GLOBAL AND LOCAL ATMOSPHERIC POLLUTION EVALUATION AND CONTROL. CHALLENGES FOR A SMALL ISLAND AND FOR DEVELOPING COUNTRIES

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ABSTRACT

The air pollution control and evaluation has acquired high importance in the modern world. Depending on the per-manence of the pollutants in the atmosphere, the pollution could be local, regional or global.

The contribution of many developing countries, such as Cuba, to global climate change is very low. In these cases, while providing importance to reducing national emissions of greenhouse gases (GHG), the priority actions would be addressed to adapting to climate change and to reducing emissions that determine local and regional pollution, which have adverse effects, especially on health.

The present paper examines Cuba's contribution to global greenhouse gases emissions, which turns out to be modest. Then, the problem of local pollution in the nation is addressed, reporting data from experimental measurements and comparing them with national regulations. The methodology employed and the results obtained on the levels of pollution generated by the national energy sector and corresponding impacts on health and its costs are discussed. The work may provide support for decision makers on the priorities in the use of available resources, with the aim of environmental preservation. Some approaches about how to deal the right balance of local and global responsibilities for countries as Cuba, are also presented. As the development of those countries proceeds, their contribution to GHG emissions is expected to become more relevant. Some planned countermeasures for reducing such a trend are illustrated.

KEYWORDS: Air pollution, greenhouse gases, local pollution, regional pollution, dispersion modelling, Cuba

INTRODUCTION

The impacts of the energy facilities on the environment and human health are very diverse and they include, among others, the emission of atmospheric pollutants. Depending on their permanence in the atmosphere, they could produce local, regional or global air pollution. The gases with long residence, as the greenhouse gases (GHG), i.e. CO_2, CH_4, N_2O and others, have global effects. Primary sulphur and nitrogen oxides produce local effects, but they are transformed into sulphate and nitrate aerosols that can remain in the atmosphere for several days and travel to a few thousand km; therefore, they also cause damage at regional or continental scale. Finally, other airborne emissions, such as hydrocarbons and heavy particles, can only cause local damage.

The trend of growth of the average temperature in correspondence with increasing concentrations of GHG in the atmosphere is an unmistakable sign that the greenhouse effect and its consequence, the global warming, is a threat that hangs over the earth. The energy sector's contribution to these emissions is significant. At national and international levels, awareness is gained from this situation and actions to mitigate it must be undertaken. Cuba's contribution to global climate change is undoubtedly very low; however, this is a topic to which an increasing importance in the country is being given.

To illustrate local pollution levels in Cuba, the paper presents the results of the study of the thermal power plants (TPP) in operation in the country during 2003. Eight TPP were evaluated, all units with 50 MW or more of installed capacity, for a total of 21 units with 2749 MW of total capacity, grouped in 12 emission points.

The studies were performed with SEIA[1]: Integrated system for the evaluation of the environmental impact of energy facilities in Central America and the Caribbean. SEIA estimates the emissions, processes the local meteo-

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rological data, calculates the local (with ISCST3 model [1]) and regional atmospheric pollutant dispersion, and, finally, it evaluates the human health impacts and their associated damage costs.

Greenhouse gases pollution

Recently, after more than 10 years of research and analysis, considering the most accurate and updated data on what has happened and could happen on Earth in relation to climate, a panel made up of 2,500 scientists said: "It is very likely that climate changes experienced around the world is due to human action: it is due to the indiscriminate increase in the emission of the greenhouse gases."

The panel has assessed an increase of 0.6 degrees in global temperature over the last century, which has heated the surface of oceans, melting glaciers and snow in the snowy peaks. As a side effect, it has caused, at short-term, the change of the shape of the coastlines in many parts of the world. The panel even dared to assert for the first time that there is a close relationship between global warming and events like Hurricane Katrina.

The above-quoted one is a much stronger statement than that in 1990, when the Intergovernmental Panel on Climate Change (IPCC) wrote the first of these reports. Back then, scientists had said that climate change could be caused both by nature and man. This doubt is due to natural forces that naturally shape the climate on Earth, for example the glaciation periods, and the recent change in the Sun power.

However, today there is no doubt that man has overcome these natural forces to create an imbalance. The CO_2, the most important greenhouse gas, is the result of burning coal, oil and other fossil fuels. The IPCC report states that the atmospheric concentration of this gas has increased from 280 to 379 ppm during the industrial era. There is an excessive accumulation of these GHG gases in the atmosphere, at a rate that the planet itself is unable to recycle.

The report makes projections into the future and shows several scenarios depending on actions taken today. The most optimistic (i.e. if mitigation strategies are followed to reduce the emission of greenhouse gases) foresees an increase of 1.7 degrees centigrade in the temperature of the planet in 100 years.

A commitment at government level is indispensable to achieve emissions reductions: the Kyoto protocol has been just a beginning. In the opinion of many, it did not meet all expectations and is being replaced by a new agreement to establish new commitments from the year 2012. Nevertheless, the Kyoto Protocol has created a scenario in which significant results have been achieved and created conditions for the maturation of more objective approach to the future.

The implementation of a climate policy could also create opportunities for savings. In some countries, it is possible that this policy will encourage the reform of inefficient energy systems and eliminate distorted energy subsidies. The most polluting countries should apply heavy taxes on emissions.

Countries contribution to global GHG pollution

The energy sector's contribution to greenhouse gases emissions is significant; indeed the main source of CO_2 is the burning of fossil fuels. This section discusses the contribution of several countries to global emissions of CO_2 due to fossil fuel burning and cement production. These activities represent nearly 80% of total CO_2 emissions and 60% of all greenhouse gases.

According to 2002 estimates made by the Department of Energy United States[2], total CO_2 emissions by the above activities amounted to 25,575 million tons (MM Ton), and the 20 countries that contributed most to these emissions are included in Fig. 1. Their emissions account for more than 75% of the total. The first contribution is from the United States, with more than 22%.

Cuba´s contribution to global GHG pollution

In Fig. 1, Cuba ranks 75 and its contribution is only 0.09%. The 74 countries that exceed Cuba, contribute with 93% of the total. A similar behavior is observed if we consider the total emissions of all greenhouse gases. According to recent reports, these emissions in the world (2002) amounted to 48,078 million tons of CO_2 equivalents, disaggregated as shown in the second column of Table 2.

Moreover, according to the National Inventory of Greenhouse Gases Emissions for 2002, updated for 1990, 1994, 1996, 1998 and 2000 [2], net emissions estimated in Cuba of the three main greenhouse gases (CO_2, CH_4 and N_2O) during 2002 totaled 24 million tons (see column 3 of Table 2) which represents 0.05% of world emissions. As it can be seen, even if the greenhouse gases emissions were reduced to zero in the country, the climate change will occur at roughly the same level. This indicates that the actions of adaptation must have primacy over those of mitigation.

Nevertheless, the country has taken important actions to insert itself in the Clean Development Mechanism (CDM) established under Article 12 of the Kyoto Protocol. A preliminary analysis of a dozen project ideas submitted for CDM have shown that, the use of electricity generation from renewable energies (hydro, wind and biomass), the biogas use and the increase of energy efficiency would reduce greenhouse gas emissions by 2.3 million tons of CO_2 equivalents with respect to the baseline emissions.

A similar situation occurs in many small developing countries; their contribution to global warming is very

[2] Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy. See website: http://cdiac.ornl.gov/

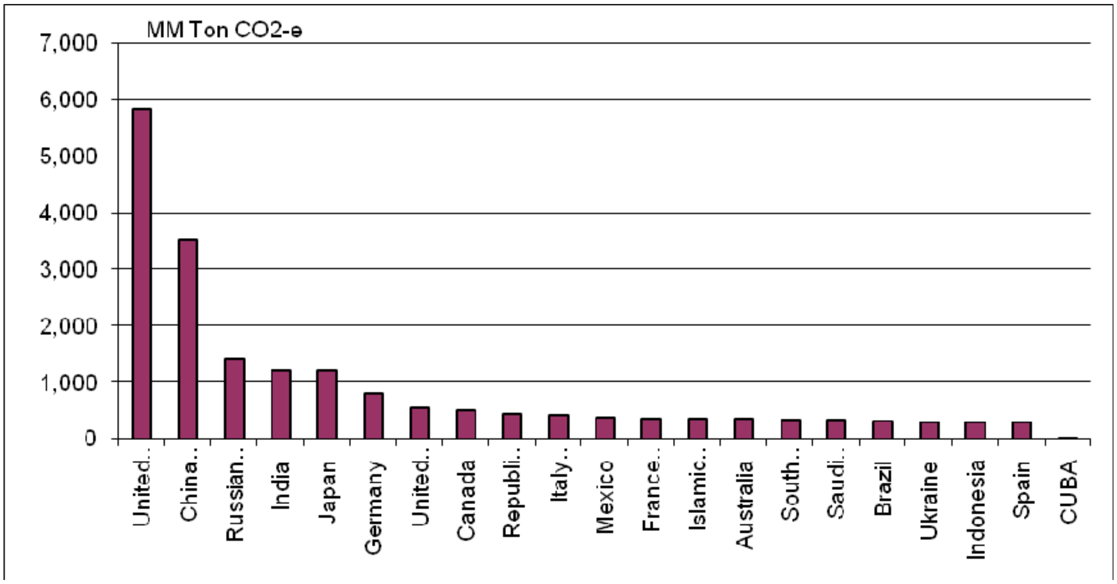

FIGURE 1 - Ranking of the world's countries by 2002 total CO_2 emissions from fossil-fuel burning, cement production, and gas flaring.

TABLE 1 - Emissions of greenhouse gases in the world and in Cuba, 2002

Pollutants	Global Emissions ton **CO_2-e**	Cuba, ton **CO_2-e**	Cuba, % of Total
CO_2	3.539E+10	7,344,870	0.02
CH_4	6.853E+09	8,081,220	0.12
N_2O	3.809E+09	8,915,600	0.23
HFCs, PFCs, SF_6, and other Ozone Depletion Potential gases (ODP)	2.026E+09		
Total	48,078,329,983.36	24,341,690.00	0.05

low, in contrast to the high levels of local pollution presented by any of the following reasons: use of outdated technologies with low efficiency and fuel of low quality without abatement technologies, located in major settlements, etc.

However, some big developing countries are now contributing to world GHG pollution in a relevant way. China's greenhouse gas emissions and policies are frequently invoked in international debates over appropriate climate change policy [3]. Chinese CO_2 emissions are high due to the country's large population, strong capital investment and urbanization, and heavy reliance on coal, but are constrained by low incomes. Current forecasts are speculative, but foresee Chinese emissions to grow rapidly with its economy. Cuba and other small developing countries should avoid such a trend in their future emission levels of pollutants. The rest of our study, bearing this in mind, will concentrate upon the local pollution problems in Cuba, illustrating a case study and its results.

Cuban Case Study at local level

In Cubaenergía, several studies have been completed to assess local air pollution and health impacts due to air pollutant emissions from different sources: power plants, generation sets, industrial boilers, refineries, landfills. The studies were performed with SEIA[3]: Integrated system for the evaluation of the environmental impact of energy facilities in Central America and the Caribbean. This software was developed by the Group of Environmental Impact, based on the Impact Pathways Methodology [4] adapted for applications in Cuba [5]. SEIA estimates the emissions, processes the local meteorological data, calculates the local (with ISCST3 model [1]) and regional atmospheric pollutant dispersion, and, finally, it evaluates the human health impacts and their associated damage costs.

MATERIALS AND METHODS

The evaluation was performed with the presented system SEIA 1.0, based on Impact Pathways Methodology. This methodology contains four steps: characterization of the source, dispersion of pollutants and estimation of concentrations, evaluation of impacts, and, finally, the economic

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evaluation. The paper deals especially with the first two steps. The study was, however, completed in all steps and the results appear in the Project final report PRN/5-1/2 "Development and implementation of a system (software) for the assessment of environmental impacts of energy facilities."

For the emission estimation, a methodology based on 4 levels was used: a) measurements, b) theoretical calculation of combustion, based on the operating characteristics of the facility and the fuel composition, c) same as b), but considering the results of basic measurements of the composition of the exhaust gases that are carried out routinely in the thermoelectric power, and d) use of emission factors.

Pollutants

From all the pollutants emitted by the power plants were those selected being considered as critical by the World Health Organization (WHO) due to their recognized impacts on human health: sulphur and nitrogen oxides and particulates. Another important pollutant is ozone, but it is not a primary pollutant (it is not emitted directly by sources), but is formed by photochemical reactions in the atmosphere from nitrogen oxides and hydrocarbons, so that its modeling is much more complex and beyond the scope of this work.

There are important evidences about the health effects of particulates, which are present in urban centres of both developed and developing countries. The studies include impacts on mortality and morbidity, both acute and chronic, predominantly in the respiratory and cardiovascular systems. The impact risks increase with the level of exposure, and it has not confirmed a threshold below which effects dis-appear. All the exposed populations may be affected, but susceptibility varies with the health and age.

Although for sulphur and nitrogen oxides the available literature is not as extensive as in the case of particles, their effects are demonstrated, at least being a part of the mix of pollutants under consideration in many studies.

The obtained concentration values obtained were compared to the values of the National Ambient Air Quality Standards (NC 93-02-202/1987 [6], NC 39: 1999 [7], NC 111-2002 [8]) for 1 and 24 hours. For the annual concentration, the references for SO_2 and NO_2 are the guide values of the WHO, 2000 [9] and for PM10, the United States standard; because in Cuba there are no standards for a year (see Table 3), is adopted.

TABLE 1 - Reference regulation levels for pollutants in Cuba

Pollutant	Reference values (μg/m^3)		
	1 hour	24 hours	Annual
SO_2	500	50	50 *
NO_2	85	40	40 *
PM10	150	50	50**

*WMS, 2000
** United Stated, National Ambient Air Quality Standards, US NAAQS

Receptors

For the selection of the receptor network, some sensitivity studies were completed with simplified models (Berland for 24 hours and 20 min, SCREEN3) which permitted a preliminary assessment of the spatial distribution of the highest concentrations. Sensitivity studies with the ISCST3 established that selected grid reflects the maximum values.

For each TPP, 400 receptors were evaluated. The receptors are located on the central points of the cells of 5 x 5 km that make up a domain of 100 x 100 km centered on

TABLE 2 - Pollutant inventory

TPP/ Units	SOx		NOx		PM_{10}	
	g/s	ton/year	g/s	ton/year	g/s	ton/year
MAXIMO GOMEZ						
1. Units of 50 MW	129.8	4093.7	5.0	157.7	5.5	174.7
2. Units of 100 MW	2979.3	93955.8	114.7	3618.4	127.2	4009.8
ANTONIO GUITERAS						
3. 330	2534.2	79919.8	96.3	3036.3	108.1	3407.8
C. M. CESPEDES						
4. 158	1145.1	36112.2	67.2	2119.2	50.7	1600.8
10 DE OCTUBRE						
5. Unit of 60 MW	66.7	2103.1	6.4	201.8	3.4	108.5
6. Units of 125 MW	2173.6	68547.3	90.8	2862.5	93.3	2943.6
ANTONIO MACEO						
7. Unit of 50 MW	167.5	5281.3	6.9	218.2	7.2	226.7
8. Unit 3, 100 MW	637.6	20108.3	26.3	831.0	27.4	863.5
9. Units 5 and 6, 100 MW	985.8	31088.5	40.7	1284.8	42.3	1334.9
FELTON						
10. 250	2658.4	83834.7	116.2	3663.5	114.5	3611.5
EAST OF HAVANA						
11. 100	2269.6	71575.1	82.4	2590.4	96.6	3045.1
OTTO PARELLADA						
12. 64	196.9	6210.4	18.9	596.3	10.2	320.4

the emission source. This type of grid receptor network (Cartesian with uniform spacing) is appropriate for the subsequent assessment of the impacts and costs. For each receptor, hourly concentrations during a year were estimated, in correspondence with the meteorological data.

Other required data

The methodology requires the location and technical characteristics of the TPP (stack height and diameter, temperature and velocity of exhaust gases), and the pollutant inventory. Digital elevation models of the modeling domains were processed in order to obtain topographical information. In addition, it was required the hourly meteorological data of representative surface meteorological station. Required primary meteorological data include wind speed and direction, temperature, cloud coverage, height of cloud base, pressure, relative humidity and precipitation rate.

To create the input file for ISCST3, primary meteorological data were processed with the pre-processor PCRAMMET [10]. The utilized version includes several modifications to take into account the Cuban conditions (tropical atmosphere, the absence of upper air data, tri-hourly surface data), conducted under the National Project ¨Atmospheric Environmental Externalities of Electricity Generation” [11].

RESULTS

The results provide important information on three issues:

- The inventory of emissions of criteria pollutants associated with electricity generation from fossil fuels,
- The incremental concentrations of SO_2, NO_X and PM_{10} in the local domain of the evaluated TPPs (100 x 100 km),
- The incremental depositions of SO_2, NOx and PM_{10} in local domains.

Table 4 shows the annual emissions (tons/year) of SO_2, NOx and PM_{10}. The emissions in g/s, required by dispersion model ISCST3, were estimated considering a uniform distribution of emissions throughout the year.

The presented results were obtained with the ISCST3 model for periods of 1 and 24 h as well as 1 year, with the following specifications:

- Options Regulatory Model
- Actual height of the receptors and sources
- Uniform distribution of annual emissions
- Hourly or 3-hourly meteorological data
- Wet and dry deposition of gases

For PM10 and NOx, the hourly, daily and annual incremental concentrations are below the reference values. However, as expected, given the high concentration of sulphur in the national crude oil (burned in most of the evaluated power plants), the incremental concentrations for sulphur dioxides are higher than the hourly and daily references. Table 4 shows the maximum concentrations for all periods, in μg/m^3. The numbers of receptors exceeding the reference values are indicated too.

ISCST3 model estimates wet and dry deposition of gaseous and particulate pollutants. The particles deposition has a considerable influence on the concentration values. Table 5 presents the results in g/m^2. For each TPP, the first row shows the average value in the domain, and the second row, the maximum value.

TABLE 4 - Hourly, daily and annual maximum concentrations (μg/m^3).

TPP		SOx			NOx			PM10		
		1 h	24 h	Annual	1 h	24 h	Annual	1 h	24 h	Annual
MAXIMO GOMEZ	**Max.**	1455.7	318.2	20.8	56.0	12.2	0.8	89.4	17.3	0.7
	NoRecep	114	906	0	0	0	0	0	0	0
ANTONIO GUITERAS	Max.	1261.2	269.0	22.3	47.9	10.2	0.8	76.1	16.6	1.0
	NoRecep	96	606	0	0	0	0	0	0	0
C. M. CESPEDES	**Max.**	815.6	154.9	22.4	47.8	9.1	1.3	46.9	7.8	0.8
	NoRecep	18	177	0	0	0	0	0	0	0
10 DE OCTUBRE	**Max.**	702.1	203.2	14.0	31.0	9.3	0.7	26.3	7.4	0.5
	NoRecep	3	90	0	0	0	0	0	0	0
ANTONIO MACEO	**Max.**	2851.8	662.2	32.1	117.8	27.4	1.3	151.9	31.4	1.4
	NoRecep	291	1028	0	4	0	0	1	0	0
FELTON	**Max.**	1065.9	182.3	35.9	46.5	7.9	1.6	61.7	10.3	1.3
	NoRecep	36	407	0	0	0	0	0	0	0
EAST OF HAVANA	**Max.**	677.4	432.1	9.6	24.5	15.6	0.3	40.6	24.4	0.3
	NoRecep	2	30	0	0	0	0	0	0	0
OTTO PARELLADA	**Max.**	398.0	375.7	10.6	38.1	36.0	1.0	33.6	26.2	0.4
	NoRecep	0	18	0	0	0	0	0	0	0

TABLE 3. Incremental depositions (g/m^2).

TPP		SO_2			NOx			PM_{10}		
		1 h	24 h	Annual	1 h	24 h	Annual	1 h	24 h	Annual
MAXIMO GOMEZ	Average	0.0336	0.0361	0.1550	0.0001	0.0001	0.0014	0.0015	0.0018	0.0177
	Max	0.7058	0.7058	3.6297	0.0003	0.0005	0.0122	0.0600	0.0909	0.7410
ANTONIO GUITERAS	Average	0.1022	0.1076	0.2656	0.0001	0.0001	0.0011	0.0466	0.0491	0.1326
	Max	2.2100	2.2502	3.3010	0.0003	0.0006	0.0148	1.0033	1.0215	1.5335
C. M. CESPEDES	Average	0.0102	0.0103	0.0378	0.0001	0.0001	0.0009	0.0006	0.0006	0.0050
	Max	0.5651	0.5651	2.4787	0.0004	0.0004	0.0165	0.0369	0.0369	0.2397
10 DE OCTUBRE	Average	0.0165	0.0216	0.0840	0	0.0001	0.0011	0.0008	0.0011	0.0108
	Max	0.6001	1.1269	3.8781	0.0002	0.0004	0.0145	0.0336	0.0654	0.4117
ANTONIO MACEO	Average	0.1015	0.1061	0.2029	0.0001	0.0001	0.0013	0.0460	0.0481	0.0948
	Max	1.6006	1.6006	2.2631	0.0005	0.0010	0.0167	0.7341	0.7341	1.0322
FELTON	Average	0.0153	0.0160	0.0829	0	0.0001	0.0009	0.0007	0.0008	0.0101
	Max	0.3706	0.3801	3.2325	0.0003	0.0004	0.0147	0.0337	0.0485	0.7221
EAST OF HAVANA	Average	0.0255	0.0117	0.1971	0	0	0.0021	0.0011	0.0007	0.0296
	Max	0.8122	0.3377	6.2953	0.0002	0.0001	0.0195	0.0403	0.0268	0.9363
OTTO PARELLADA	Average	0.0024	0.0012	0.0321	0	0	0.0017	0.0001	0.0001	0.0086
	Max	0.0871	0.0388	0.9812	0.0002	0.0002	0.0370	0.0045	0.0030	0.5544

As the critical load values for Cuban conditions have not been established, it can only be noted that the maximum values obtained for SO_2 are in the order of, or exceed, those established for various European ecosystems (250-1500 eq/ha/year). Considering 1 eq/ha = 0.0032 g SO_2/m^2 (obtained from: 1 eq H+ =16 g S, 1 g SO_2 = 0.5 g S, 1 ha = 104 m^2), the average values reported in column 5 vary between 4.6 and 44, while the maximum ranged between 187.1 and 1836 eq/ha. For nitrogen compounds, the critical loads for Europe range from 5-35 kg N/ha-year, so the NOx depositions are not close to critical values.

The critical load depends on the past and present management, the ecosystem type and the soil conditions. It is not known how these critical load values proposed for Europe could be applied in other regions.

CONCLUSIONS

The case of growing pollutions and greenhouse gas emissions from big developing countries shows how it is important that developing countries too face the pollution question by time, and adopt adequate policies in order to limit it. Cuba, however contributing to global warming in a negligible way, is already tackling the question of atmospheric pollution, starting from pollutant emissions from power plants.

The paper presents the incremental concentrations of three criteria pollutants (PM_{10}, SO_2 and NOx) in the local domains of the power plants in Cuba during 2003. The paper shows that the incremental daily and hourly concentrations of SO_2 exceed the standard values. Really, local pollution levels are higher because there are other sources such as transport sector, refineries, industrial boilers, etc.

The people residing in these areas have a high risk of serious health effects. In particular, recent studies have reported that levels of environmental exposure until short time ago were considered to be harmless, could cause adverse health effects on the general population and, particularly, on more vulnerable groups such as children, asthmatics, chronically ill and elderly people, without the recognition of specific response thresholds for different pollutants. WHO and its regional offices have established new guide values to criteria air pollutants, based on latest available evidence from toxicological, clinical and epidemiological studies. These values are stricter than those previously established in 2000 and used as reference in this work.

Given that Cuba's contribution to global climate change is very low, but reduce to zero our greenhouse gas emissions, this will occur at roughly the same level, the adaptation actions must have primacy over mitigation one. During 2002, Cuba emitted about a 0.05% of total greenhouse gases generated worldwide (24 million tons of CO_2 equivalents vs 48.078 million tons). This argument allows us to conclude on the need to prioritize immediate actions and resources for reducing emissions of pollutants that produce local pollution.

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