Introduction

In chapter two of the previous work: Islas, et. al. 2005, *SO_2, NOx, and Particle Control Technologies and Abatement Costs for the Mexican Electricity Sector*, were obtained SO_2 abatement costs in 10 most polluting power stations in the Mexican Electrical System (MES) (see table 2.1 from cited work). Based on this information, two combinatorial alternative choices were formulated in chapter 5, considering the lowest abatement costs technologies and practices for SO_2 emissions control of every analyzed power plants. These two alternatives were named the “best abatement cost route” and the “second-best abatement cost route”. In the first alternative, cumulative SO_2 reductions of 41 percent in terms of global emissions[1], cumulative total costs of 464 and investments of 841 million dollars were obtained. This difference between cumulative costs and investments is due to the substitution of fuel oil by imported coal (shipped by sea) at Petacalco power plant, which brought economic benefits for 1320 million dollars. Likewise, this alternative had abatement costs ranging from 0 to 449 USD/ton SO_2. Similarly, the second-best abatement cost route showed more significant SO_2 reduction levels with 57%; however, cumulative total costs and investments of 4229 and 2358 million dollars were obtained, respectively. As a result, higher abatement costs, ranging from 216 to 580 USD/ton SO_2 were obtained.

Even though the above-mentioned alternatives offer good solutions to deal with the SO_2 emission control problems in the MES, they certainly may not consider other combinatorial alternative choices, which may also represent optimal solutions in terms of SO_2 emissions and total costs reduction. Therefore, such routes may not include the set of least-costs technologies and practices for SO_2 removal. Similarly, if these control options are evaluated on the basis of generating units instead of power plants, the best and the second-best route are not the least-cost combinatorial alternative choices.

[1] Considering the overall SO_2 emissions from all Mexican power plants

Thereby, this chapter develops a Pareto based optimization approach in order to find the least-cost for the reduction of SO_2 emissions in a generating unit-based analysis. In doing so, a Pareto's optimal subset of the space combination of emission control options can be identified as the best combination for which there is not a better combination to reduce the sulphur dioxide emissions, when a set of given restriction criteria have to be defined and fulfilled.

In order to find this optimal solution, a first step consisted in sorting some data in a table by power plant and control option. These data refer to the investment, operation and maintenance (O&M), fuel, total and abatement costs as well as the SO_2 avoided emissions found in chapter 2 (see table I-1 in appendix I).

According to CFE (2006) we later obtained this information for every generating unit by assuming that the number of boilers is equal to the number of emission points, which is as well equal to the number of power stations. Considering the 10 power plants discussed in this analysis, we have a total of 41 generating units.

This chapter gives special emphasis to the generating units and so as we can refer data provided in table I-1 in appendix I to this approach, each generating unit's capacity was weighed by the overall capacity of the power plant where it is installed. Doing so, results can be obtained for every generating unit as shown in table I-2 in appendix I.

Taking into account some considerations agreed with SENER's decision makers, it was suggested that it would be of high interest for energy-environmental policies to find out the optimal combination of SO_2 control options that minimizes the total abatement costs of this pollutant in 10% intervals, expressed as a percentage reduction of the overall SO_2 levels emitted by the all considered units[2]. Additionally, other criterion that would have to be fulfilled by all generating units is the SO_2 allowable emission levels set in the Mexican Official Norm "NOM-085-ECOL-1994" (DOF,1994) for fixed sources of pollution within a geographical zone.

[2] These generating units represent the total sum of SO_2 emissions of the 10 most polluting power plants in the MES

Norm 085 sets the limits of emissions depending on the location of the fixed source and divides the Mexican Republic into 3 zones: 1) metropolitan zone, 2) critical zone and, 3) rest of the country. In our case analysis, 13 generating units (installed at Tula, Salamanca and Altamira power stations) are located in "critical zones" while the remaining units in the "rest of the country" zone.

Consequently, this optimization model considers that the first 13 generating units meet the limits imposed by the norm (tighter restrictions) within critical zones, while the other ones comply with the regulations (less severe restrictions) applicable to the rest of the country.

In order to fulfil this criterion, allowable emission levels were calculated for every generating unit, based on the allowable emission factors set by the norm NOM-085-ECOL-1994 and the fuel type and consumption rate (see table 1) of each generating unit. With regard to fuel supply, it is important to bear in mind that we are going to analyze a set of generating units of which 8 burn a solid fuel (coal) at Rio Escondido and Carbon I power stations while the other units burn fuel oil.

Table 1. Allowable emission factors according to the norm 085

Fuel type	Critical zone	Rest of the country
	Kg SO_2 / 10^6 Kcal	Kg SO_2 / 10^6 Kcal
Liquid (fuel oil)	4.08	8.16
Solid (coal)	4.31	8.16

Source: NOM-085-ECOL-1994

Table I-3 in appendix I shows the allowable emission levels according to the norm 085 in terms of tonnes of SO_2 (tons of SO_2), and categorized by fuel type and geographical zones. We can then observe in this table that all units installed in critical zones do not meet these limits while the units installed in the rest of the country fulfil the Mexican norm even without the installation of a control option.

Since the 13 generating units located in critical zones exceed the limits set by the norm, it is necessary to express in our optimization model that these units have to reduce their SO_2 emissions to comply with the regulations. Thus, our model has to include a restriction criterion for not exceeding the SO_2 limits allowed by the norm 085 (in tons of SO_2, according to the data provided in table 1) for every unit located within critical zones.

Taking this into account, we state the problem of finding the optimal combination of generating units and control options that not only have the minimum cost for each 10% interval reduction of the overall sulphur dioxide emitted by the 41 generating units in the country's 10 most polluting power plants but also fulfil the norm 085 within the critical zones. Next section covers this issue by developing a mathematical optimization model. Later, it will be discussed its implementation and solution in a software application.