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Emissions from power generation in Greece: past data and possible future evolution

Z. Samaras, G. Tsilingiridis, T. Zachariadis
Department of Mechanical Engineering, Aristotle University Thessaloniki, 54006 Thessaloniki, Greece

Abstract

Current emissions from power plants in Greece are presented and analysed. The effect of Directives 88/609/EEC pertaining to the emissions of large combustion installations and 93/12/EEC on the sulphur content of gas oil is examined. It is concluded that Greek power plants can meet NO_X emissions requirements without abatement measures, while new plants will have to employ SO_2 reduction devices. The evolution of emissions from power generation up to the year 2010 is studied according to three technology-oriented scenarios, revealing that there is substantial emission reduction potential which, however, is not likely to be exhausted as Greece does not face severe acidification problems and NO_X emissions are of concern in urban areas only, where power plants are not relevant.

1. Introduction

Power generation accounts for a major part of primary energy demand in Greece, and over 90% of this comes from fossil fuel burning. Out of the total installed electric capacity of 6.4 GW in thermal power plants in 1990, a few large steam plants (having a thermal capacity of over 50 MW each) accounted for approximately 90% of it; the rest are mainly diesel or heavy oil powered generator sets and gas turbines, spread in the islands of the Aegean (see Figure 1).

As a result of its large share in the Greek energy balance, power generation is responsible for a significant fraction of air pollutant emissions, mainly sulphur dioxide (SO_2) and nitrogen oxides (NO_x), as well as greenhouse gas emissions - notably carbon dioxide (CO_2) - its contribution being 25% for NO_x and 51% for CO_2 of the total emissions in the country in 1990 (Christolis et al.[1]); for SO_2 the authors' updated calculations show a 73% share of the sector in total emissions in 1990. As electricity demand is expected to rise in the future, so are emissions from power generation. Aim of this paper is therefore to forecast emissions of SO_2 and NO_x from Greek power plants up to the year 2010, taking into account electricity demand forecasts, emission standards for existing and new installations as imposed by Directive 88/609/EEC[2] and further potential improvements by using available pollution abatement technology. The study focuses on the plants of the Greek Public Power Corporation (PPC) as these account for a very high fraction (over 98%) of total power generation and a large part of the rest is not covered by the above Directive.

As regards CO_2 emissions, which are not dealt with by the above Directive and are planned to be limited on a voluntary basis, a detailed analysis and forecast according to a number of technological and economic scenarios has been carried out elsewhere (Capros et al.[3]). Therefore, the present study does not deal with CO_2 forecasts; it only presents the current situation.

Figure 1: The locations of thermal power plants of the Public Power Corporation (PPC) in Greece.

The estimated emissions of SO_2, NO_x and CO_2 from power generation in Greece in the year 1990 according to updated calculations of the authors, which are in line with previous ones (Christolis et al.[1], Tsilingiridis[4]), are given in Table 1. It is evident that the main part of SO_2 emissions comes from

Table 1: Estimated emissions of SO_2, NO_x and CO_2 from power generation in Greece in 1990.

	PPC power plants	*Fuel*	*Inst. capacity [MW$_{el}$]*	*Emissions [kt/y]* SO_2	NO_x	CO_2
1	LIPTOL	Lignite	43	1.0	0.5	393
2	Kardia	Lignite	1 200	26.3	16.6	8 227
3	Ptolemais	Lignite	620	12.3	9.7	4 816
4	Agios Dimitrios	Lignite	1 220	32.5	23.8	11 793
5	Amyntaio	Lignite	600	15.7	10.7	5 273
6	Megalopolis	Lignite	550	162.1	8.8	4 370
7	Aliveri	RFO	380	43.3	5.0	1 836
8	Lavrio (steam turbine)	RFO	450	5.8	3.5	1 290
	Lavrio (gas turbine)	Diesel	114	0.5	1.3	248
9	Agios Georgios	RFO	470			
10	Iraklio (steam turbine)	RFO	111	14.7	1.5	623
	Iraklio (ICE)	RFO	49	3.5	2.3	148
	Iraklio (gas turbine)	Diesel	33	0.1	0.2	47
11	Chania (gas turbine)	Diesel	101	0.3	0.8	164
12	Soroni/Rhodos (steam turbine)	RFO	30	4.4	0.4	188
	Soroni/Rhodos (ICE)	Diesel	12	0.0	0.0	0
	Soroni/Rhodos (gas turbine)	Diesel	60	0.2	0.5	96
13	A.P.P. Rhodos (ICE)	Diesel /RFO	11	0.1	0.3	21
	A.P.P. Rhodos (gas turbine)	Diesel	25	0.0	0.1	10
14	A.P.P. Islands (42 plants,ICE)	Diesel /RFO	327	8.6	7.9	500
	TOTAL		6 406	331.2	93.7	40 044

A.P.P.: Autonomous Power Plant; RFO: Residual Fuel Oil; ICE: Internal Combustion Engines

Megalopolis (which is due to the high sulphur content and the low sulphur retention factor of local lignite), while NO_x and CO_2 are mostly emitted in the plants of Ptolemais-Amyntaio (plants 1-5 of Table 1), which account for 70% of total electricity production in Greece. Figure 2 shows the share of each fuel in power plant emissions in 1990.

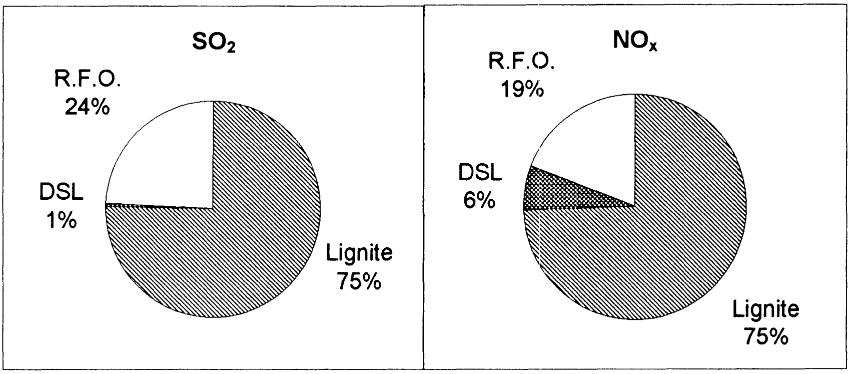

Figure 2: Contribution of each fuel used in Greek power plants to their emissions in 1990. DSL: diesel (gas) oil; RFO: residual fuel oil.

2. The impact of Directive 88/609/EEC on power plant emissions in Greece

According to Directive 88/609/EEC, SO_2 emissions from all existing combustion plants in Greece with a thermal capacity greater than 50 MW should not exceed from 1993 onwards the ceiling of 320 kt/y, i.e. 6% more than the estimated 303 kt/y in 1980. NO_x emissions are allowed to reach an upper limit of 70 kt/y in 1993, 94% more than the estimated value of 36 kt/y in 1980.

Based on the CORINAIR methodology and on emission factors coming partly from local fuel data and measurements (PPC[5,6] Kakaras & Papageorgiou[7]] and partly from CORINAIR[8] default emission factors, the authors have re-calculated emissions in 1980 and compared them with their 1992 estimates and Directive requirements. (Although it would be appropriate to compare the estimates of 1993, it was not possible to obtain fuel consumption data for this year and hence 1992 calculations were used; as no drastic change has taken place between 1992 and 1993, the assessment is valid). This comparison, shown in Table 2, reveals that, as far as existing power plants are concerned, compliance with the Directive is already achieved for both SO_2 and NO_x emissions, although no primary or secondary measures regarding these pollutants have been applied in any plant. The increase in NO_x emissions, which has to be attributed to the considerable rise in electricity generation between 1980 and 1992, was not followed by a similar change of SO_2 emissions mainly because the plant of Agios Georgios, burning residual fuel oil which has a high sulphur content, came out of operation for environmental reasons in the 90s. Moreover, in the light of Directive 93/12/EEC[9], which foresees a reduction in the sulphur content of industrial, heating and bunker gas oil to 0.2% by weight as of October 1994 and possibly less as of October 1999, SO_2 emissions from existing diesel powered plants may slightly decrease if the plants are not used more intensively in the future. It should be noted that plant Megalopolis IV, which became operational after 1987, is not included in the estimates of Table 2 and is treated as a new plant that has to comply with the corresponding Directive requirements.

Table 2: Estimated emissions from power plants with thermal capacity greater than 50 MW in 1980 and 1992 and comparison of their evolution with the one required by Directive 88/609/EEC.

	1980 emissions [kt/y]	*1992 emissions [kt/y]*	*Difference*	*Required difference*
SO_2	321.1	292.8	-9%	+6%
NO_x	44.9	82.6	+84%	+94%

As electricity demand in Greece is expected to rise substantially in the next two decades, additional power plants are planned to enter the Greek energy system (see Table 3). All these plants will be large enough to fall under the provisions of Directive 88/609/EEC. Lignite powered installations will use the same (or a similar) type of lignite used in current plants, and therefore they will have to apply an emission abatement technique in order to meet the standards set by the Directive. As regards NO_x emissions, existing power plants emit NO_x ranging from 130 mg NO_2 /nm^3 or 90 g/GJ (Megalopolis) to 450 mg NO_2 /nm^3 or 270 g/GJ (Agios Dimitrios) according to stack measurements (Kakaras & Papageorgiou[7,10]), already below the Directive requirements for new plants (set to 650, 450 and 350 mg NO_2 /nm^3 for fossil, liquid and gaseous fuelled plants respectively), with the hard coal - fired plant of Aliveri being the only potential exception in the future.

3. Forecast of power plant emissions in the year 2010

In order to assess the impact of pollution abatement measures in Greek power plants, the evolution of their SO_2 and NO_x emissions was studied for the period

Table 3: New power plants that are under construction or considered to be constructed in Greece in the near future (PPC[6]). The estimated emission factor is the 'uncontrolled' one (no abatement measures), while the indicated emission standard is the one of Directive 88/609/EEC converted to g/GJ of thermal input for comparative purposes.

Power plant	*Installed capacity [MW_{el}]*	*Fuel & plant type*	*Estimated emission factor [g/GJ]*		*Emission standard [g/GJ]*	
			SO_2	NO_x	SO_2	NO_x
Ag. Dimitrios V	350	Lignite, steam turbine	354	270	240	390
Komnina I & II	600	Lignite, steam turbine	233	260*	175	380-450
Amyntaio III	300	Lignite, steam turbine	233	260*	175	380-450
Florina I & II	600	Lignite, steam turbine	191	260*	140	380-450
Drama I - IV	1200	Lignite, steam turbine	114	260*	170	380-450
Lavrio	185	Natural gas, gas turbine	0	120*	14	135
Lavrio/Thraki	300	Natural gas, combined cycle	0	120*	14	135
Aliveri V	600	Hard coal, steam turbine	508	380*	160	250
Ptolemais V	350	Lignite, steam turbine	354	260*	240	390

*CORINAIR[8] default emission factor

1990-2010 according to a number of scenarios. As the focus was on the technical side, i.e. on the effect of using improved combustion or exhaust gas after-treatment technologies, a number of parameters concerning the patterns of electricity production remained unchanged in all scenarios. More specifically, the mean load duration curve of the years 1980 to 1990 was assumed to be valid for the future as well. Furthermore, the new power plants entering the Greek energy system were selected in accordance with current plans and in consistency with the overall prediction of electricity demand (see below), but also in such a way that this demand is covered by appropriate means (e.g. lignite plants for base load requirements, gas turbines for peak load demand etc.). New hydropower plants were also included in order to meet a part of the intermediate and peak load demand. Wind generators were considered too,

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although their impact on total electricity is negligible. Finally, the technical characteristics (availability and exploitation) of the Greek mainland power system, which comprises all power plants except the ones located in islands, were assumed to remain as in the past decade.

Concerning the evolution of electricity demand, a common forecast was used irrespective of scenario through correlations with population and Gross Domestic Product data, as illustrated in Figure 3; these are in line with energy forecasts presented elsewhere (PPC[6], Skiadas et al.[11]). Emission forecasts were performed with both high and low demand values of these projections.

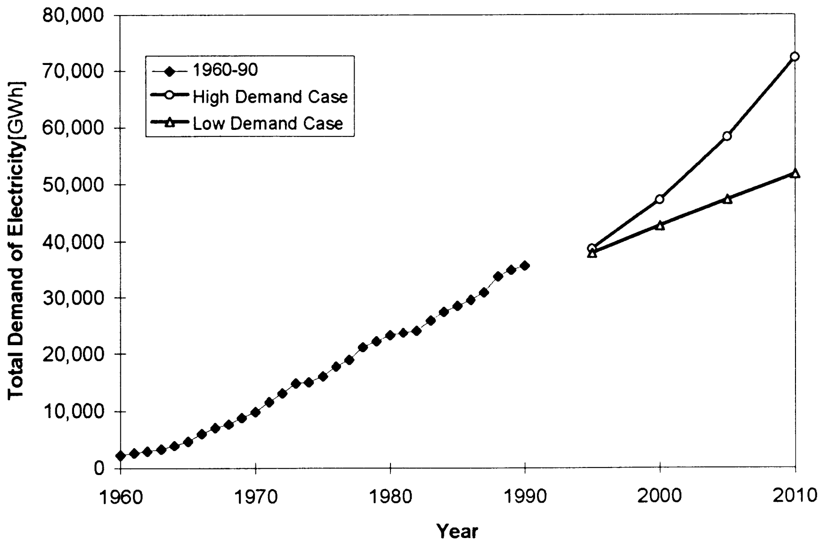

Figure 3: Electricity demand in the years 1960 to 1990 and forecast of its evolution up to 2010 (upper and lower values).

With regard to the different technology-oriented assumptions, three scenarios have been set up:

- "Business as usual", which accounts for the impact of Directives 88/609/EEC and 93/12/EEC. As mentioned above, implementation of the former will cause additional measures to be taken for new plants relating to their SO_2 emissions; it was therefore assumed that all new solid-fuelled plants (including the already operating one of Megalopolis IV) will have wet scrubbers for flue gas desulphurisation. The latter Directive will affect SO_2 emissions from all power plants burning gas oil as it requires a maximum sulphur content of 0.2% by weight in this fuel. No effect on NO_X emissions was modelled.

- Improved technology scenario, which assumes that wet scrubbers will be installed even in the existing lignite plants in the near future in order to drastically reduce SO_2 emissions; an efficiency of 90% was taken (Oertel & Rentz[12]). Moreover, the scenario assumes that primary measures will be employed in all new plants to enhance combustion and thereby reduce NO_x emissions. An emission of 200 mg NO_2 /nm^3 was taken for solid fuelled plants and 150 mg NO_2 /nm^3 for liquid fuelled plants, which is the level that primary measures can achieve today (Papageorgiou & Kakaras[10]).
- Improved energy utilisation scenario, which assumes the same measures with those of the improved technology scenario and additionally higher exploitation of hydropower, causing a partial shift from coal to hydropower and natural gas - as far as this is allowed by the natural possibilities of the Greek energy system - coupled with a different distribution of existing capacity in order to avoid frequent peak load demand. This scenario, which was meaningful only when combined with the high electricity demand forecast (because otherwise there was too little potential to re-adjust the capacity distribution), covers essentially all realistic technical possibilities for the reduction of SO_2 and NO_x emissions.

Table 4 displays the evolution of SO_2 and NO_x emissions according to the three outlined scenarios. A "do-nothing" case (i.e. no measures at all) was also added for comparative purposes. It is evident that the implementation of Directive 88/609/EEC, while not affecting NO_x, will cause a clear improvement in SO_2 emissions because new (post-1987) power plants will have to apply abatement measures. If the widely used wet scrubber technology is also applied in the old plants, the upwards trend of SO_2 emissions can even be inverted, with possible reductions of up to 60%. On the other hand, the significant rise in electricity production may lead to a proportional evolution of NO_x emissions unless their rate of increase is slowed down by implementing available technology that is not required by the Directive nor by national legislation. Finally, a shift towards better exploitation of the available power plants coupled with a minor fuel switch (from coal to hydropower and natural gas as far as possible) seems hardly capable of bringing any change at all; this finding should be attributed to the limited flexibility of the energy system, which has to satisfy an ever growing electricity demand.

As regards CO_2, it has to be reminded that a "business as usual" scenario presented by Capros et al.[3] foresees a 60% to 70% rise in CO_2 emissions in 2010 compared to 1990, which is in accordance with the estimated rise in uncontrolled NO_x emissions of Table 4.

Table 4: SO_2 and NO_x emissions from power generation in Greece in 2010, as calculated with the different scenarios. All values are expressed in kt/y.

Scenario		*1990*	*Electricity demand* *Low 2010*	*High 2010*	*Difference (2010)-(1990)* *Low 2010*	*High 2010*
Do nothing	SO_2	331	511	549	54%	66%
	NO_x	94	128	159	36%	69%
Business as usual	SO_2	331	377	385	14%	16%
	NO_x	94	128	159	36%	69%
Improved technology	SO_2	331	128	133	-61%	-59%
	NO_x	94	101	112	7%	19%
Impr. techn. + utilisation	SO_2	331	-	131	-	-60%
	NO_x	94	-	111	-	18%

4. Conclusions

Compliance of Greek large combustion installations (both existing and new ones) with Directive 88/609/EEC can be achieved without significant efforts as the Directive requirements are not particularly stringent. New installations, however, will have to apply a SO_2 abatement technique. If they are equipped with wet scrubbers, which is the most widely used technology, the rate of increase of SO_2 emissions will be slowed down. Application of available technology in both old and new plants can have remarkable results: it can curb SO_2 emissions by significant amounts and impede the rise of NO_x emissions, which will otherwise follow the high growth patterns of electricity consumption.

The finding that Directive 88/609/EEC is rather lenient towards the Greek power generation system is not surprising since acidification, which was the main concern that led to adoption of legislative measures against SO_2 and NO_x emissions, has never been an acute problem in Greece and NO_x emissions is mostly a critical issue in urban areas due to photosmog formation, where road traffic contributes the highest fraction. Taking into account that traffic will continue to be the main source of NO_x emissions in Greece (emissions are expected to grow by 30-40% in 2010), the efficiency of applying the best available technology to power plants is not guaranteed. Such measures therefore have to be considered in the framework of national target-setting, which should consider the cost-effectiveness of emission reductions in each sector as well as the pollutants that should be given special priority (e.g. ozone or greenhouse gases).

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