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THE IMPACT OF A CARBON TAX ON GREEK ELECTRICITY PRODUCTION

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Abstract

The impact of proposed carbon taxes on the electric power industry, using the Greek power system as a case study, is investigated in this paper. It uses the WASP model for electric generation capacity expansion to explore the optimal expansion path under alternative carbon tax scenarios and to estimate their impact on CO_2 and other types of emissions and on electricity production costs. The findings suggest that low carbon taxes would lead to a considerable reduction of the use of conventional lignite fired power plants counterbalanced predominantly by natural gas fired plants. High carbon taxes (100-200 US dollars per ton of carbon) would lead to a drastic reduction of the use of conventional lignite fired power plants which would be mainly replaced by coal or lignite fired technologies with CO_2 removal capabilities, which are not available today but might become available within the time horizon of the present study. Hydropower and renewable sources would be the second least-cost alternatives to lignite under both low and high tax scenarios.

The study provides evidence that carbon taxes also result in significant increases in the cost of producing electricity, implying adverse economic effects on electricity consumers and the Greek economy in general.

I. INTRODUCTION

In 1990, the Inter-Governmental Panel on Climate Change (IPCC) presented a comprehensive report on the nature and the consequences of global warming, reflecting thus the worldwide growing concern about the possible and undesirable impact of the Greenhouse Effect. Carbon dioxide (CO_2) emissions were recognized as being the main contributors to man-induced climate change. They are produced primarily from the burning of fossil fuels, a great proportion of which being used in electric power generation.

In 1990, for example, electricity generation was the major contributor (32%) to CO_2 emissions in countries of the European Community (EC) while transport, industry, residential/ commercial and the energy sectors were responsible for 23%, 20%, 21%, and 4%, respectively. In Greece, for the same year, the electricity sector has contributed by 50% to CO_2 emissions, which represents the highest percentage compared to other EC member states [Commission of the European Communities (CEC), 1991], while transport, industry, residential/commercial and energy sectors were responsible for 18%, 10%, 19% and 3% respectively. In Greece, the electricity sector should play an important role in reducing CO_2 emissions.

Although EC countries contribute to almost 13% of the global CO_2 emissions, compared to 23% for the United States, 5% for Japan and 25% for Eastern Europe and the former USSR, the joint Energy/Environment Council, at its meeting on 29 October 1990, suggested to stabilize CO_2 emissions in the EC at 1990 levels by the year 2000 (CEC, 1991). One of the key elements of the strategy to limit CO_2 emissions in the EC and worldwide is the introduction of a carbon tax, i.e., a tax based on the carbon content of fossil fuels. Carbon tax is an economic tool which is considered to have many advantages compared to other policies. It (a) allows the internalization of external costs and is in line with "the polluter pays" principle; (b) minimizes total CO_2 emissions control costs; (c) provides an economic incentive to adopt cleaner technologies and energy conservation techniques; (d) can be easily adjusted to new circumstances in order to be continuously effective; and (e) raises revenues that can be used for environmental purposes or be redistributed to avoid undesired distributional effects. As a result, several countries like Sweden, Finland and the Netherlands have already adopted carbon taxes while the United States and the EC are seriously examining a number of tax options.

This paper examines the effects of several proposed carbon tax rates on the electric power industry in Greece - the main contributing sector to emissions of CO_2, nitrogen oxides, sulfur dioxides and dust. It investigates whether tax rates would lead to technological changes in the structure of the industry and what would be the exact effect on the level of CO_2 and other types of environmental burdens. It also assesses the impact of carbon taxes on the optimum, i.e., least-cost, electricity expansion plan in terms of costs (control costs plus tax charges). The analysis is based on an adapted economic-engineering model for electricity generation capacity expansion which allows for a rich and detailed description of available technologies and takes explicitly into account the specific technical and economic characteristics of the sector, providing thus highly reliable results.

Section II summarizes the cost and performance characteristics of alternative technologies and provides a forecast of electricity demand. Section III presents the optimal expansion plans under alternative carbon tax scenarios and their impact on costs. General conclusions and some policy implications are given in the final section.

II. THE ECONOMIC-ENGINEERING MODEL

The well known planning tool Wien Automatic System Planning Package (WASP) is the economic-engineering model utilized in this study. WASP uses probabilistic estimation of production costs, amount of energy not served and reliability of the electricity system, together with the dynamic method of optimization for comparing the costs of alternative system expansion policies [3]. In particular, the dynamic programming approach determines the implementation of new generating units in the system and finds the optimum expansion policy under a number of operational, environmental and other constraints.

III. DATA

Before running WASP, collection of information is necessary, i.e., information on site-specific energy sources, present structure of electricity generation, economic and technical data for the initial stage (base year) and the planning period. The implementation of the model also requires the specification of capital investment costs of the expansion candidates, operating costs of existing and candidate units, cost of unserved energy, discount rates, escalation parameters and information related to the constraints to be imposed to the solution of the problem.

At the end of 1993, the mainland (interconnected) power system of the only producer and distributor of electricity in Greece, namely the Public Power Corporation (PPC), was composed of 32 thermal and 43 hydroelectric units, located in West Macedonia, Southern and Central Greece. Thermal units account for 90% of the total production of electricity, of which 78% is generated by lignite fired plants. The lignite mines owned by PPC are located in Northern Greece (Macedonia) and Southern Greece (Megalopolis). Additional lignite mines are being developed in the same areas in order to supply new lignite fired units. Exploration of new lignite reserves are carried out nationwide by PPC and the Institute of Geological and Mineral Research (IGME). In 1991, the economically recoverable lignite reserves were estimated at 4000 million tons (550 millions TOE) [17].

In 1993, hydropower had an installed capacity representing approximately 30% of the total capacity and accounted for only 8% of the total generation of electricity. The potential of hydropower is estimated at 20 x 10^6 MWh per year while the potential of windpower is estimated to exceed 5 x 10^6 MWh per year in the mainland Greece and the Aegean islands. In order to take into account the uncertainty of these estimates, for the needs of the study, it was assumed that approximately 16 x 10^6 MWh can be produced by hydropower and renewable sources. [21] Heavy fuel oil is used in steam power stations which are located near the large consumption areas of Athens (Aliveri and Lavrio) and accounts for about 12% of the produced electricity. In 1990, CO_2 emissions, as measured by PPC, amounted to 35460 thousands of tons (kton).

The objective function used in the WASP model can be written as:

$$L(x) = \sum_{t=1}^{T} [(E_{j,t} - S_{j,t}) + (F_{j,t} + NF_{j,t} + M_{j,t})]$$

The various cost components of WASP objective function L(x) are calculated in ways that account for: (1) the characteristics of the electric load forecast, and the characteristics of thermal, nuclear and hydroelectric plants; (2) the stochastic nature of hydrology (i.e., hydrological conditions); and (3) the cost of energy not served. Specifically:

1. The load is represented by the peak load, the energy demand for each period, and the shape of the corresponding inverted load duration curve. Nuclear and thermal plants are described in terms of maximum and minimum generating capacities, plant life for each expansion candidate, heat rate at annual maximum capacity and incremental heat rate between minimum and maximum capacities, annual maintenance requirements (i.e., scheduled outages), failure rate (i.e., forced outage rate), capital investment costs for the expansion candidates, variable fuel costs, fuel inventory costs and non-fuel operation and maintenance costs (fixed and variable).

2. The capacity of hydroelectric plants is assumed to be totally reliable with no associated costs for the use of water. The stochastic nature of the hydrology is introduced through the hydrological conditions or equivalent years of water inflow (dry year, average year, wet year). The probability of occurrence of each hydrological condition is determined from the statistical information which applies to the whole hydroelectric system. On the basis of this probability, the capacity and energy available from each hydroelectric project is specified. The probabilistic simulation approach is used to calculate the energy generated by each unit in the system.

Table 1a lists the basic economic and technical data of the existing units in the system while Table 1b shows the data of existing and candidate units. Since the present analysis was conducted in constant prices (1993), fuel prices and prices of other products or services included in O&M variable and fixed costs, are assumed to remain constant over the period of the study (1955-2025), implying that relative prices remain unchanged. Three hydrological conditions are considered and their probability of occurrence is 45%, 30% and 25% for dry, average and wet condition, respectively.

With respect to capacity constraints, it is required that the installed capacity in the critical period is above 20% of the peak load demand for the period 1995-2015 and above 15% of the peak load demand after the year 2015. Similarly, the maximum acceptable reserve margin (b_t) should be 50% of the peak load for the period 1995-2005, 40% for the period 2005-2015, and 35% after 2015. Finally, the annual loss of load probability should remain below ca. 0.5% (1.825 days per year).

The main forecasting data that includes data for potential expansion candidates, peak load and demand, is presented in Table 2. The electricity demand of the mainland GPPC system raised from 29,600 GWh in 1990 to 32,400 GWh in 1993, with a peak load of 5.5 GW. The basic load demand for this particular study is expected to grow by an average rate of 3% for the next decade and will decrease gradually to less than 2% during the last decade of the study. This represents an average growth rate of 2.1% per year over the 30 years of the study.

Table 1a
Technical and Economic Data of GPPC Existing Generating Units

Location of Power Station	Fuel Type	Installed Capacity (MW)	Heat Rate (kcal/kWh)	CEC (kg/MWh)	FOR* (%)	Non-Fuel O&M Costs	
						Variable** ($/MWh)	Fixed** ($/KWyr)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
West Macedonia	Lignite	3683	2650	1320	5-13	1.4	20
Southern Greece	Lignite	850	2860	1450	10-15	4.0	30
Central Greece	Heavy fuel oil	830	2360	900	10-17	1.0	28
	Hydro	2524	-	-	-	-	7.2

Notes:

* The Forced Outage Rate (FOR) associated to the individual generating units varies from unit to unit. The table reflects the range of variation rather than the exact figure; estimated FORs from Vassos et.al. (1993).

** Variable operation and maintenance (O&M) costs include the cost of FGO sorbent, lubricants, consumable supplies, water, etc. Fixed O&M costs includes wages and salaries, insurance, etc.

Table 1b
Fuel Cost and Annual Maintenance Schedule of GPPC
Existing and Candidate Units

Fuel Type	Fuel Cost ($/Gcal)	Maintenance (Weeks)
Lignite (West Macedonia)	4.10	6
Lignite (Southern Greece)	5.00	6
Heavy Fuel Oil	8.75	4
Natural Gas	15.00	4
Coal	7.26	6
Uranium	7.00	8

Table 2
Characteristics of the Expansion Candidates and Predicted Peak Load and Demand

Plants by type of fuel	Heat Rate	Capital Cost	Carbon Emission Coefficient	FOR	Non-Fuel O & M Costs		Predicted Peak Load & Demand		
	(kcal/kWh)	($/kW)	(kg/MWh)	(%)	Variable ($/MWh)	Fixed ($/kW/year)	Year	Peak (MW)	Demand (TWh)
Lignite	2600	2000	1320	10	1.4	20.0	1993	5500	32.4
Coal-N*	2350	1450	940	10	2.8	26.4	2000	6365	38.5
Coal-R**	2300	1765	187	10	2.8	26.4	2005	7130	43.1
Natural Gas	1850	850	400	6	1.2	21.6	2010	7950	48.1
Oil	2200	1150	850	8	1.2	24.4	2015	8860	53.6
Nuclear	2550	2900	-	12	1.6	48.0	2020	9790	59.2
Renewables							2025	10700	64.7
Hydro	N/A	Site Specific	-	-	-	7.2	-	-	-
Wind	N/A	1120	-	-	-	7.2	-	-	-

Notes:

* New coal or lignite technology of conventional type.

** Coal gasification technologies. Cost and performance data come from Vejtasa and Shulman (1989); the table reflects only the figures for a 20% CO_2 reduction.

In addition to the existing fuel-types, the study considers: (1) natural gas, nuclear power, traditional coal (Coal-N), new coal or lignite (Coal-R) technologies with CO_2 removal capabilities; (2) the power units which are presently under construction; and (3) units that are presently retired or that will be retired in the course of the study period. The retirement was assumed to occur 45 years after the initial operation of each unit. In addition, a discount rate of 6%, which has been used by PPC until the end of 1993, was applied for all costs (capital and operational expenditures and the cost of unserved energy). The cost of unserved energy selected was 2 US$/kWh.

IV. RESULTS

The objective of the study was to evaluate the impact of different carbon tax policies on the optimum expansion plan in Greece. The analysis of the GPPC interconnected power system was carried out using the WASP-III model for the planning horizon 1995-2025 and under seven alternative scenarios classified into three general categories: (1) business-as-usual scenario; (2) low carbon tax scenarios; (3) high carbon tax scenarios.

Business-as-usual expansion scenario (Scenario I)

Under this scenario, usually called reference or business-as-usual scenario, no tax on CO_2 emissions is imposed. As a result, the optimum (least-cost) plan is obtained by assuming that all potential candidates (Table 2) are equally treated on the basis of only economic and technical considerations. Table 3 presents the optimal production of electricity by fuel type.

Table 3

Production of Electricity by Fuel-Type (in GWh) and Emissions (in kton)
Scenario I (Business-as-usual)

	2000 (GWh) (%)	2005 (GWh) (%)	2010 (GWh) (%)	2015 (GWh) (%)	2020 (GWh) (%)	2025 (GWh) (%)
LIGNITE	27270 70.8	30103 69.8	33389 69.4	37970 70.8	34078 57.6	41115 63.5
NATURAL GAS	2916 7.6	2848 6.6	3110 6.5	2947 5.5	6962 11.8	6335 9.8
OIL	3163 8.2	3065 7.1	2575 5.4	3078 5.7	7419 12.5	6530 10.1
COAL-R	- -	- -	- -	- -	- -	- -
HYDRO-RENEWABLES	5141 13.4	7104 16.5	9006 18.7	9605 17.9	10721 18.1	10720 16.6
TOTAL PRODUCTION	38490 100.0	43120 100.0	48080 100.0	53600 100.0	59180 100.0	64700 100.0
CO_2 Emissions (kton)	39283	46427	51872	59988	64132	69762

The figures in this table display the following results: First, in terms of the optimal expansion production (Table 3), lignite fired plants account for 70.8% of the total generation in 2000 and for 63.5% in 2025, hydropower and other renewable sources account for 13.4% in 2000 and 16.6% in 2025. The low fuel cost of indigenous lignite makes it very attractive for the power sector in Greece; however, lignite fired plants contribute the most to the increase of CO_2 emissions. On the other hand, hydro and renewables, which are carbon free energy sources, are cost-effective options even under the business-as-usual scenario; thus, limiting the increase of CO_2 emissions.

Secondly, the contribution of oil and natural gas fired units is small (15.8% and 19.9% in 2000 and 2025, respectively) but necessary for meeting the demand of electricity. Natural gas will be introduced only in 1996 at the Agios Georgios plant, an oil fired plant that is being converted into a gas fired plant. The utilization of oil fired units has been reduced over the past decades and will continue to diminish until 2015.

However, as lignite reserves deplete, oil technologies seem to compete successfully with traditional coal candidates and are introduced in the last years of the study. Thus, traditional coal technologies are not included in the basic expansion path. Nuclear power is also considered as a cost-effective option for the power sector in Greece. Since both natural gas and oil have a lower CO_2 emission coefficient than lignite, their contribution to the concentration of carbon in the atmosphere is comparatively less.

In general, the business-as-usual expansion path (Scenario I) for the study period (1995-2025) is characterized by:

(1) A predominance of lignite fired units for the production of electricity; and

(2) A significant increase of CO_2 emissions from 39,283 KT in 2000 to almost 70,000 kton in 2025. Reaching the 1990 level would require to cut by 49% the CO_2 emissions of 2025.

Low carbon tax scenarios

The impact of a carbon tax will depend, among other things, on the level of the tax, the available technologies, and their associated cost for producing electricity as well on the energy resource endowments of the country. On the assumption that all potential candidates (Table 2) are considered, we examine first the impact of three low carbon tax rates:

- a tax of 5 US$ per ton of carbon (scenario II),
- a tax of 25 US$ per ton of carbon (scenario III) and
- a tax of 50 US$ per ton of carbon (scenario IV).

Table 4 shows the least cost expansion plans under these three low tax scenarios.

The comparison of these results with those obtained under Scenario I shows that conventional lignite production decreases under the three low tax scenarios but this reduction becomes significant only after the year 2015. Specifically, the production of electricity by lignite fired plants accounts for ca. 70% of the total production in 2000 and diminishes to 52.6% under Scenario II, 43.1% under scenario III, and 36.8% under scenario IV in 2025. Lignite fired plants contribute the more to the growth of CO_2 emissions and are therefore affected even by the lowest carbon tax rate. In 2025, lignite production under Scenario II is 17.2% lower than its business as usual level.

The operation of oil fired units which are the second major contributor to CO_2 emissions in the Greek power system is also reduced under the low tax scenarios. By the year 2025, oil will account for ca. 3% of the total production under all three scenarios.

Table 4
Production of Electricity by Fuel Type and Emissions under the Low-tax Scenarios

	Scenarios	2000 (GWh) (%)	2005 (GWh) (%)	2010 (GWh) (%)	2015 (GWh) (%)	2020 (GWh) (%)	2025 (GWh) (%)
LIGNITE	II	27270 70,88	961 67,1	31687 65,9	34387 64,2	33268 56,2	34055 52,6
	III	27270 70,8	27642 64,1	27780 57,8	28317 52,8	28035 47,4	27888 43,1
	IV	26830	26742	25940	25137	24710	23845
NATURAL	II	3771 9,8	4643 10,8	4263 8,9	6509 12,1	12635 21,4	17335 26,8
	III	3771 9,8	5937 13,8	5745 11,9	11888 22,2	13287 22,5	15334 23,7
	IV	4142	5288	8225	14068	16495	18188
OIL	II	2313 6,0	2390 5,5	2544 5,3	1417 2,6	2010 ,4	2023 3,1
	III	2313 6,0	2415 5,6	3155 6,6	1815 3,4	1920 3,2	1840 2,8
	IV	2382	2420	2515	2105	1880	2115
COAL - R	II	-	-	-	-	-	-
	III	-	-	-	-	3672 6,2	7352 11,4
	IV	-	-	-	-	3745	7432
HYDRO-RENEWABLES	II	5136 13,3	7160 16,6	9586 19,9	11287 21,1	11267 19,0	11287 17,4
	III	5136 13,3	7126 16,5	11400 23,7	11580 21,6	12266 20,7	12286 19,0
	IV	5136	8670	11400	12290	12350	13120
TOTAL PRODUCTION		38490 100	43154 100	48080 100	53600 100	59180 100	6470 100
CO_2 Emissions		kton (*)	kton (*)	kton (*)	kton (*)	kton (*)	kton (*)
	II	39529 11,5	42177 18,9	45758 29,0	49234 38,8	50727 43,1	53657 51,3
	III	39529 11,5	40975 15,6	41728 17,6	43722 23,3	44688 26,0	45931 29,5
	IV	39157 10,4	39532 11,5	39731 12,0	40650 14,6	41561 17,2	41991 18,4

Note (*): Percent changes as compared to the 1990 level (35460 ktons)

The expected reduction of the use of lignite and oil is mostly counterbalanced by an increasing penetration of natural gas technologies but also by hydropower and other renewables which contribute to 17.5% of the total production in 2025 under scenario II, 19% under scenario III, and 20.3% under scenario IV. A minor but increasing penetration of coal or lignite technologies with CO_2 removal capabilities (Coal-R) is also observed as of 2020 under scenarios II and III. It should be noted that nuclear power is not a least cost option under the three low tax scenarios.

As expected (see Table 4), CO_2 emissions are reduced under the three low tax scenarios compared to the business as usual scenario. In 2025, the reductions amount to 23.1% under scenario II, 34.2% under scenario III and 39.8% under scenario IV compared to scenario I. However, CO_2 emissions keep growing compared to the 1990 level which is the level targeted for stabilizing CO_2 emissions.

<u>High carbon tax scenarios:</u>

As part of the study, it was also investigated the impact of three high carbon tax rates:

-a tax of 100 US$ per ton of carbon (scenario V),
-a tax of 150 US$ per ton of carbon (scenario VI), and
-a tax of 200 US$ per ton of carbon (scenario VII).

Table 5 shows the least expansion paths under these three scenarios.

A detailed inspection of the figures in this table shows a drastic reduction in conventional lignite generation. In 2025, lignite generation accounts for only 24.9%, 8.1% and 4.4% of the total production under scenarios V, VI, and VII respectively. In addition, oil generation under scenarios VI and VII disappears from the mix of generating technologies after 2020.

These drastic reductions in conventional and oil generation are mainly counterbalanced by an increasing penetration of lignite or coal technologies with CO_2 removal capabilities, and not by natural gas as it was the case under the low tax scenarios. The use of natural gas which is a low but not carbon free option, has been highly restricted by the year 2025 under the high tax scenarios as compared to the low tax scenarios. Moreover, the results show an increased penetration of hydropower and renewables to counterbalance the reduction of conventional lignite and oil generation; actually, all hydro and renewable sources available for electricity generation are included in the optimal plans by the year 2025. On the other hand, nuclear power is not included in the optimal plans even under the highest tax rate.

Table 5 indicates that high carbon taxes are quite effective in reducing CO_2 emissions at their 1990 level during the period 2000-2005 and even in reducing them by additional 10-12% afterwards. The high taxes produce considerable reductions of CO_2 emissions compared to the 1990 level: 51.5% and 57.9% under scenarios VI and VII, respectively, in 2020.

Table 5
Production of Electricity by Fuel-Type
and Emissions under the High-tax Scenarios

	Scenarios	2000	2005	2010	2015	2020	2025
		GWh %	GWh %	GWh %	GWh %	GWh %	GWh %
LIGNITE	V	23070 59,9	21849 50,7	18701 45,1	18740 45,4	17563 42,8	14072 36,5
	VI	21581 56,1	19850 46,0	15925 38,4	13905 33,7	5680 13,9	5250 13,6
	VII	20819	17710	12559	8758	4480	2850
NATURAL GAS	V	5170 13,4	6480 15,0	6655 16,0	6540 15,8	7155 17,5	7068 18,3
	VI	6525 17,0	6310 14,6	6910 16,7	6040 14,6	10850 26,5	9495 24,6
	VII	7135	7071	7108	6845	6917	7212
OIL	V	2954 7,7	4247 9,8	3018 7,3	2785 6,7	2849 -7,0	3410 8,8
	VI	2818 7,3	2908 6,7	3787 9,1	2835 6,9	- -	- -
	VII	3240	3885	3745	3410	-	-
COAL - R	V	- -	- -	6580 15.6	12315 29.8	18190 44,4	24150
	VI	- -	3507 8.1	8332 20.1	15372 37.2	28470 48,1	35275 54,5
	VII	-	3507	11240	20387	33353	39528
HYDRO RENEWABLES	V	7294 19,0	10544 24,5	13126 31,6	13220 32,0	13423 32,7	14000 36,3
	VI	7566 19,7	10545 24,5	13126 31,6	15448 37,4	13980 34,1	14480 37,6
	VII	7296	10947	13428	14000	14430	15110
TOTAL PRODUCTION	All	38488 100	43120 100	41500 100	41285 100	40990 100	38550 100
CO_2 Emissions		kton (*)	kton (*)	kton (*)	kton (*)	kton (*)	kton (*)
	V	37310 5,2	35149 -0,9	31219 -12,0	32093 -9,0	31940 -9,9	31542 -11,1
	VI	33563 -5,3	31924 -10,0	28657 -19,2	26126 -24,3	17199 -51,5	17404 -50,9
	VII	33170 -6,5	30260 -14,7	24800 -30,0	21270 -40,0	14917 -57,9	14039 -60,4

Notes (*): Percent changes as compared to the 1990 level (35460 ktons)

Figure 1 presents the time paths of CO_2 emissions under scenario V in comparison with scenario I and the 1990 emission level.

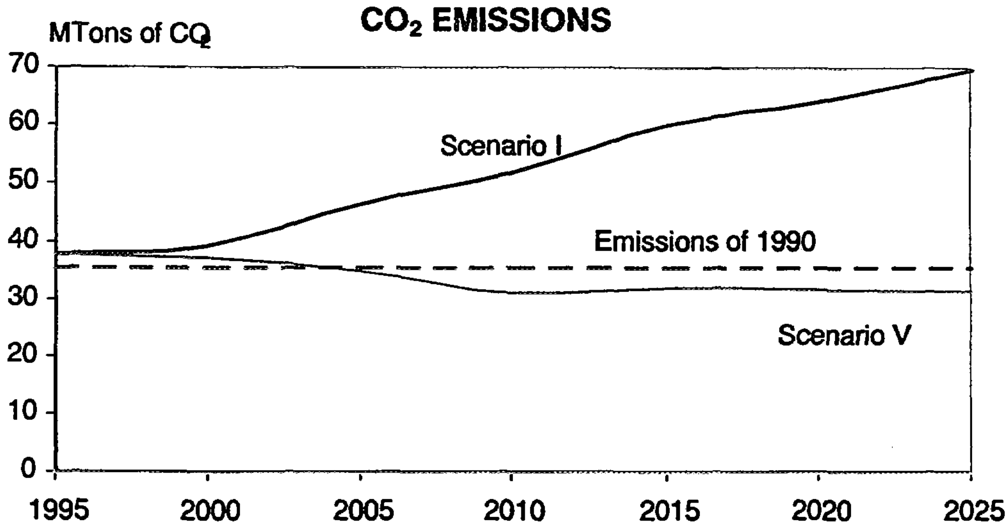

Figure 1. CO_2 under different Scenarios.

The impact of carbon taxes on other externalities

A secondary effect of imposing carbon taxes is the reduction of other types of emissions such as nitrogen oxides (NO_x), sulphur dioxide (SO_2) and dust. The level of NO_x , SO_2 and dust under the reference case, the low and the high tax scenarios are presented in table 6. The figures in the table indicate that the reduction of NO_x, SO_2 and dust compared to the level of the business-as-usual scenario is significant in the last years of the study. In addition, it should be noted that since lignite, oil and natural gas generation are substituted by lignite or coal-R generation and by hydro and renewables generation under the high tax scenarios, NO_x and SO_2 emissions are reduced drastically.

The impact on the cost of producing electricity

Carbon taxes increase fuel costs and the total cost of producing electricity. By increasing fuel costs, carbon taxes induce the adoption of low or carbon-free generating technologies which are however, characterized by higher costs, as Table 2 indicates.

Consequently, the present value of the total costs of the optimum expansion path under the alternative tax scenarios is expected to increase due to the higher cost of the new mix of generating technologies induced by the carbon taxes. It will also increase because of the taxes paid on uncontrolled emissions.

Table 7 presents the increase of the fuel cost of one kWh and in the present value of total costs which reflects both the emission control cost and the taxes paid on uncontrolled emissions. The figures in the table indicate significant increases in the total costs of 17% to 259% under a 5 US$ and a 200 US$ tax per ton of carbon. Apparently, carbon taxes lead to a heavy burden on the Greek electricity industry and its final consumers with further adverse economic effects on the competitive position of Greece's industries and on the Greek economy in general. Carbon taxes need thus to be designed with great care in order to be environmentally efficient and at the same time to limit their adverse economic effects. It is important in this sense, as also indicated by the Commission of the EC (1991-8), that "the particular situation of each Member state would need to be taken into account in the final choice of solution. In introducing such a tax it will be necessary to provide for its temporary suspension and for modification of the rate in the light of economic developments and progress towards the stabilization objective". For Greece who has serious economic problems, these considerations become very essential.

The results of this study were based on several assumptions about technical and economic parameters drawn from highly reliable information provided by international sources and studies, and from accumulated experience of the Greek electric power industry. However, the sensitivity of the results to some central parametric assumptions have been investigated.

Data Sensitivity

In the basic analysis presented before, it was assumed that the relative fuel prices remain constant over the study horizon. However, if the demand for natural gas increases at the international level, its price will rise. The results of the sensitivity analyses show that an annual increase of up to 2% in the (real) price of natural gas would make this alterative less attractive than lignite or coal-R technologies and would lead to a greater penetration of hydropower and renewables. Increases in the price of natural gas under the high tax scenarios would reinforce the results described above. The investigation of similar increases in the price of oil indicates a similar pattern of changes.

It was also investigated whether nuclear power - a carbon free technology - might be considered as the least cost option under the highest tax scenario (Scenario VII) if its capital cost is reduced. The results show that when the cost of capital is reduced to 2500 US$/kW, nuclear power becomes more attractive for system expansion than lignite or coal-R technologies and thus becomes part of the optimal solution after 2005. The result is an additional reduction of CO_2 emissions and a small reduction of total costs. However, we still believe that a cost of capital of the level of 2900 $/kW is a more appropriate assumption for the Greek electric power system.

On the demand side, two major issues would need to be discussed: improvements of the efficiency of electricity generation plants and price-induced conservation caused by the carbon taxes.

Following the oil crisis of 1973, there have been increases in the price of electricity, resulting in significant improvements in the efficiency of electric power stations. If this tendency continues in the future, it might result in a lower growth rate of electricity demand.

On the other hand, as demonstrated by the present study, carbon taxes increase the cost of electricity. The higher the carbon tax is, the greater the increases in the price of electricity are. Such increases will reduce electricity demand and make carbon taxes more effective. Our previous analysis provides the upper limit on CO_2 emissions and total costs of producing electricity under different carbon tax rates. Should the growth of electricity demand be lower, due to efficiency improvements, price (tax) and induced conservation, CO_2 emissions and total cost would be lower, too. A sensitivity analysis on the growth rate of electricity demand confirms this expected finding.

Table 6
NOx, CO_2 and Dust Emissions under alternative Scenarios

kton

Scenarios	2000			2010			2020		
	NOx	SO_2	Dust	NOx	SO_2	Dust	NOx	SO_2	Dust
II	53,0	198,5	251,1	57,5	212,2	276,6	62,7	222,0	305,6
III	53,0	198,5	251,1	57,3	212,7	273,5	56,8	204,6	261,7
IV	52,0	196,9	250,9	53,7	198,7	253,9	48,7	177,8	225,3
V	49,6	186,0	235,5	50,1	198,1	222,5	44,6	168,6	209,8
VI	47,9	167,3	220,7	44,5	156,6	203,1	43,4	153,2	197,1
VII	47,8	171,8	217,4	43,8	154,0	198,5	35,3	126,1	154,8

Table 7
Impact of Carbon Taxes on the Fuel and Total Cost of Electricity (kWh)

Scenarios	Tax Rates ($/ton of Carbon)	Percentage Increase in the Fuel Cost of 1 kWh (1993=100)[1]				Total Cost Increase [2]	
		Lignite	Nat. Gas	Oil	Coal-R	US$ million	%
II	5	27	8	11	18	2013	16.5
III	25	86	16	34	26	5169	42.4
IV	50	163	26	63	35	8367	68.6
V	100	310	46	110	53	15963	130.4
VI	150	460	65	178	72	25516	209.2
VII	200	610	85	230	90	31539	258.6

Notes:

1. Calculations were done assuming an exchange rate of 250 drachmas per US$ in 1993. They also take into account the specific consumption of each type of fuel per kWh.

2. Total cost increases are expressed in Present Value Terms.

V. CONCLUSIONS

This paper has attempted to evaluate the impact of carbon taxes on (i) the technological structure of the electric power industry; (ii) the level of CO_2 and other types of externalities, and (iii) the total cost of generating electricity. The evidence provided by the study indicates that carbon taxes induce a technical restructuration of the industry towards less polluting technologies but at significant cost increases. Specifically, the findings have shown that:

- The imposition of low carbon taxes (5-50 US$ per ton of carbon) results in a considerable reduction in the use of conventional lignite fired plants which is counterbalanced mainly by natural gas fired plants, followed by hydropower and renewables. The growth of CO_2 emissions is slowing down but their level is well above the 1990 level. NO_x, SO_2 and dust emissions are also reduced, especially after 2015.

- Imposing high carbon taxes (100-200 US$ per ton of carbon) results in drastic reduction in the use of conventional lignite and oil generation counterbalanced predominantly by lignite or coal technologies with CO_2 removal capabilities, followed by all available hydropower and renewable sources. Under the high taxes, natural gas is loosing its benefit over lignite or coal-R technologies. CO_2 emissions and other emissions are also reduced drastically. Significantly, a tax of 100 US$ per ton of carbon would stabilize CO_2 emissions at their 1990 level during the period 2000-2005 and would even reduce them from this level thereafter. Higher taxes would result in a more significant reduction of CO_2 emissions.

- Carbon taxes increase the cost of producing electricity significantly. Low taxes result in cost raises ranging from 17% to 69%, while higher taxes lead to cost increases up to 259%. This growth of the cost implies that further adverse economic effects might affect the competitiveness of the Greek industries, especially the electricity-intensive ones, and of the Greek economy in general.

- Improvements of energy efficiencies and conservation techniques can increase the effectiveness of carbon taxes in reducing CO_2 emissions and reducing electricity production costs.

- In general the results provided by the present analysis indicate that the level of a carbon tax should be designed with great care so that it is efficient in reducing CO_2 emissions. At the same time, it should not create any significant adverse effects on the electric power industry and the economy. The findings of the study also suggest more research and development in the field of lignite or coal-R technologies, hydropower, renewable sources, energy efficiency and conservation techniques.

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