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EMISSIONS DUE TO FOSSIL-FUEL CONSUMPTION AND CEMENT PRODUCTION IN TURKEY (1970–1991)

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Abstract—Standard emission factors are used for estimating levels of particulate matter (PM), SO_x, CO, volatile organic compounds (VOC), NO_x and CO_2. Results are presented for different fuels and energy-consuming sectors. In the early 1970s households utilizing lignite made the most significant contributions to emissions, while manufacturing industries with both lignite and petroleum utilization were responsible for SO_x, NO_x, and PM emissions. Households continued to produce the same CO and VOC emissions and manufacturing industries continued to be responsible for NO_x emissions through the 1970–1990 period. Power production had gained in importance with regard to SO_x, CO_2, and PM emissions by 1990.

1. INTRODUCTION

Air pollution is a symptom of industrial growth in developed and developing countries alike.[1] Among the most critical compounds affecting the quality of our atmosphere are SO_2, NO_x, CO, O_3, and CO_2. In the late 1980s, the international community responded to air pollution through environmental initiatives with the objective of establishing international emissions standards. The European community announced that emissions from large combustion plants ought to be reduced below the 1980 emissions level by 20% by the end of 1993, 40% by 1998 and 60% by 2003. Turkey is a developing country. There is very limited information available on annual pollutant emissions. In this study, we assess air-pollution indicators in Turkey for the period 1970–1991, using yearly fossil-fuel consumption as basis for the computations.

2. DATA AND METHODOLOGY

Fossil-fuel consumption data have been collected from yearly publications on energy statistics in Turkey.[2] The polluting sectors are households, manufacturing industry, power production, and transportation. Fossil-fuel consumptions includes the use of coal, lignite, petroleum, and natural gas (NG). For estimations of air pollution, methods suggested by the U.S. EPA[3] and Marland[4] were applied. The EPA method yields concentrations of SO_2, NO_x, CO, particulate matter (PM), and volatile organic compounds (VOC) for fossil-fuels using standard emission factors.

The energy-consuming sectors of Turkey are identified in the manner of Tasdemiroglu.[5] Standard tables for uncontrolled emissions are chosen for computations of yearly emissions of SO_2, NO_x, CO, VOC, and PM for 1970–1991. Marland's method[4] was applied to calculate CO_2 emissions. Yearly CO_2 emissions (CO_{2i}) are determined by the amount of fuel consumed (P_i), the fraction of fuel that is oxidized (FO_i) and the carbon content of the fuel (C_i), i.e.

$$CO_{2i} = (P_i)\,(FO_i)\,(C_i), \tag{1}$$

where the subscript i indicates a particular fuel group and CO_{2i} is the mass of carbon. All coal, NG or crude oil are not of the same composition and hence have different CO_2 potentials. Results were obtained according to Marland's method and are listed in Table 1.

The most significant contributors to CO_2 emissions are fossil-fuel burning and cement manufacturing. Since cement production requires the use of both fossil-fuels and $CaCO_3$, its CO_2 emissions are significant. According to Marland,[4] for each mole of CaO produced from $CaCO_3$, one mole of CO_2 is emitted. Thus, in the production of one metric ton of cement, 0.137 mt of C is released into the atmosphere as CO_2.

Table 1. Factors and units for calculating annual CO_2 emissions in 10^6 mt of C from Eq. (1).

NG consumption (P_g) = annual consumption ($\pm 10\%$) of NG in Q (10^{15}J), FO_g = effective fraction oxidized in the year of consumption = 0.98 ± 1%, C_g = carbon content in 10^6 mt per 10^{15}J = 0.0137 ± 2%.

Petroleum and NG consumption (P_l) = annual consumption in 10^6 mt ($\pm 8\%$), FO_l = effective fraction oxidized in the year of consumption = 0.918 ± 3%, C_l = carbon content in mt C per mt crude oil = 0.85 ± 1%.

Coal consumption (P_S) = annual consumption in 10^6 mt coal equivalent ($\pm 11.2\%$), FO_S = effective fraction oxidized in the year of consumption = 0.982 ± 2%, C_S = carbon content in mt C per mt coal equivalent = 0.746 ± 2%.

3. RESULTS AND DISCUSSION

For each of the pollutants, the contribution made by fossil-fuel consumption has been computed (see Fig. 1). Prior to 1979, the major contributor to CO_2 was petroleum consumption; after 1980, lignite consumption became dominant. The importance of lignite as a major contributing factor in the production of SO_2, PM, and CO may be observed in Figs. 2–5.

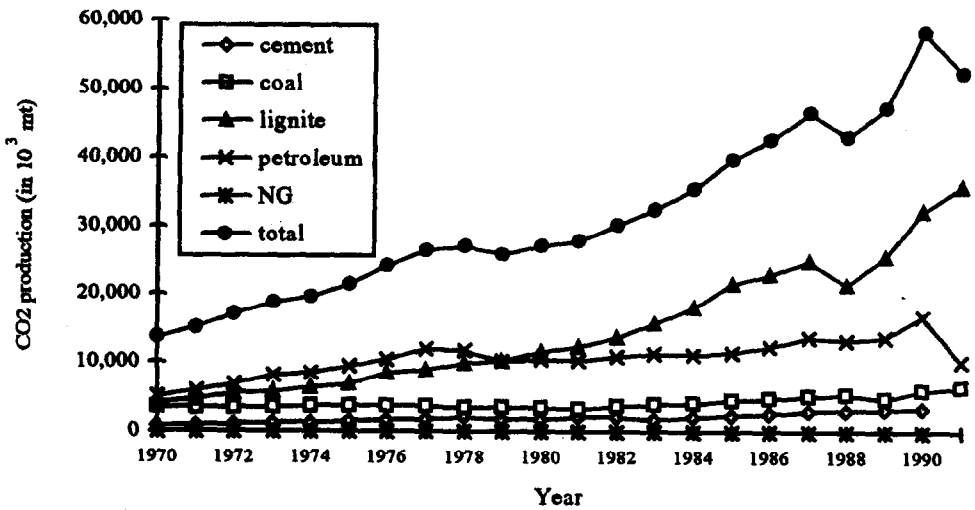

Fig. 1. Annual CO_2 production in Turkey from fossil-fuel burning (1970–1991).

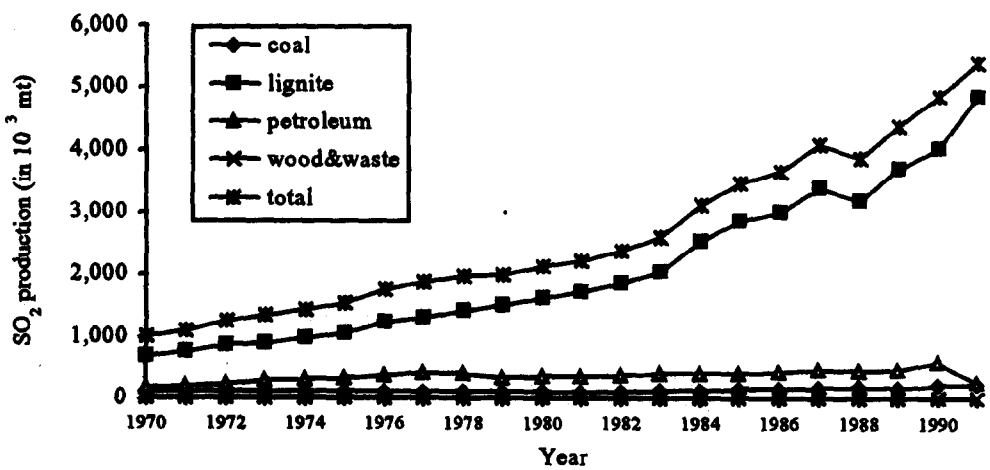

Fig. 2. Annual SO_2 production in Turkey from fossil-fuel burning (1970–1991).

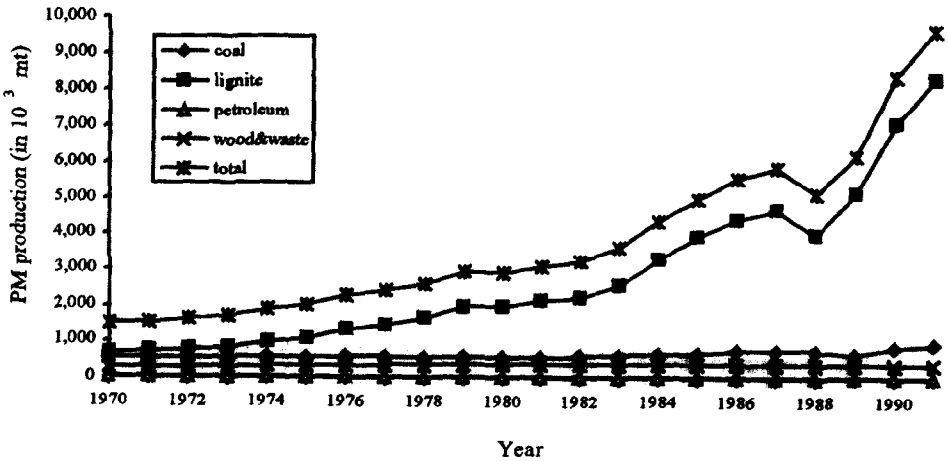

Fig. 3. Annual PM production in Turkey from fossil-fuel burning (1970–1991).

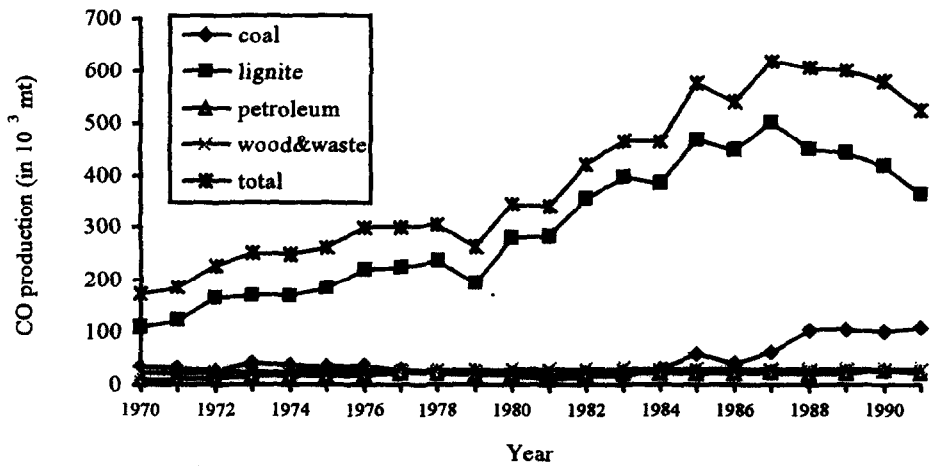

Fig. 4. Annual CO production in Turkey from fossil-fuel burning (1970–1991).

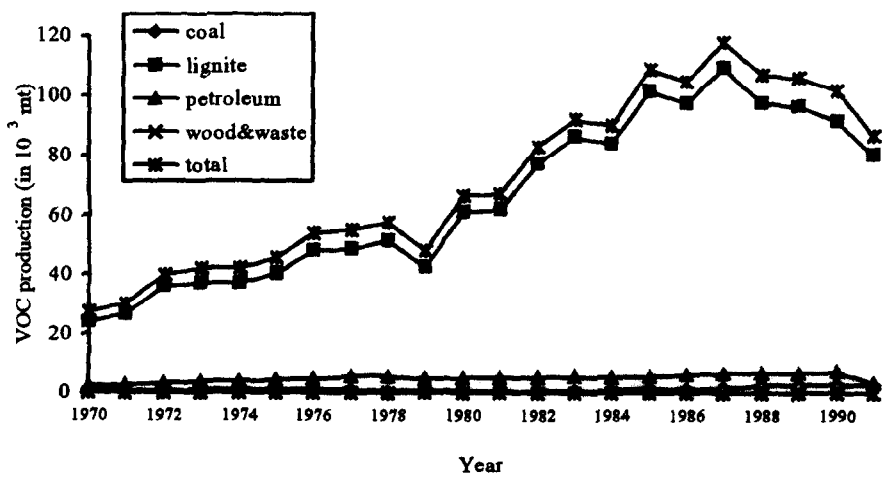

Fig. 5. Annual VOC production in Turkey from fossil-fuel burning (1970–1991).

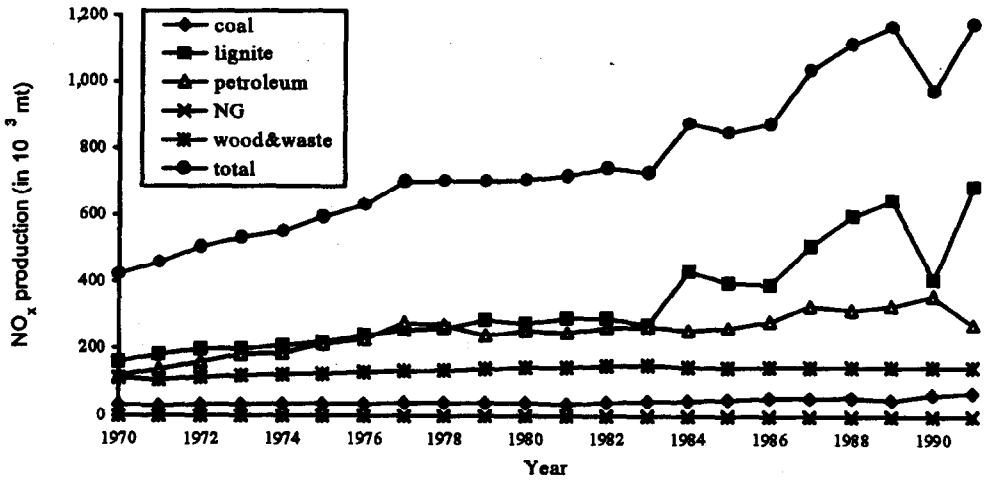

Fig. 6. Annual NO_x production in Turkey from fossil-fuel burning (1970–1991).

For NO_x production, both lignite and petroleum consumption play important roles (see Fig. 6).

SO_2 production for various sectors is summarized in Table 2 for various fossil-fuels, wood and waste in five-year intervals from 1970–1990. Similar tables are given for NO_x, CO_2, CO, VOC, and PM in Tables 3–7, respectively. These tables show which combination of sectors and fossil-fuel consumption is most detrimental for a specific air-pollution indicator. Furthermore, we see how the contributions change over time.

Industrial activities using lignite were responsible for 41% of emissions in 1970 for SO_2. Their importance has decreased with time and reached a level of 21% in 1990. At the same time, power production using lignite as an energy source increased. In 1990, power production was responsible for 53% of SO_2 emissions.

For NO_x emissions, contributed 56% in 1970 and 51% in 1990. The decreasing importance of industrial activities for NO_x emissions was more than offset by the increased importance of power production (see Table 3).

Household lignite consumption contributed 42% of CO_2 emissions 1970 and then decreased to 20% by 1990. Power production using lignite gained in importance and contributed 37.8% by 1990. Cement production was responsible for about 6% of CO_2 emissions between 1970 and 1990.

Table 2. Sectoral shares of SO_2 emissions (in %); subtotals add to 100%.

Source	1970	1975	1980	1985	1990
Household—Coal	1.69	1.13	0.39	0.88	1.11
—Lignite	18.64	20.21	22.15	22.58	14.1
—Petroleum	2.80	3.3	2.52	1.46	2.38
—Wood & waste	1.53	1.13	0.94	0.54	0.42
Subtotal	24.66	25.77	26	25.46	18.01
Industry—Coal	1.05	1.10	0.66	0.49	0.70
—Lignite	40.23	36.24	32.79	28.99	21.38
—Petroleum	0.43	0.49	0.43	0.26	0.26
Subtotal	41.71	37.84	33.88	29.74	22.34
Power production—Coal	7.41	5.06	4.11	3.18	2.76
—Lignite	9.09	12.17	21.57	31.03	47.26
—Petroleum	4.53	6.64	5.22	3.81	3.16
Subtotal	21.84	23.87	30.9	38.02	53.18
Transportation—Coal	1.89	0.96	0.26	0.19	0.05
—Petroleum	9.9	11.56	8.96	6.59	6.42
Subtotal	11.79	12.52	9.22	6.78	6.47

Table 3. Sectoral shares of NO_x emissions (in %); subtotals add to 100%.

Source	1970	1975	1980	1985	1990
Household—Coal	0.25	0.18	0.07	0.20	0.28
—Lignite	0.84	0.98	1.21	1.56	1.07
—Petroleum	0.28	0.35	0.3	0.22	0.4
—Natural gas	0.01	0.01	0.00	0.00	0.00
—Wood and waste	25.41	20.31	18.82	14.56	11.63
Subtotal	26.79	21.83	20.4	16.54	13.38
Industry—Coal	0.88	0.99	0.67	0.63	0.98
—Lignite	36.10	34.48	34.89	39.09	31.60
—Petroleum	19.02	22.94	22.71	17.31	19.18
Subtotal	56	58.41	58.27	57.07	51.76
Power production—Coal	6.24	4.59	4.18	3.18	3.89
—Lignite	2.49	3.61	7.15	31.03	21.78
—Petroleum	3.46	5.47	4.8	3.81	4.04
Subtotal	12.19	13.67	16.13	38.02	29.71
Transportation—Coal	0.34	0.22	0.12	0.19	0.06
—Petroleum	4.68	5.87	5.08	6.59	5.09
Subtotal	5.02	6.09	5.2	6.78	5.15

Table 4. Sectoral shares of CO_2 emissions (in %); subtotals add to 100%.

Source	1970	1975	1980	1985	1990
Cement production	6.36	6.93	6.49	6.05	5.72
Household—Coal	5.41	5.15	4.25	4.02	5.06
—Lignite	40.40	40.41	39.28	34.15	20.06
—Petroleum	4.70	4.74	5.42	4.14	5.4330.55
Subtotal	51.51	50.30	48.95	42.31	
Industry—Coal	2.35	2.39	1.58	1.30	1.05
—Lignite	9.00	9.54	9.4	8.22	6.79
—Petroleum	8.51	8.51	9.09	7.00	6.13
Subtotal	19.86	20.44	20.07	16.52	13.97
Power production—Coal	8.43	7.98	6.73	6.34	5.20
—Lignite	4.44	4.46	11.32	20.04	37.00
—Petroleum	3.77	4.29	3.09	3.04	3.04
Subtotal	16.64	16.73	21.14	29.42	45.24
Transportation—Coal	0.41	0.21	0.25	0.22	0.01
—Lignite	0.51	0.07	0.03	0.09	0.01
—Petroleum	4.71	5.32	3.31	5.29	4.5
Subtotal	4.71	5.60	3.63	5.70	4.52

CO emission is mostly related to household activities due to lignite burning which was responsible for about 80% of emissions in 1970 and 90% in 1990 (see Table 5). A similar situation applies for volatile organic compound (VOC) emissions. The household sector utilizing lignite and wood waste emitted 51.67% of the VOC in 1970 and 87.5% in 1990 (see Table 6).

Particulate matter (PM) emissions are summarized in Table 7. In 1970, power production and the manufacturing industry played significant roles with shares of 40 and 30%, respectively. Power production utilizing coal was responsible for 25% of emissions in 1970 and 8% in 1990. This reduction in PM emissions has been offset by the increased importance of lignite utilization in the same sector.

Table 5. Sectoral shares of CO emissions (in %); subtotals add to 100%.

Source	1970	1975	1980	1985	1990
Household—Coal	18.03	12.39	4.52	4.82	11.28
—Lignite	62.72	69.81	79.85	79.44	69.33
—Petroleum	1.17	0.91	0.84	0.73	1.40
Subtotal	81.92	82.11	85.21	84.99	82.01
Industry—Coal	0.12	0.13	0.08	0.06	0.11
—Lignite	0.57	0.52	0.49	0.42	0.44
—Petroleum	3.44	2.53	2.74	2.45	2.9
Subtotal	4.13	3.18	3.31	2.93	3.45
Power production—Coal	0.84	0.59	0.50	0.37	0.45
—Lignite	1.46	2.87	0.20	1.22	2.69
—Petroleum	11.65	11.25	10.78	10.5	11.4
Subtotal	13.95	14.71	11.48	12.08	14.54

Table 6. Sectoral shares of VOC emissions (in %); subtotals add to 100%.

Source	1970	1975	1980	1985	1990
Household—Coal	1.58	1.13	0.40	1.02	1.88
—Lignite	47.53	55.38	60.25	71.71	65.64
—Petroleum	0.63	0.80	0.63	0.41	0.98
—Wood and waste	44.14	35.13	29.17	20.59	21.88
Subtotal	93.88	92.44	90.45	93.73	90.38
Industry—Coal	0.08	0.09	0.06	0.05	0.10
—Lignite	0.63	0.6	0.55	0.56	0.60
—Petroleum	1.94	2.33	2.11	1.44	2.12
Subtotal	2.65	3.02	2.72	2.05	2.82
Power production—Coal	0.10	0.08	0.06	0.10	0.07
—Lignite	0.36	0.57	0.95	1.54	3.43
—Petroleum	0.65	0.94	0.76	0.62	0.76
Subtotal	1.11	1.59	4.49	2.26	4.26
Transportation–Petroleum	2.36	2.95	2.34	1.96	2.54

Table 7. Sectoral shares of PM emissions (in %); subtotals add to 100%.

Source	1970	1975	1980	1985	1990
Household—Coal	0.07	0.05	0.01	0.04	0.04
—Lignite	1.61	2.02	2.1	2.03	1.05
—Petroleum	0.06	0.08	0.06	0.03	0.04
—Wood and waste	18.98	16.25	12.78	7.40	4.48
Subtotal	20.72	18.40	14.95	9.50	5.61
Industry—Coal	3.59	4.32	2.49	1.75	2.06
—Lignite	27.29	27.91	24.00	20.12	12.33
—Petroleum	0.29	0.37	0.31	0.18	0.15
Subtotal	31.17	32.60	26.80	22.05	14.54
Power production—Coal	25.14	19.83	15.34	11.23	8.10
—Lignite	15.86	24.55	41.35	56.4	71.40
—Petroleum	0.07	0.13	0.10	0.06	0.04
Subtotal	41.07	44.51	56.79	67.69	79.54
Transportation—Coal	6.57	3.87	1.07	0.49	0.09
—Petroleum	0.47	0.62	0.39	0.27	0.22
Subtotal	7.04	4.49	1.46	0.76	0.31

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