ESTIMATING AIR POLLUTION EMISSIONS FROM FOSSIL FUEL USE IN THE ELECTRICITY SECTOR IN MEXICO

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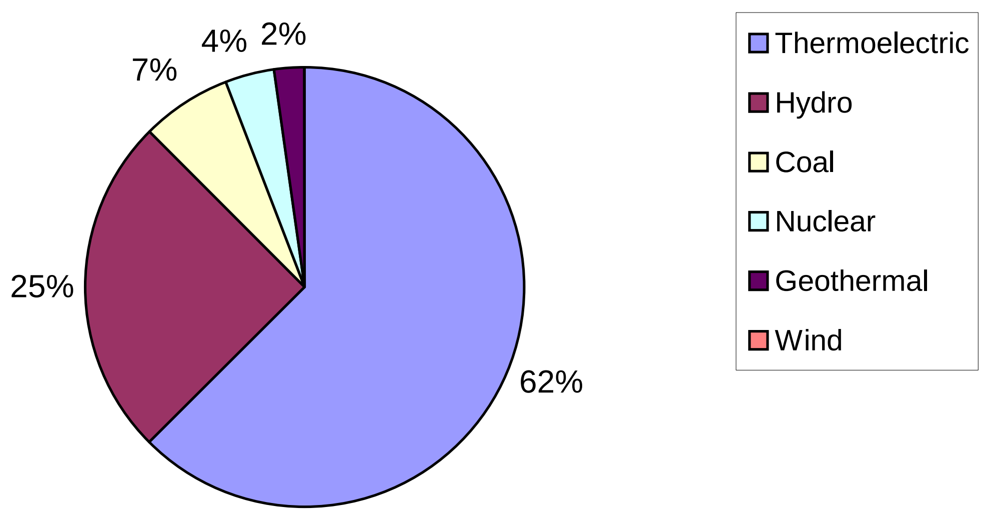
Introduction

Mexico is among the world's leading producers and exporters of energy (*Secretaría de Energía*—Sener 2004). Mexico generated about 167 TWh of electricity in year 2001 from an installed capacity base of 38.5 GW. Similar to many developing and developed countries, the majority of the installed generation capacity in Mexico is based on fossil fuels. However, the power generation profile of Mexico is significantly different from many other developing countries. For example, the installed capacity of India and China is dominated by coal-fired thermal generation, whereas in Mexico the total generation is dominated by fuel oil (*combustóleo*). This difference plays a significant role in defining the emission characteristics of the Mexican power generation sector.

In 1980, Mexico's installed power generation capacity was 14,625 MWe, which more than doubled in 20 years, and was 38,518 MWe in 2001 (Sener 2004). On average, Mexico has added every year about 1300 MW of net generation capacity.

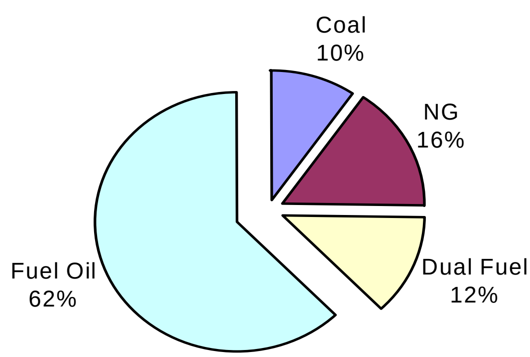
Figure 1
Composition of Generation Capacity in Mexico (2001) (Total 38518 MWe)



Source: Sener (2004)

Of the total installed generation capacity, 69 percent is fossil–fuel-based thermal power generation. Of the total 27 GW fossil–fuel-based thermal power generation capacity, the largest share comes from fuel–oil-based power stations. The distribution of fossil–fuel-based installed capacity by fuel type is shown in Figure 2, for the year 2001.

Figure 2
Composition of Fossil Fuel Based Generation Capacity in Mexico (2001)



Total 27GW

Source: Sener (2004)

With increasing environmental awareness, the power generation sector in Mexico has grabbed the attention of public and policy makers alike. This has led to efforts to quantify emissions from power plants, and has inspired the development of an emissions inventory of pollutants from the power generation sector in Mexico. All the power plants report fuel consumption, emissions and several other operating characteristics in the annual report of operations submitted to the Ministry of Environment and Natural Resources (Semarnat), known as the *Cédula de Operación* (COA); however, due to the confidential nature of these documents there have been no publicly available estimates of emissions from the electric power generation in Mexico.

Recently, in a significant development, a collaborative effort between Semarnat and the Ministry of Energy (Sener) to tackle the problem of emissions from power plants has been undertaken. A recently published report by Sener and Semarnat (Sener 2003) has resulted from this. The report is publicly available at

<http://www.energia.gob.mx/work/secciones/575/imagenes/pema2003.pdf>.

This report also published estimates of fuel consumption and emissions from power plants, from 1995 to 2001. Full document containing the emission inventories from 1995 to 2001 was presented on 29 July 2003, in an official meeting between the ministries of Environment and Energy, at Sener headquarters, and copies of the document were distributed among the audience. The current version of the report available on the web (last accessed on 28 February 2004) does not have fuel consumption and emissions data.

In this document, we have estimated emissions from power generation in Mexico, based on fuel consumption, as well as emission factors for specific power generation plants, for the years 2001 and 2002.

Methodology

We used the methodology recommended by the Emissions Inventory Improvement Program of the US EPA (EIIP 2001). We obtained installed and effective generation capacity of the thermal power units from *Informe de Operación* (Sener 2002). The document describes the number of units at each plant location and their generation capacity. Furthermore, the document lists gross generation and fossil fuel consumption data at the plant level (not at the unit level). We requested detailed information about the boiler types and combustion configurations for all the plants to estimate emissions more precisely. Sener provided us with this information for most of the power plants. Wherever such information was unavailable we assumed combustion to be normal type, as opposed to tangential firing. Information about wet or dry bottom was not available, and thus we assumed all coal-fired generation to be of dry-bottom type, as these facilities are more common. Wet-bottom boilers are more common for coal-fired plants that use fluidized bed combustion (EIIP, 2001).

For a given power plant, we have multiplied the total annual fuel consumption by plant by the respective emission factors for four pollutants, CO_2, SO_2, NO_x (expressed as NO_2), and mercury. Emission factors used for various fuel types, combustion, and firing types are listed in Tables 1, 2 and 3.

Emission Measurements

Only a few of the power plants in Mexico have continuous emissions measuring capability; therefore, the only viable options for estimation of the emissions are the use of emission factors, or periodically performed stack measurements. Although stack measurement data can provide more credible information than use of the emission factors, there are certain problems in using that approach for the Mexican power sector. First, the periodic stack emission measurements are reported as part of COA, and are not available in the public domain. Second, the periodic emission measurements are also used to compare the plant's emission performance with the current norms; therefore, the plant operators have an incentive to perform these measurements while the conditions are 'optimal.' Lack of randomness in measurements and low measurement frequency make this approach less suitable for annual emission estimations.

Conventionally, the estimation of annual emissions by Sener is based on emission factors used currently by CFE, applied to the following four categories of power plants on a uniform basis (Sener 2003): large vapor plant, small vapor plants, combined cycle plants, and turbo-gas generators. Although this approach provides reasonable first-order emission estimates, it has several problems. There is no distinction made on the basis of the firing type (tangential or normal), which can lead to an over-estimation of NO_X emissions. Further, the impact of the size of the combustion equipment is not taken into account. Larger facilities tend to have higher emission factors for NO_X due to their higher combustion temperatures, resulting in the formation of thermal NO_X (Beer, 2000). We have tried to further refine these estimates by obtaining and including plant level combustion information. We have taken into account the difference in emission factors arising from the type of firing, i.e., tangential, wall, or other. The firing type information corresponds to data from CFE that was made available to us for a large number of plants by Sener (CFE 2003), which helped us improve the accuracy of the emission estimates.

Emission Controls

Most of the plants in Mexico have no emission controls installed. Data from the *Cédula de Operación* for the year 2002 (Semarnat 2004) indicates installation of one NO_X control and two PM control devices (we can not disclose names of those plants because of the confidential nature of the information provided in the *Cédula de Operación*). However, it is safe to assume that PM controls are installed on the coal-fired power plants, due to the high ash content (37 percent, by weight) of the Mexican coal (Rangel 2002). Although PM control devices may also affect emissions of SO_2 and mercury, we have ignored this factor for the estimations presented here. NO_X control is reported to be implemented in only one plant; therefore, it should not have a significant impact on the overall emission estimations.

Estimating SO_2 Emissions

The emissions of pollutants depend not only on fuel type, but also on the type and configuration of the boiler, such as tangential or wall-fired, wet or dry bottom. However, SO_2 emissions are directly proportional to the sulfur content in the fuel, and the quantity of fuel consumed. Therefore, the accuracy of the SO_2 estimates depends on the degree of precision with which sulfur content in the fuel is reported. For our calculations, we have used the annual weighted average sulfur content for the year 2001 of CFE, provided by Sener (2003).

It is worth mentioning that the power plants use either local or imported fuel oil. The fuel oil produced by the local refineries is high in sulfur content (3–4 percent), whereas imported fuel oil contains 1–2 percent sulfur, by weight. The weighted average value of sulfur in the fuel-oil for power plants in the year 2001 was between 3.3–3.9 percent. The reported sulfur content in the imported fuel oil was 1.7 percent by weight.

The sulfur content for diesel is reported to be 0.5 percent for all the power plants using diesel. The sulfur content for coal is reported by CFE to be 1 percent for the two plants using Mexican coal, and 0.5 percent for the Petacalco plant, which uses imported coal. These values are substantially different from the previously reported values by Miller *et al.* (1996). Miller *et al.* (2002) also report higher values of sulfur content in the Mexican coal.

Estimating CO_2 emissions

For a given fuel composition, it is possible to estimate fairly accurate values of this important greenhouse gas. Assuming complete combustion of the fuel, it can be easily calculated from the chemical composition of the fuel. We have used emission factors used by the CFE for estimating CO_2 emissions. Due to the lack of information about exact fuel composition, we have not verified the accuracy of the emission factors.

Estimating NO_X emissions

The NO_X emissions are a function of the fuel type and combustion temperature. Generally, larger facilities have higher emission factors because they operate at higher temperature. Moreover, the configuration of the combustion equipment can significantly affect the rate of formation of nitrogen oxides. For boilers using fuel oil or natural gas, the emission factor for normal firing is higher than for tangentially fired boilers. Therefore, it is essential to have information about the firing type of each unit. Sener provided this information to us, which has helped to reduce the uncertainty in our estimation of NO_X emissions.

The emission factors that we used were mostly obtained from the EPA's AP-42 (1998). We used the updated version of the emission factor database FIRE 6.23, available at EPA's web site. For CO_2 estimation, emission factors were not available for all the fuels or boilers; therefore we used Sener emission factors for the same. For mercury emissions, we used a previous study commissioned by the Commission for Environmental Cooperation (CEC) to estimate emissions from different source categories in Mexico (Acosta 2001).

In Table 1, the emission factors used for fuel oil and diesel fuel are given for different combustion types and for different configurations. The NO_X emission factor for normal combustion is about 46 percent higher than that for tangential combustion. Moreover, when the same fuel is used in an internal combustion engine, e.g., in a reciprocating compression ignition engine using diesel fuel, the NO_X emission factor can be as high as 19 times as that in a tangentially fired boiler. Similarly, for the turbines using diesel fuel, the NO_X emission factor can be about four times that of an external tangentially fired boiler.

Table 1
Emission Factors Used for Power Generation in Mexico
(Fuel Oil and Diesel)

Fuel	Combustion Type	Boiler Configuration	CO_2[1] t m^{-3}	Hg[2] kg m^{-3}	NO_X Kg m^{-3}	SO_2[3] kg m^{-3}
Fuel Oil (*Combustoleo*)	External	Normal	3.04	1.35E-05	5.63	18.81*S%
	External	Tangential	3.04	1.35E-05	3.83	18.81*S%
						18.81*S%
Diesel	External	Normal	2.66	1.35E-05	5.63	18.81*S%
	External	Tangential	2.66	1.35E-05	3.83	18.81*S%
						18.81*S%
Diesel	Internal	Reciprocating Engine	2.66	1.35E-05	72.37	18.81*S%
Diesel	Internal	Turbine	2.61	2.00E-05	14.66	18.81*S%

Source: EPA AP-42 (1998), from FIRE V. 6.23
1. Sener (2003)
2. Mercury emission factors were taken from Acosta (2001)
3. S% indicates percentage of S in the respective fuel, by weight.

Table 2 depicts the emission factors used for plants using natural gas as a fuel. We note that the NO_X emission factor for normal fired boilers with a heat rating of less than 100 million BTU per hour (about 29.8 MW thermal) are about 60 percent lower than the one having higher heat rate. For an efficiency of 30 percent, such a plant would have a generation capacity of approximately 10 MWe. We note that most of the units are larger in size that 10 MWe, therefore, we use the appropriate emission factor, which result in higher NO_X emissions. Again, if natural gas is being used in tangentially fired configuration, less of thermal NO_X is formed. For combined cycle power plants using natural gas for the topping-cycle we use emission factors applicable for internal combustion in a turbine. Only NO_X emissions are affected by this distinction.

Table 2
Emission Factors Used for Power Generation in Mexico
(Natural Gas)

Fuel	**Combustion Type**	**Boiler Configuration**	**CO_2[1]** t/Mm^3	**Hg[2]** kg/Mm^3	**NO_X** kg/Mm^3	**SO_2** kg/Mm^3
Natural Gas	External	> 100 MMBTU/Hr Normal	1.92	4.17E-03	4486.14	9.61
	External	< 100 MMBTU/Hr Normal	1.92	4.17E-03	1602.19	9.61
	External	Tangential	1.92	4.17E-03	2723.73	9.61
Natural Gas	Internal	Turbine	1.92	4.17E-03	5127.02	9.61

Source: EPA, AP-42 (1998)
1. Sener (2003)
2. Acosta (2001)

Two coal-fired power plants use the indigenous supply of coal. The Río Escondido power plant (installed capacity 1200 MWe) uses 100 percent local coal, with low to moderate sulfur content and high ash content. The composition of local and imported coal is reported by Rangel (2002). Miller et al. (1996) found the sulfur content in Mexican coal to be between 1.3 and 2.5 percent. The CFE calculations assume sulfur to be 1 percent by weight, which is very low. We use a sulfur content of 1.3 percent for estimating SO_2 emissions from the Río Escondido plant. Another coal-fired plant in the north of the country, Carbon II, uses 90 percent indigenous coal and 10 percent imported coal. We use a weighted average value of 1.23 percent of sulfur content for coal burned in this plant. The Petacalco plant is currently a duel-fuel plant, using fuel oil, as well as coal. Coal used in this plant is imported – and has about 0.7 percent sulfur by weight. The fuel oil used in the plant has been reported to be 3.6 percent sulfur *combustóleo*. The difference in the fuel composition, in terms of sulfur content directly affects SO_2 emissions.

Table 3
Emission Factors for Coal-fired Plants in Mexico

Fuel	Combustion Type	Boiler Configuration	CO_2[1] t t^{-1}	Hg[2] kg t^{-1}	NO_X kg t^{-1}	SO_2[3] kg t^{-1}
Bituminous Coal	External	Wet Bottom, Wall	1.465402	8.30E-05	15.50	19*S%
Bituminous Pulverized Coal	External	Dry Bottom, Wall	1.465402	8.30E-05	11.00	19*S%
Bituminous Pulverized Coal	External	Wet Bottom, Tangential	1.465402	8.30E-05	7.00	19*S%
Bituminous Pulverized Coal	External	Dry Bottom, Tangential	1.465402	8.30E-05	7.50	19*S%

Source: EPA, AP-42 (1998)
1. Sener (2003)
2. Acosta (2001)
3. S% is the percentage of sulfur in the fuel by weight

All the units of the Río Escondido power plant are wall-fired, and as such have a higher emission factor for NO_X. The bottom-type, dry or wet, also affects NO_X emissions. Due to the lack of any concrete information about this characteristic, we assume all the plants to be dry-bottom type. Particularly for the wall-fired boiler type, this distinction may result in significant differences in the NO_X emission. The Carbon II thermal station has two tangentially fired and two wall-fired units. In the dual fuel Petacalco power plant, all the units are tangentially fired, resulting in lower emission factors for NO_X emissions.

We have used the emission factors for NO_X from the EPA's AP-42, and for mercury emissions we have used data from Acosta (2001). For CO_2 emissions we use the emission factors used by the CFE and provided by Sener (2003).

Geographical Distribution of Emissions from Thermoelectric Power Stations

Tables 4 and 5 list emissions of the four pollutants considered in this study for all the states and the installed capacity in each.

Of the total 32 states, nine states did not have any fossil–fuel-based installed generation capacity or had negligible emissions of the four pollutants considered here. These states are Aguascalientes, Chiapas, Michoacán, Morelos, Oaxaca, Puebla, Tabasco, Tlaxcala, and Zacatecas. For most of the pollutants, Veracruz is the most polluted state, emitting 261 kt of SO_2, and 20.67 kt of NO_X annually. The Tuxpan power generation plant (6x350MWe) using fuel oil with high sulfur content is primarily responsible for the state's emission profile. Coahuila has the highest NO_X emissions of all the states (99 kt). The state of Coahuila also has the largest installed fossil-fuel thermal power generation capacity (2688 MWe) and emits the highest amounts of carbon dioxide and mercury.

Table 4

Installed Fossil–fuel-based Generation Capacity and Estimated Emissions for CO_2, Hg, NO_X, and SO_2, by State (2001)

S. No.	State	Installed Capacity (MWe)	CO_2 (kt)	Hg (t)	NO_X (kt)	SO_2 (kt)
1	Baja California Norte	1443	3015.94	0.01	7.35	18.43
2	Baja California Sur	355	1074.92	0.01	5.34	11.47
3	Campeche	164	938.23	0.00	1.18	20.91
4	Chihuahua	1829	5292.96	0.02	12.32	59.71
5	Coahuila	2688	14625.71	0.81	99.39	237.16
6	Colima	1900	9455.83	0.04	11.96	206.04
7	Distrito Federal	148	117.57	0.00	0.33	0.00
8	Durango	615	2442.56	0.01	4.10	42.56
9	Guanajuato	866	4085.27	0.02	5.85	84.48
10	Guerrero	2143	9350.72	0.16	21.08	176.17
11	Hidalgo	1993	9413.50	0.04	16.07	163.17
12	Jalisco	24	1.88	0.00	0.01	0.01
13	México	1449	3416.60	0.01	5.52	0.02
14	Nayarit	1	0.00	0.00	0.00	0.00
15	Nuevo León	1733	5778.91	0.02	13.31	30.43
16	Querétaro	469	1177.72	0.00	3.33	0.02
17	Quintana Roo	257	67.28	0.00	0.38	0.24
18	San Luis Potosí	700	3812.77	0.02	4.88	80.25
19	Sinaloa	1006	4317.66	0.02	7.30	101.86
20	Sonora	1389	5345.95	0.02	8.44	118.49
21	Tamaulipas	1344	6367.91	0.03	11.85	116.12
22	Veracruz	2569	12391.31	0.05	20.67	261.04
23	Yucatán	564	2009.37	0.01	3.76	28.36
	Total	**25650**	**104501**	**1.2951**	**264.43**	**1756.94**

Note: Of the total 32 states, 9 states were not included in the list due to their zero contribution to the emissions. The list of such states is provided separately in the text.
Source: Sener (2003); CFE (2002), and calculations by the authors.

Table 5

Installed Fossil–fuel-based Generation Capacity and Estimated Emissions for CO_2, Hg, NO_X, and SO_2, by State (2002)

S. No.	State	Installed Capacity (MWe)	CO_2 (kt)	Hg (t)	NO_X (kt)	SO_2 (kt)
1	Baja California Norte	1443	2402.74	0.01	5.97	7.12
2	Baja California Sur	355	1028.15	0.00	4.49	12.55
3	Campeche	164	796.03	0.00	1.01	17.74
4	Chihuahua	1960	5318.74	0.02	12.85	51.71
5	Coahuila	2688	12848.75	0.71	86.35	206.97
6	Colima	1900	8384.66	0.04	10.70	182.45
7	Distrito Federal	148	99.47	0.00	0.28	0.00
8	Durango	615	2276.00	0.01	4.02	36.19
9	Guanajuato	866	3762.23	0.02	5.39	83.02
10	Guerrero	2143	8302.23	0.31	31.24	113.41
11	Hidalgo	1993	8719.34	0.04	15.04	158.33
12	Jalisco	24	28.39	0.00	0.11	0.04
13	México	1449	2746.66	0.01	4.51	0.01
14	Nayarit	1	0.00	0.00	0.00	0.00
15	Nuevo León	1594	3977.50	0.01	8.70	26.86
16	Querétaro	469	1433.03	0.00	4.18	0.18
17	Quintana Roo	257	129.82	0.00	0.73	0.47
18	San Luis Potosí	700	2175.63	0.01	2.88	45.73
19	Sinaloa	1006	4115.41	0.02	6.93	97.35
20	Sonora	1389	4984.18	0.02	8.39	108.48
21	Tamaulipas	1344	6201.20	0.02	12.03	110.89
22	Veracruz	2669	12524.98	0.05	20.73	266.20
23	Yucatán	564	2226.80	0.01	4.22	31.87
	Total	**25741**	**94481.95**	**1.31**	**250.76**	**1557.58**

Note: Of the total 32 states, 9 states were not included in the list due to their zero contribution to the emissions. The list of such states is provided separately in the text.
Source: Sener (2003); CFE (2003), and calculations by the authors.

Sources of Error and Uncertainty

Using emission factors is the not necessarily the best way to estimate emissions; however, given the lack of any continuous emissions measurements or frequent stack measurements, it is the only feasible option. Even if we assume emission factors to result in good quality estimations, there are several other simplifications and assumptions made that further affect the precision of the estimations. Such factors and their potential impact on estimation of emissions are discussed below.

For any fossil-fuel plant, the exact percentage of carbon in the fuel would directly affect the CO_2 emissions. This can cause error and uncertainty particularly in the coal-fired plants, as coal composition can vary significantly for different sources, and even for the same source, two batches may have very different ash and moisture content, affecting actual CO_2 emissions. We have used the emission factors from the CFE emission estimates, but have not verified the primary source of those factors. We are not certain if the factors for coal and other fuels are based on an analysis of Mexican fuel composition.

For sulfur content in the fuel, a study conducted by Miller *et al.* (1996) indicates a wide range of sulfur content in the coal. However, Rangel (2002) reports lower sulfur content than Miller (1996), and Sener uses 1 percent sulfur content, for emission estimations from local coal, and 0.5 percent sulfur content for imported coal. We believe that both of these estimates are on the lower side. Moreover, the Carbon I plant uses only coal from local mines, whereas Carbon II uses a mix of local and imported coal. A variation of this mixture could result in 10 to 15 percent difference in sulfur emissions. The source of imported coal is also not fixed and the various sources considered have different sulfur contents. Initially, the Petacalco power plant started operating using fuel oil but is being converted to burn only coal. As all the units are converted from high sulfur fuel oil to low sulfur imported coal, SO_2 emissions from this plant should further decrease.

NO_X emissions for tangentially fired boilers are lower than that for normal or wall-fired boilers. In certain power plants, all the units are of tangential or wall type; however, in certain cases some units are tangentially fired and some are normal or wall-fired. On the other hand, we do not have unit-level generation or fuel consumption information;

therefore, we have used installed-capacity-weighted NO_X emission factors for such plants, which can add to the uncertainty in estimating NO_X emissions.

Mercury emissions are neither reported in the *Cédula de Operación*, nor estimated by Sener or CFE. Therefore, it is difficult to find suitable emission factors. In this document, we have used emission factors derived from the CEC-sponsored study for development of the mercury emissions inventory in Mexico (Acosta 2001). End-of-pipe controls, particularly in the coal-fired power plants, can affect mercury emissions, but due to a lack of complete information we have assumed no controls, which is contrary to the actual situation and thus will result in an overestimation of the mercury emissions.

Conclusion

Our study shows that there is no significant difference in the generation capacity of all the plants in Mexico. For the pollutants considered here, from 2001 to 2002, there seems to be a trend toward reduction in emissions. Particularly, reduction in CO_2 is significant, which is probably a result of higher plant load factor for the cleaner plants, and less use of peaking units. Mercury emissions have increased slightly in 2002, compared to 2001, as a result of fuel switching from fuel oil to coal at the Petalco plant. NO_X and SO_2 emissions have also declined in 2002.

Thermal power generation using fossil fuels will play a significant role in the Mexican electricity sector in the foreseeable future. The emissions inventory developed in this document is the most comprehensive and up-to-date emissions inventory for the pollutants considered, namely CO_2, mercury, SO_2, and NO_X. This emissions inventory should provide a very important tool for designing programs to reduce air pollution from thermal power stations in Mexico.

We also recognize that the emissions inventory can be further improved by incorporating better information about fuel composition, particularly coal, and by obtaining the data from the installed continuous emission measurement equipment.

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Appendix

The CO_2 emissions estimates in the CEC report, based on CFE emission factors, seem to be low for the coal-fired power plants in Mexico. Specifically, the Petacalco power plant, which uses imported coal, having a high percentage of fixed carbon, should have higher emissions. In this appendix, we estimate emission factors for CO_2 emissions from coal-fired power plants in Mexico using the percent fixed carbon (FC) values, and volatile matter (VM) in the coal composition reported by Rangel (2002), and contrast it with the CO_2 emission estimates produced by CFE emission factors.

According to Rangel, local (Mexican) coal has about 31% fixed carbon (FC), whereas imported coal (used by the Petacalco plant) has at minimum 45% and maximum 57% fixed carbon. Using a formula to derive the approximate total carbon percentage in coal: Total C (% by wt) = FC (% by wt) + 0.5 VM (% by wt). This is in no way a substitute of ultimate analysis of coal samples of course; however, in the absence of more exact data it provides a good approximation consistent with proximate and ultimate analysis values by Miller *et al.* (1996). The coal used by the Carbon II plant is 90% local and 10% imported.

Our calculations show that using the CFE emission factors significantly underestimates CO_2 emissions from Petacalco. The revised emission factors predict 40% more CO_2 emissions, whereas for the Rio Escondido and Carbon II plant, our revised CO_2 emissions are, respectively, 10% and 6% greater than the emissions estimates derived from the CFE emission factors.

Table A1
Characteristics of Coal-fired Power Plants in Mexico (2002)

Plant Name	Installed Capacity (MW)	Generation (GWh)	Fuel Used: Fuel Oil (km^3)	Fuel Used: Coal (kt)	Fuel Used: Diesel (km^3)
PETACALCO	2100	13879.47	957.53	3631.24	6.65
RIO ESCONDIDO	1200	7515.56	0	4201.94	45.15
C.T. CARBON II	1400	8636.35	0	4345.71	36.56

Source: CFE 2003

Table A2
Coal Type and CO_2 Emission Factors for Coal-fired Thermal Plants in Mexico

Plant Name	Coal Type	Fixed C (% Wt.) [1]	VM (%)	C (%)	Emission Factor (tt^{-1}): CFE [2]	Emission Factor (tt^{-1}): CEC [3]
PETACALCO	Imported	51	31.5	66.75	1.465	2.448
RIO ESCONDIDO	Local	30	25.2	42.6	1.465	1.562
C.T. CARBON II	Imported and Local	31.2	25.8	44.1	1.465	1.617

Notes: 1. For imported coal, min FC is specified to be 45%, and max to be 57%. We used an average value of 51%
2. We estimated total C% as sum of FC and half of VM, which is consistent with proximate and ultimate analysis by Miller *et al.* (1996).

Sources: [1] Rangel 2002

[2] CFE 2003

[3] Estimated by the authors
CEC = Commission for Environmental Cooperation of North America

Table A3

Total and Per Unit Output CO_2 Emissions from Coal-fired Plants in Mexico (2002)

Plant Name	Total Generation (GWh)	CO_2 Emissions (kt): CFE	CO_2 Emissions (kt): CEC	kg/MWh: CFE	kg/MWh: CEC
PETACALCO	13879.47	8245.7	11813	594	851
RIO ESCONDIDO	7515.56	6276.1	6684	835	889
C.T. CARBON II	8636.35	6463.9	7124	748	825

Source: Estimated by the authors using the emission factors of Table A2