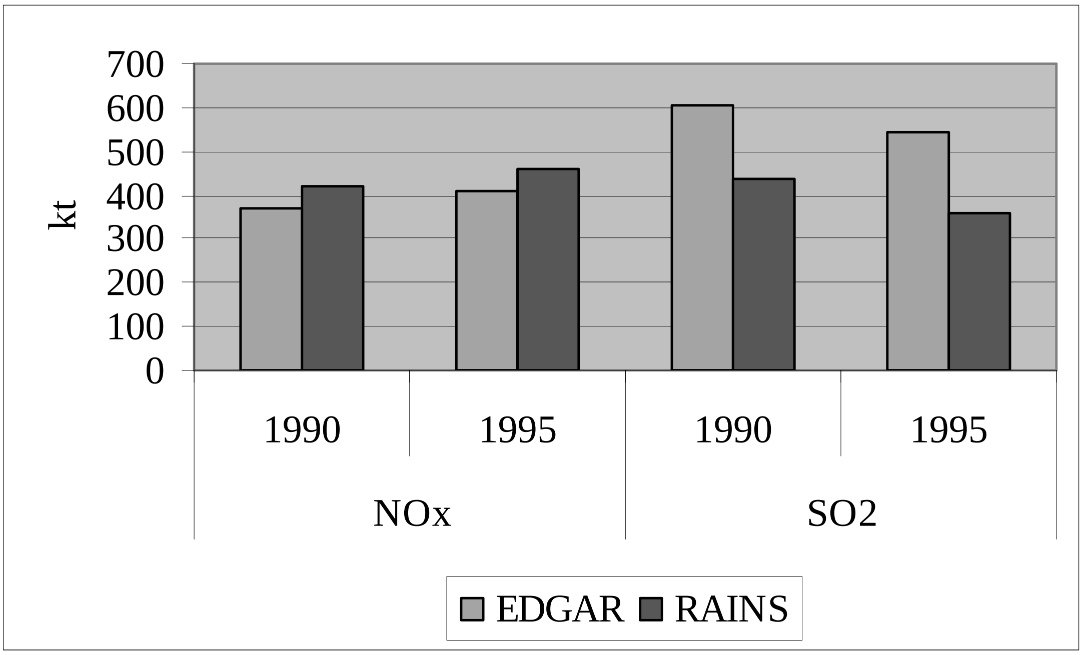

Figure 5.5:. Comparison between RAINS and EDGAR estaimtes for SO_2 and NO_x emission in Egypt

5.3 Emissions of CO_2

Total national carbon dioxide emission for 1995 was 82.897 million tons as shown in Table 5.11.. In this section, a comparison between the national reported emission data and the results estimated RAINS is presented. Approximately full agreement between the two estimates. Figure 5.6 draws a closer look in the calculation by RAINS, revealing for 2000 a discrepancy of 1 percent, which is reasonably well within the model uncertainties.

Table 5.11: CO_2 emissions by sector [Mt CO2] Egypt, as calculated by the RAINS-Egypt model

Sector\year	1990	1995	2000	2010	2020	2030
CON_COMB	3.57	4.79	5.62	7.2	7.84	7.46
IN_BO	0	0	0	0	0	0
IN_OC	12.98	10.64	21.91	18.29	14.14	15.29
DOM	9.36	9.7	10.61	21.91	13.67	7.04
TRA_RD	0	0	0	0	0	0
TRA_RD_LD2	0	0	0	0	0	0
TRA_RD_LD4	6.67	6	7.16	7.94	9.3	12.6
TRA_RD_HD	5.01	6.86	17.22	19.12	22.39	30.31
TRA_OT	0	0	0	0	0	0
TRA_OT_LD2	0	0	0	0	0	0
TRA_OT_LB	7.94	9.47	7.56	8.39	9.83	13.31
TRA_OTS_M	0	0	0	0	0	0
TRA_OTS_L	0	0	0	0	0	0
PP_EX_WB	0	0	0	0	0	0
PP_EX_OTH	22.04	15.73	14.43	7.01	0	0
PP_NEW	0	7.32	17.22	43.75	69.09	97.63
NONEN	2.55	3.33	4.04	8.58	12.55	21.7
OTHER	0	0	0	0	0	0
IN_PR	7.09	7.49	8.24	8.75	9.33	10.16
SUM	77.22	81.33	114.02	150.95	168.15	215.5

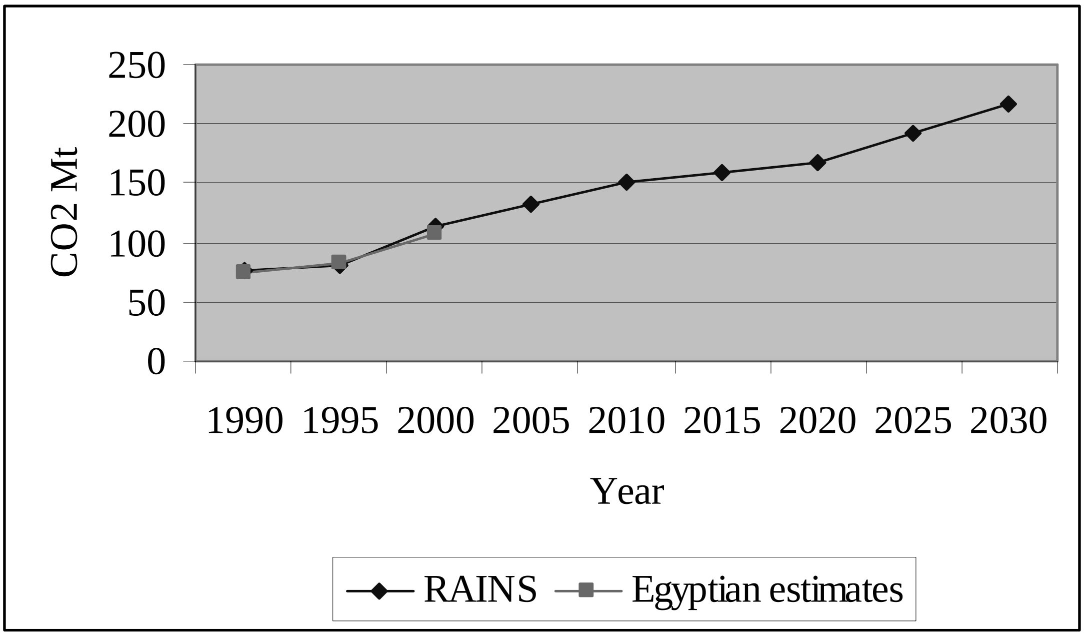

Figure 5.6: Egyptian emission estimates for CO_2 compared with RAINS

5.4 Preliminary estimates of emission control costs

Preliminary cost estimates for the pollutants PM, SO_2, and NO_x as calculated by RAINS with the assumption that if Egypt has control measures like in Hungary are presented in Table 5.12 to Table 5.14 and drawn in Figure 5.7. The analysis shows that emissions controls are costly and therefore should be designed in a cost-efficient way. RAINS provides a possibility to look for cost-efficient solutions.

Table 5.12: Preliminary estimates of PM abatement costs (Mio /year) by sector (region totals); of the "Hungarian legislation" scenario for Egypt

Aggregated sector\year	1990	1995	2000	2010	2020	2030
Conversion.comb	0.15	0.15	0.14	0.24	0.35	0.35
Domestic comb.	0	0	0	6.68	5.86	5.78
Industrial comb	1.23	1.54	2.53	0.54	0.28	0.14
Power plants	1.2	0.74	0.77	0.43	0.2	0.1
Road - HDV	0	0	0	0	0	0
Road - LDV	0	0	0	19.26	22.55	30.53
Off-road	0	0	0	0	0	0
Shipping	0	0	0	0	0	0
Road non-exhst.	0	0	0	0	0	0
Off-road non-ex	0	0	0	0	0	0
Ind. Process	55.76	86.04	88	165.49	166.83	168.73
Mining	0	0	0	0	0	0
Waste	0	0	0	0	0	0
Mat. handling	0	0	0	0	0	0
Agriculture	0	0	0	0	0	0
Other	0	0	0	0	0	0
Nonenergy	0	0	0	0	0	0
SUM	58.34	88.48	91.44	192.64	196.08	205.63

Table 5.13: Preliminary estimates of SO_2 abatement costs (Mio /year) by sector (region totals); of the "Hungarian legislation" scenario for Egypt

Sector\year	1990	1995	2000	2010	2020	2030
CON_COMB	0	0	4.71	18.3	28.22	29.71
IN_BO	0	0	0	0	0	0
IN_OC	0	0	0	15.45	6.23	4.09
DOM	0	0	0	0	0	0
TRA_RD	0	0	222.01	334.29	391.51	530.04
TRA_OT	0	0	61.65	108.2	126.72	171.56
TRA_OTS	0	0	0	0	0	0
PP_EX_WB	0	0	0	0	0	0
PP_EX_OTH	0	0	0.5	21.72	0	0
PP_NEW	0	0	0	4.44	16.73	8.23
PROC	0	0	0	0	0	0
SUM	0	0	288.87	502.4	569.41	743.64

Table 5.14: Preliminary estimates of NO_x abatement costs (Mio /year) by sector (region totals); of the "Hungarian legislation" scenario for Egypt

Sector\year	1990	1995	2000	2010	2020	2030
CON_COMB	0	0	0.21	0.7	0.71	0.64
IN_BO	0	0	0	0	0	0
IN_OC	0	0	0.85	1.57	1.1	1.18
DOM	0	0	0	0	0	0
TRA_RD	0	16.61	148.47	985.59	2321.81	3375.28
TRA_OT	0	0	5.42	43	53.12	75.61
TRA_OTS	0	0	0	0	0	0
PP_EX_WB	0	0	0	0	0	0
PP_EX_OTH	0	0	0.29	0.42	0	0
PP_NEW	0	0	0	0	0	0
PROC	0	0	0	0	0	0
SUM	0	16.61	155.24	1031.28	2376.75	3452.71

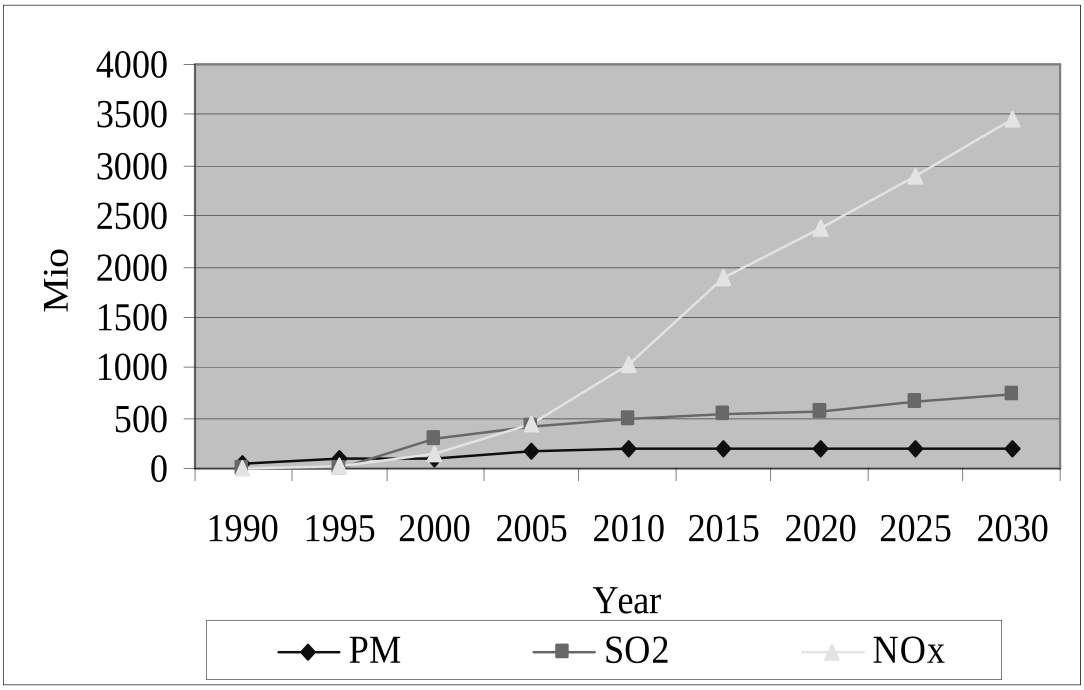

Figure 5.7: Preliminary estimates of abatement costs (Mio /year) by sector of the "Hungarian legislation" scenario for Egypt

5.5 Discussion

The preliminary results from the model study indicate that emissions released within Egypt reach significant amounts that are potentially harmful to human health and the environment. Major sources of emissions are the combustion of fossil fuels as well as primary and secondary non-ferrous metal smelters, electric power plants in industrial, commercial, and residential facilities, the roasting and smelting of ores in non-ferrous metal smelters, melting operations in non-ferrous foundries, incineration of industrial and urban solid wastes and kiln operations.

The analysis also demonstrates that a wide array of technical means are available to control emissions of air pollutants and thereby keep air quality at levels that does not threaten human health and the environment. However, many of these measures, which are already applied on a routine basis in developed countries, are relatively expensive, especially for an economy of a developing country. In such a situation, the design of cost-effective emission control strategies becomes imperative. The RAINS-Egypt model, once fully implemented, could provide valuable assistance in finding emission control strategies that do not compromise the economic development.

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Appendix 1

Egyptian National Data

Energy production and consumption for the year 2000

Energy Production (Quads) = 2.6259 **Energy Consumption (Quads) = 2.0181**

Oil

(Thousand Barrels per Day)

	Production	Refinery	Recycled	Imports	Exports	Stock Build	Consump- tion	Unaccounted for Supply
Crude Oil	748.00	528.00		0.00	220.00	0.00	0.00	0.00
NGL's	102.00	102.00		0.00	0.00	0.00	0.00	0.00
Other Oils	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Refinery Gain	1.00	-84.13						-85.13
Gasoline		52.69		0.98	0.00	0.00	54.28	0.61
Jet Fuel		20.65		0.61	0.28	0.00	9.51	-11.46
Kerosene		21.12		0.00	0.00	0.00	21.12	0.00
Distillate		117.49		45.60	0.00	0.00	163.08	0.00
Residual		210.20		0.00	23.11	0.00	187.09	0.00
LPG's		15.63		26.05	0.00	0.00	74.42	32.74
Unspecified		108.09		1.92	62.29	0.00	51.29	3.57
TOTALS	851.00	545.87		75.15	305.68	0.00	560.80	**-59.67**

Natural Gas

(Billion Cubic Feet and Quadrillion Btu)

Gross Production	(Billion Cubic Feet)	860.27	**Dry Imports**	(Billion Cubic Feet)	0.00
Vented and Flared	(Billion Cubic Feet)	30.37	**Dry Exports**	(Billion Cubic Feet)	0.00
Reinjected	(Billion Cubic Feet)	28.25			
Marketed Production	(Billion Cubic Feet)	801.65			
Dry Production	(Billion Cubic Feet)	646.26	**Dry Production**	(Quadrillion Btu)	0.6766
Dry Consumption	(Billion Cubic Feet)	646.26	**Dry Consumption**	(Quadrillion Btu)	0.6766

Coal (Thousand Short Tons and Quadrillion Btu)

	Production		Imports		Exports		Stock Build	
	(1000 Tons)	(Quads)	(1000 Tons)	(Quads)	(1000 Tons)	(Quads)	(1000 Tons)	(Quads)
Hard Coal			519	0.0121	14	0.0003	0	0.0000
--- Anthracite	0	0.0000						
--- Bituminous	0	0.0000						
Lignite	0	0.0000	0	0.0000	0	0.0000	0	0.0000
Coke			1344	0.0330	611	0.0150	0	0.0000
Total Coal	0	0.0000	1863	0.0451	625	0.0153	0	0.0000

Consumption : (1000 Tons) = 1238 **(Quads) =** 0.0297

Electricity (Million Kilowatts, Billion Kilowatt Hours, and Quadrillion Btu)

	Capacity	Generation				
	(Million kw)		(Billion kwh)	(Quads)	(Billion kwh)	(Quads)
Hydroelectric	2.810	13.802	0.1436	**Total Imports**	0.000	0.0000
Nuclear	0.000	0.000	0.0000	**Total Exports**	0.000	0.0000
Geothermal and Other	0.000	0.000	0.0000	**Losses**	5.016	
Thermal	14.860	57.856				
Totals	**17.670**	**71.658**	**Consumption**			**66.642**

http://www.eia.doe.gov/emeu/world/country/cntry_EG.html

Appendix 2:

Table 1. Major baseline national data for Egypt

	Years		
	1997	2000	2001
Population	60.4	64.0	65.2
AAGR*	1.9	1.9	1.8
Life expectancy	66.3	67.8	68.3
GDP (Billion $)	75.9	99.4	98.5
Share services in GDB%	50.5	50.2	50.1
Primary energy use per capita (kg of oil equivalent)	643.9	752.6	…..
Electricity use per capita (Kwh)	819.9	976.0	…..
CO2 emission (metric ton per capita)	1.8	…..	…..

*AAGR (annual average growth rate)

Source: World Bank Group (2003).

Table 2. In-movement licensed vehicle (at the end of December 2001) in Egypt

Type	Total No. in Egypt
Lorry	658499
Buses	
School	3927
Travel	8486
Tourism	8073
Private	21135
Public	13870
Burry's cars	1258
Taxi	308383
Caravan	551
Private cars	1450366
Governorate	30089
Government	56003
Public sector	64200
With customs number	58211
Commercial & temporary	13864
Diplomatic	7846
Motorcycles	519575
Tractors	22094
Trucks	50914

Source: General Traffic Department, Egypt. December, 2001

Table 3. General Energy Data for Egypt

	1980	1990	1995	1996	1997
Population 10^{-6}	40.9	52.4	58.2	59.3	..
GDP 10^{-9} USD (1990)	25.3	43.1	50.8	53.4	..
GDP 10^{-9} NC (1990)	..	..	..	..	..
Per Capita USD (1990)	620	822	874	900	..
Per Capita NC (1990)	..	..	..	..	..
Primary Energy Supply PJ	842	1371	1466	1527	..
Per Capita GJ	20.6	26.1	25.2	25.8	..
Per GDP MJ/USD (1990)	33.2	31.8	28.8	28.6	..
Per GDP MJ/NC (1990)	..	..	..	..	..
Final Energy Demand PJ	675	1096	1232	1252	..
Per Capita GJ	16.5	20.9	21.2	21.1	..
Per GDP MJ/USD (1990)	26.6	25.4	24.2	23.5	..
Per GDP MJ/NC (1990)	..	..	..	..	..
Electricity Supply TWh	20	43	54	58	..
Per Capita kWh	486	829	936	973	..
Per GDP Wh/USD (1990)	784	1008	1071	1080	..
Per GDP Wh/NC (1990)	..	..	..	..	..

Table 4. Fossil Fuel-related Carbon Dioxide Emissions in Egypt, 1990-2001(in millions of metric tons of carbon)

Component	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
CO_2 from coal	1.02	0.81	0.72	0.87	0.83	0.54	0.89	0.69	0.70	0.57	0.85	0.85
CO_2 from natural gas	4.90	6.01	6.39	6.66	6.98	7.19	7.68	7.71	7.77	8.27	10.17	11.71
CO_2 from petroleum	19.61	19.18	18.59	18.75	19.30	19.09	20.75	21.89	22.34	22.28	21.69	21.73
Total CO_2 from all fossil fuels	25.54	25.99	25.69	26.28	27.10	26.82	29.32	30.30	30.81	31.12	32.70	34.29

http://www.fe.doe.gov/international/egypt.htm

Table 5. CO_2 Emissions from Energy Combustion by Sector

	Other	Industry	Transport	Power Plant
1980	6.0	13	10	10
1990	12	21	18	24
1995	9	26	22	26
1996	9	27	22	27
1997	..	..	..	..

Table 6. CO_2 Emissions from Energy Combustion by Source

	Other	Gas	Coal	Oil
1980	-	3	..	36
1990	-	15	..	60
1995	-	26	..	57
1996	-	27	..	58
1997	..	..	..	..

Source: World Energy Council: Extract from International energy data report 1998.

Table 7. Energy consumption and GHG emissions in Egypt, 1995

Transport mode	Energy Consumption (PJ)	GHG- Emissions		
		CO_2 (kt)	CH_4 (t)	N_2O (t)
Urban transport				
• fossil oil modes	85.65	6410	5275	2856
• electric modes	2.007	151	16	102
Intercity transport	85.678	6391	3068	3579
Air and maritime	18.31	1375	171	772
Total	**191.645**	**14327**	**8530**	**7309**

Source: See References; Hassan and Attalah (1999)

Table 8. Distribution of fuel consumption according to fuel type and transport modes in thousand tons, Egypt, 1995

	Gasoline	Gas oil	Fuel oil	Jet-Fuel	Total
Roads	1865.062	1862.411	--	--	3727.473
Railways	--	243.817	--	--	243.817
Waterways	--	81.186	--	--	81.186
Ports	--	324.683	2164.869	--	2489.552
Airports	--	--	--	429	429
Total	1865.062	2512.097	2164.869	429	6971.028

Source: See References; Hassan and Attalah (1999)

Appendix 3

Abbreviations used in RAINS for sectors

Abbreviation	Sector
CON_COMB1	Fuel production & conversion: Combustion, grate firing
CON_COMB2	Fuel production & conversion: Combustion, fluidized bed boiler
CON_COMB3	Fuel production & conversion: Combustion, pulverized fuel combustion
CON_COMB	Fuel production & conversion: Combustion
CON_LOSS	Losses during transmission & distribution of final product
DOM	Combustion in residential-commercial sector (liquid fuels)
DOM_FPLACE	Residential-Commercial: Fireplaces
DOM_STOVE	Residential-Commercial: Stoves
DOM_SHB_M	Residential-Commercial: Single house boilers (<50 kW) - manual
DOM_SHB_A	Residential-Commercial: Single house boilers (<50 kW) - automatic
DOM_MB_M	Residential-Commercial: Medium boilers (<1 MW) – manual
DOM_MB_A	Residential-Commercial: Medium boilers (<50 MW) – automatic
IN_BO1	Industry: Combustion in boilers, grate firing
IN_BO2	Industry: Combustion in boilers, fluidized bed boiler
IN_BO3	Industry: Combustion in boilers, pulverized fuel combustion
IN_BO	Industry: Combustion in boilers
IN_OC1	Industry: Other combustion, grate firing
IN_OC2	Industry: Other combustion, fluidized bed boiler
IN_OC3	Industry: Other combustion, pulverized fuel combustion
IN_OC	Industry: Other combustion
PP_EX_OTH1	Power & district heat plants: Existing plants, other, grate firing
PP_EX_OTH2	Power & district heat plants: Existing plants, other, fluidized bed boiler
PP_EX_OTH3	Power & district heat plants: Existing plants, other, pulverized fuel combustion
PP_EX_OTH	Power & district heat plants: Existing plants, other
PP_EX_WB	Power & district heat plants: Existing plants, wet bottom boiler
PP_NEW1	Power & district heat plants: New plants, grate firing
PP_NEW2	Power & district heat plants: New plants, fluidized bed boiler
PP_NEW3	Power & district heat plants: New plants, pulverized fuel combustion
PP_NEW	Power & district heat plants: New plants
PP_TOTAL	Power & district heat plants (total)
TRA_RD_HD	Heavy duty trucks and buses (exhaust)
TRA_RD_LD2	Motorcycles: 2-stroke; mopeds (also cars) (exhaust)
TRA_RD_M4	Motorcycles: 4-stroke (exhaust)
TRA_RD	Light duty vehicles: cars, motorcycles (electric, renewable)
TRA_RD_LD4	Light duty vehicles: 4-stroke (excluding GDI) (exhaust)
TRA_RDXLD4	Light duty vehicles: gasoline direct injection (GDI) (exhaust)
LEAD_GASOL	Heavy and light duty vehicles: leaded gasoline (exhaust)
TRA_OT	Other transport: Rail (solid fuels), Heating (stationary combustion)
TRA_OT_LD2	Other transport: Off-road; 2-stroke (exhaust)
TRA_OT_CNS	Other transport: Construction machinery (exhaust)
TRA_OT_AGR	Other transport: Agriculture (exhaust)
TRA_OT_RAI	Other transport: Rail (exhaust)

Abbreviation	Sector
TRA_OT_INW	Other transport: Inland waterways (exhaust)
TRA_OT_AIR	Other transport: Air traffic (LTO)
TRA_OT_LB	Other transport: Other off-road; 4-stroke (military, households, etc.)
TRA_OTS_M	Other transport: Ships; medium vessels (exhaust)
TRA_OTS_L	Other transport: Ships; large vessels (exhaust)
TRT_RD_HD	Heavy duty trucks and buses (tyre wear)
TRT_RD_LD2	Motorcycles: 2-stroke; mopeds (also cars) (tyre wear)
TRT_RD_M4	Motorcycles: 4-stroke (tyre wear)
TRT_RD_LD4	Light duty vehicles: 4-stroke (excl. GDI) (tyre wear)
TRT_RDXLD4	Light duty vehicles: Gasoline direct injection (GDI) (tyre wear)
TRB_RD_HD	Heavy duty trucks and buses (brake wear)
TRB_RD_LD2	Motorcycles: 2-stroke; mopeds (also cars) (brake wear)
TRB_RD_M4	Motorcycles: 4-stroke (brake wear)
TRB_RD_LD4	Light duty vehicles: 4-stroke (excl. GDI) (brake wear)
TRB_RDXLD4	Light duty vehicles: Gasoline direct injection (GDI) (brake wear)
TRD_RD_HD	Heavy duty trucks and buses (abrasion)
TRD_RD_LD2	Motorcycles: 2-stroke; mopeds (also cars) (abrasion)
TRD_RD_M4	Motorcycles: 4-stroke (abrasion)
TRD_RD_LD4	Light duty vehicles: 4-stroke (excl. GDI) (abrasion)
TRD_RDXLD4	Light duty vehicles: Gasoline direct injection (GDI) (abrasion)
TRB_OT_RAI	Other transport: Rail (non-exhaust)
PR_PIGI	Industrial Process: Pig iron, blast furnace
PR_PIGI_F	Industrial Process: Pig iron, blast furnace (fugitive)
PR_COKE	Industrial Process: Coke oven
PR_PELL	Industrial Process: Agglomeration plant – pellets
PR_SINT	Industrial Process: Agglomeration plant – sinter
PR_SINT_F	Industrial Process: Agglomeration plant – sinter (fugitive)
PR_HEARTH	Industrial Process: Open hearth furnace
PR_BAOX	Industrial Process: Basic oxygen furnace
PR_EARC	Industrial Process: Electric arc furnace
PR_CAST	Industrial Process: Cast iron (grey iron foundries)
PR_CAST_F	Industrial Process: Cast iron (grey iron foundries) (fugitive)
PR_ALPRIM	Industrial Process: Aluminum production - primary
PR_ALSEC	Industrial Process: Aluminum production - secondary
PR_OT_NFME	Industrial Process: Other non-ferrous metals production - primary and secondary
PR_BRIQ	Industrial Process: Briquettes production
PR_CEM	Industrial Process: Cement production
PR_LIME	Industrial Process: Lime production
PR_CBLACK	Industrial Process: Carbon black production
PR_OTHER	Industrial Process: Production of glass fiber, gypsum, PVC, other
PR_REF	Industrial Process: Petroleum refineries
PR_GLASS	Industrial Process: Glass production (flat, blown, container glass)
PR_FERT	Industrial Process: Fertilizer production
PR_SMIND_F	Industrial Process: Small industrial and business facilities (fugitive)
MINE_BC	Mining: Brown coal
MINE_HC	Mining: Hard coal
MINE_OTH	Mining: Bauxite, copper, iron ore, zinc ore, manganese ore, other

Abbreviation	Sector
WASTE_FLR	Waste: Flaring in gas and oil industry
WASTE_AGR	Waste: Agricultural waste burning
WASTE_RES	Waste: Open burning of residential waste
STH_COAL	Storage and handling: Coal
STH_FEORE	Storage and handling: Iron ore
STH_NPK	Storage and handling: N,P,K fertilizers
STH_OTH_IN	Storage and handling: Other industrial products (cement, bauxite, coke
STH_AGR	Storage and handling: Agricultural products (crops)
AGR_POULT	Agriculture: Livestock - poultry
AGR_PIG	Agriculture: Livestock - pigs
AGR_COWS	Agriculture: Livestock - dairy cattle
AGR_BEEF	Agriculture: Livestock - other cattle
AGR_OTANI	Agriculture: Livestock - other animals (sheep, horses)
AGR_ARABLE	Agriculture: Ploughing, tilling, harvesting
AGR_OTHER	Agriculture: Other (activity as emissions in kt)
CONSTRUCT	Construction activities
RES_BBQ	Residential: Meat frying, food preparation, BBQ
RES_CIGAR	Residential: Cigarette smoking
RES_FIREW	Residential: Fireworks
OTHER	Other: (activity given as emissions in kt)
NONEN	Non-energy use of fuels

Appendix 4

Abbreviations used in RAINS for control technologies

Abbreviation	Technology
NOC	No Control
NSC	Stock not suitable for control
ESP1	Electrostatic precipitator: 1 field - power plants
ESP2	Electrostatic precipitator: 2 fields - power plants
ESP3P	Electrostatic precipitator: more than 2 fields - power plant
FF	Fabric filters - power plants
CYC	Cyclone - power plants
WSCRB	Wet scrubber - power plants
IN_ESP1	Electrostatic precipitator: 1 field - industrial combustion
IN_ESP2	Electrostatic precipitator: 2 fields - industrial combustion
IN_ESP3P	Electrostatic precipitator: more than 2 fields - industrial combustion
IN_FF	Fabric filters - industrial combustion
IN_CYC	Cyclone - industrial combustion
IN_WSCRB	Wet scrubber – industrial combustion
PR_ESP1	Electrostatic precipitator: 1 field - industrial processes
PR_ESP2	Electrostatic precipitator: 2 fields - industrial processes
PR_ESP3P	Electrostatic precipitator: more than 2 fields - industrial processes
PR_WESP	Wet electrostatic precipitator: industrial processes
PR_FF	Fabric filters - industrial processes
PR_CYC	Cyclone - industrial processes
PR_WSCRB	Wet scrubber – industrial processes
GHIND	Good housekeeping: industrial oil boilers
PRF_GP1	Good practice: industrial processes - stage 1 (fugitive)
PRF_GP2	Good practice: industrial processes - stage 2 (fugitive)
FP_CAT	Fireplaces, catalytic insert
FP_ENC	Fireplaces, non-catalytic insert
WOOD1	New domestic stoves (wood): non-catalytic
WOOD2	New domestic stoves (wood): catalytic
COAL1	New domestic stoves (coal): stage 1
COAL2	New domestic stoves (coal): stage 2
NB_COAL	New domestic boilers: (coal)
MB_PELL	New medium (automatic) size boilers: (wood chips, pellets)
MB_PLBAG	New medium size boilers: (wood chips, pellets) with end-of-pipe abatement
MB_CYC	Cyclone for medium boilers in domestic sectors
MB_BAG	Baghouse for medium (automatic) boilers in domestic sector
GHDOM	Good housekeeping: domestic oil boilers
MDEUI	EURO I -1992/94, diesel light duty and passenger cars
MDEUII	EURO II -1996, diesel light duty and passenger cars
MDEUIII	EURO III -2000, diesel light duty and passenger cars
MDEUIV	EURO IV -2005, diesel light duty and passenger cars
MDEUV	EURO V -diesel light duty and passenger cars, post-2005 St.1

Abbreviation	Technology
MDEUVI	EURO VI -diesel light duty and passenger cars - post 2005, St.2
CAGEUI	Construction and agriculture - off-road -1998, as EUROI for HDV
CAGEUII	Construction and agriculture - off-road -2000/02, as EUROII for HDV
CAGEUIII	Construction and agriculture - off-road; as EUROIII for HDV
CAGEUIV	Construction and agriculture - off-road; as EUROIV for HDV
CAGEUV	Construction and agriculture - off-road; as EUROV for HDV
CAGEUVI	Construction and agriculture - off-road; as EUROVI for HDV
TIWEUI	Rail and inland waterways - off-road -1998, as EUROI for HDV
TIWEUII	Rail and inland waterways - off-road -2000/02, as EUROII for HDV
TIWEUIII	Rail and inland waterways - off-road; as EUROIII for HDV
TIWEUIV	Rail and inland waterways - off-road; as EUROIV for HDV
TIWEUV	Rail and inland waterways - off-road; as EUROV for HDV
TIWEUVI	Rail and inland waterways - off-road; as EUROVI for HDV
HDEUI	EURO I - 1992, heavy duty diesel vehicles
HDEUII	EURO II - 1996, heavy duty diesel vehicles
HDEUIII	EURO III - 2000, heavy duty diesel vehicles
HDEUIV	EURO IV - 2005, heavy duty diesel vehicles
HDEUV	EURO V - 2008, heavy duty diesel vehicles
HDEUVI	EURO VI, heavy duty diesel vehicles, post-2008
LFGDIII	EURO III, gasoline direct injection engines
LFGDIV	EURO IV, gasoline direct injection engines
LFGDV	EURO V, gasoline direct injection engines
LFGDVI	EURO VI, gasoline direct injection engines
LFEUI	EURO I, light duty, spark ignition engines: 4-stroke, not DI
LFEUII	EURO II, light duty, spark ignition engines: 4-stroke, not DI
LFEUIII	EURO III, light duty, spark ignition engines: 4-stroke, not DI
LFEUIV	EURO IV, light duty, spark ignition engines: 4-stroke, not DI
LFEUV	EURO V, light duty, spark ignition engines: 4-stroke, not DI
LFEUVI	EURO VI, light duty, spark ignition engines: 4-stroke, not DI
MMO2I	Motorcycles and mopeds, 2-stroke, stage 1
MMO2II	Motorcycles and mopeds, 2-stroke, stage 2
MMO2III	Motorcycles and mopeds, 2-stroke, stage 3
MOT4I	Motorcycles, 4-stroke, stage 1
MOT4II	Motorcycles, 4-stroke, stage 2
MOT4III	Motorcycles, 4-stroke, stage 3
HDSEI	Heavy duty vehicles, spark ignition engines, stage 1
HDSEII	Heavy duty vehicles, spark ignition engines, stage 2
HDSEIII	Heavy duty vehicles, spark ignition engines, stage 3
STMCM	Combustion modification: ships (medium vessels)
STLHCM	Combustion modification: ships (large vessels-fuel oil)
STLMCM	Combustion modification: ships (large vessels-diesel)
STH_GP	Good practice: storage and handling
FEED_MOD	Feed modification (all livestock)
HAY_SIL	Hay-silage for cattle
FREE	Free range poultry
ALTER	Low-till farming, alternative cereal harvesting
AGR1	A generic option for 'other animals' - good practice

Abbreviation	Technology
FLR_GP	Good practice in oil and gas industry - flaring
BAN	Ban on open burning of agricultural or residential waste
MINE_GP	Good practice in mining industry
SPRAY	Spraying water at construction places
FILTER	Filters in households (kitchen)
RESP1	Generic, e.g. street washing