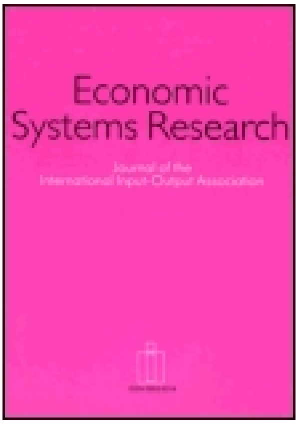

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OPTIMIZING PRODUCTION IN THE GREEK ECONOMY: EXPLORING THE INTERACTION BETWEEN GREENHOUSE GAS EMISSIONS AND SOLID WASTE VIA INPUT-OUTPUT ANALYSIS

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OPTIMIZING PRODUCTION IN THE GREEK ECONOMY: EXPLORING THE INTERACTION BETWEEN GREENHOUSE GAS EMISSIONS AND SOLID WASTE VIA INPUT–OUTPUT ANALYSIS

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We explore an input–output based framework for optimizing production in the Greek economy, under constraints relating to energy use, final demand, greenhouse gas emissions and solid waste. Using empirical data, we consider the effects on the maximum attainable gross value of production when imposing various pollution abatement targets. Our results quantify those effects as well as the magnitude of economic sacrifices required to achieve environmental goals, in a series of policy scenarios of practical importance. Because air pollution and solid waste are not produced independently of one another, we identify the settings in which it is meaningful to institute a separate policy for mitigating each pollutant, versus those in which only one pollutant needs to be actively addressed. The scenarios considered here represent a range of options that could be available to policy makers, depending on the country's international commitments and the effects on economic and environmental variables.

Keywords: GHG emissions; Solid waste; Input–output analysis; Greek economy

1. INTRODUCTION

In the last decade, the environment has become an increasingly prominent global issue whose significance is perhaps trumped only by its complexity. The struggle by scientists and policy makers to better understand the interdependence between the environment and economic activity has led to the development of the System of Integrated Environmental and Economic Accounting (SEEA), an accounting approach linking environmental and economic data sets in a consistent manner, and in a format that is compatible with the System of National Accounts (SNA).[1] The SEEA provides a common framework for maintaining and jointly analysing economic and environmental data, and has gradually developed into a key decision-making tool. By tying information about the physical pressures exerted on the environment to the associated economic activities, the SEEA enables policy-makers to assess measures aimed at reducing these

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[1] See http://unstats.un.org/unsd/envaccounting/seea.asp

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pressures and at meeting environmental objectives in an economically 'optimal' way (Schenau and ten Ham, 2005).

This work draws on a particular SEEA (named the 'National Accounting Matrix with Environmental Accounts' – NAMEA), in order to examine the problem of optimizing sectoral production in Greece, with an eye towards promoting the rational utilization of energy and reducing environmental pressures. This is especially important in the current setting, where Greece is undergoing perhaps its most serious economic crisis in decades. The fact that the country will, in all likelihood, have to undergo a significant transformation in order to prosper, gives rise to opportunities for policy-making that will drive new growth while also living up to existing environmental commitments. We are interested in determining which sectors policy should focus on for maximum effectiveness, and how fluctuations in those strategic sectors are likely to affect the others.

The environmental pressure variables on which this paper focuses are greenhouse gas (GHG) emissions, and solid waste. For GHGs, a major component of global warming, Greece has a target of no more than a 25% increase above 1990 levels. This target, established under the Kyoto protocol, concerns the period 2008–2012, but was already surpassed in 2005. At the same time, the minimization of solid waste generation has been a major priority spelled out in the EU Sustainable Development Strategy, the sixth Environment Action Programme, and various directives (e.g. IPPC Directive 2008/1/EC and Council Directive 99/31/EC). The main objectives specified in the EC Waste Directive are to prevent or reduce as far as possible the negative effects of landfilling of solid waste on the environment and human health. In recent years, municipal waste management in Greece has been undergoing drastic changes with respect to policy and legislation. Thus far, however, there has not been a national strategy to reduce the landfilling of commercial and industrial waste.

This paper's contribution is twofold. First, we employ input–output analysis to quantify the macroeconomic and sectoral effects that arise by optimizing production while attempting to satisfy both GHG and solid waste reduction targets simultaneously. Our model, calibrated with empirical data for Greece, 'translates' pollution targets to sectoral production targets, which are optimal in the sense that they meet environmental goals with the smallest possible adverse economic effect. Second, our analysis allows us to determine whether policy decisions must explicitly account for both pollutants, or whether reductions in one pollutant come 'automatically' by regulating the other, in which case there could be cost and bureaucracy savings without loss of effectiveness.

To proceed with these goals, we pose an optimization problem where we seek to maximize the economy's Gross Value of Production (GVP) subject to constraints on energy use, final demand, GHG emissions and solid waste generation. The underlying model is based on Leontief's Input–Output analysis (Leontief and Ford, 1972). Input–output analysis is used here to allocate production of harmful materials (in our case, air pollutants and waste) to the various sectors of the economy, to account for the interdependence of sectors with respect to changes in final demand, and to link pollution and energy usage to economic production on a sectoral basis. Although linear by construction, this approach was chosen mainly because it is tractable, and allows us to (i) account for intersectoral coupling, and (ii) demonstrate the kinds of optimal production/pollution levels that are feasible, without changing the basic production characteristics (required inputs, technology coefficients and refuse products). The proposed methodology is flexible and could serve as a useful tool for decision makers, as they attempt to promote economic growth while taking into account environmental and sustainability issues simultaneously.

Recent works on the problem of jointly optimizing production with GHG and solid waste objectives include (Oliveira and Antunes, 2009a, 2009b). In addition, there are several recent papers that address CO_2 or GHG emissions alone, and which are relevant to our approach. These include San Cristóbal (2010), Alcantara and Padilla (2009), Lixon et al. (2008), Turner et al. (2007), Wiedmann et al. (2007), and Wiedmann (2009). Furthermore, several authors have used input–output models to link an entity's (e.g. a country or region) macroeconomic variables with its environmental impact. Hristu-Varsakelis et al. (2010) employs input–output analysis to study the problem of attaining various GHG targets by reallocating production. A series of models has focused on the impact of water pollution, e.g. Cho (1999) and Spörri et al. (2007). Kondo and Nakamura (2005) proposed a waste input–output model used to select optimal waste management and recycling strategies, whereas Ni et al. (2001) considered the problem of water pollution and waste load allocation in different economic sectors for Shenzhen (China), using a two-objective model. Other models linking the economy (from a sectoral viewpoint) and the environment, with emphasis on sustainable energy usage, continuous growth, social welfare and reduced environmental degradation, include those proposed by Kravtsov and Pashkevich (2004), Oliveira and Antunes (2002, 2004), Hsu and Chou (2000), and Dong (2008).

The remainder of this paper is structured as follows. Section 2 discusses the empirical data used with our model; those data are taken from the Greek NAMEA, which includes air pollution and waste statistics for each sector of the economy. The main optimization problems, including the input–output model, objective function and constraints used, are detailed in Section 3. Section 4 discusses the optimal solution under a series of possible reduction targets for GHG emissions and solid waste.

2. DATA AND METHODOLOGY

This section discusses the empirical data that will be used to calibrate our model. They consist of: (i) economic data, including the Greek input–output matrix, which will allow us to calculate the effect of a change in production in any one sector on the remaining ones, as we seek to maximize the economy's GVP; and also data on (ii) energy consumption by sector; (iii) air pollution; and (iv) solid waste generated per sector. We briefly discuss each set of data.

The input–output table for the Greek economy was obtained from the study by Skountzos and Stromplos (2007); it is based on data from the National Statistical Service of Greece (NSSG). The table includes data for 26 sectors, which are listed in Table A1 in the Appendix, along with their codes as per the Classification of Economic Activities in the European Community (NACE). Sector 26 (recreational, cultural and sporting acti vities, activities of households, extra-territorial organizations) was excluded from the analysis that follows because the economic activities contained therein are outside the scope of this study.

Energy consumption data were obtained from the Eurostat and PRODCOMS databases, the Greek Ministry of Development, and the United Nations Production Statistics website.[2] The data were assigned to the various sectors using factors (production and activity data) derived from those databases. The per-sector energy usage is given in Table A2 in the Appendix. For a fuller discussion of energy consumption in the Greek economy and its relationship to economic growth and pollution see, for example, Hondroyiannis et al. (2002) and Diakoulaki et al. (2006).

Data on air pollution and solid waste were taken from the Greek NAMEA for the year 2005 (Economidis et. al., 2008). The NAMEA is structured in a composite matrix format that combines supply-use tables and sectoral accounts into a comprehensive accounting framework (de Haan and Kee, 2004). The economic accounts in the NAM-part of the NAMEA contain the complete set of accounts in the System of National Accounts (SNA). The environmental accounts in the NAMEA are denominated in physical units and focus on the consistent presentation of material inputs (natural resources and energy), and residual outputs of the national economy, which in our work are GHG emissions and solid waste. The NAMEA allows us to calculate variations that would result in emissions or solid waste as a result of changes in: (i) the economic structure; (ii) the production volume; (iii) the efficiency of the 'ecosystems' of producers and consumers and (iv) energy supply (Mylonas et al., 2000).

We quantified the impact of the environmental stressors on the economy production levels as in Economidis et al. (2008). Briefly, in a setting where k pollutants are considered (in our case $k = 2$), we assumed a linear relationship between pollution and production levels, and defined a vector of coefficients, $\mathbf{a_k}$, whose jth entry, a_{kj}, is defined as the quantity of pollutant k emitted by the jth sector, q_{kj}, divided by gross output, x_j, for that sector:

$$a_{kj} = q_{kj}/x_j \tag{1}$$

The air emissions data used in this study were reported by the Greek Ministry of Environment and Public Works in fulfilment of the country's UNFCCC (United Nations Framework Convention on Climate Change) obligations.[3] For additional discussion on that data, including how they were processed and allocated to NACE activities, see Economidis et al. (2008). We note that the European Environment Agency (Moll et al., 2006) mentions three main environmental pressure variables, namely Greenhouse Gases (GHG), pollutants contributing to acidification (ACID), and Tropospheric Ozone Forming Potential (TOFP). Nevertheless, previous analysis (Hristu-Varsakelis et al., 2010) has shown that the impact of the last two variables was at least an order of magnitude smaller than that of GHG. For this reason, we only consider GHG when referring to air pollution in this work. The GHG emissions for each sector are listed in Table A2 in the Appendix, where GHG amounts are calculated as a weighted average of the major pollutants contributing to the Global Warming Potential, estimated in CO_2 equivalents: GHG= $CO_2 + 310 * N_2O + 21 * CH_4$, with each pollutant measured in kTons.

The solid waste data used here consist of figures for the total waste produced per sector, including both hazardous and non-hazardous products. According to the National Statistical Service of Greece (NSSG, 2006), the amount of waste produced annually in Greece as

2 http://epp.eurostat.ec.europa.eu/portal/page/portal/prodcom/introduction; http://www.cres.gr/kape/pdf/datainfo/2005_gr.pdf; http://unstats.un.org/unsd/industry/

3 Data obtained online at http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/2761.php and http://www.ceip.at/emission-data-webdab/emissions-as-reported-by-parties

a result of economic activity, reaches nearly 40 million tonnes. That figure is dominated by non-hazardous waste, including minerals (70%), household waste (16%), paper, metal, wood, textiles, plastic (5.9%), residues from animals (3.6%), chemicals, (2%), and others (2%). The remainder (approximately 0.88%) is classified as hazardous waste, composed mostly (0.81%) of chemical waste. We note that the amount of solid waste is modified somewhat, via recycling. We have chosen to use solid waste as one of our main indicators because, at this time, there are no official data on the percentage of waste being recycled. However, recycling is included in the analysis as a distinct economic activity (sector 14 – Table A1).

The majority of existing solid waste data (from sectors 1–17 and households – see Table A1) were already in a NACE classification format, as part of the Waste Generation and Treatment data published by the National Statistical Service of Greece (NSSG, 2006). For the remaining sectors (numbers 18–25), waste data were only available in aggregated form and were apportioned using ancillary data, including fuel consumption, number of employees and number of enterprises in each sector. The resulting solid waste generated per sector is listed in Table A2 in the Appendix, along with tax and VAT revenue data. We note that, because we are interested in the interaction between solid waste and GHG, our analysis includes the effects of GHG emissions resulting from solid waste disposal (sectors 14 and 22 of the Greek NAMEA).

3. MODEL AND MAIN OPTIMIZATION PROBLEM

We proceed to formulate an optimization problem where we seek to maximize production on a sectoral basis, subject to energy and pollution constraints. The model described next is a version of that used in Hristu-Varsakelis et al. (2010), augmented to include constraints on solid waste generation. For an economy of n sectors, the standard linear input–output model (Leontief, 1966) is given by:

$$\mathbf{X} = \mathbf{Xu} + \mathbf{y} - \mathbf{m} \tag{2}$$

where $\mathbf{x} \in \mathbb{R}^n_*$ stands for the gross value of production vector, $\mathbf{X}$ is the $n \times n$ intermediate input–output matrix, $\mathbf{u}$ = 1,. . .,1' with prime denoting transpose, $\mathbf{y}$ is the final demand, and $\mathbf{m}$ are imports. Technical coefficients are calculated as the ratio of each element of the intermediate input–output matrix to the total output of the corresponding activity branch:

$$A_{ij} = X_{ij}/x_j, \quad i, j = 1, \ldots, n \tag{3}$$

whereA_{ij} and X_{ij} are the (i,j)th elements of $\mathbf{A}$ and $\mathbf{X}$, respectively.

By observing that $\mathbf{X} = \mathbf{A} \cdot \mathrm{diag}(\mathbf{x})$ and $\mathbf{Xu} = \mathbf{Ax}$, the basic input–output model can be rewritten as:

$$\mathbf{x} = \mathbf{Ax} + \mathbf{y} - \mathbf{m} \Rightarrow (\mathbf{I} - \mathbf{A})\mathbf{x} = \mathbf{y} - \mathbf{m} \tag{4}$$

By summing the total intermediate inputs at basic prices $\mathbf{X}'\mathbf{u}$, tax revenues $\mathbf{t}$, subsidies $\mathbf{s}$, VAT revenues $\mathbf{v}$, and the gross value added (GVA), $\mathbf{g}$, for each sector, we obtain the sectoral gross value of production (the summation of the first four variables provides the value of total inputs in market prices):

$$\mathbf{x} = \mathbf{X}'\mathbf{u} + \mathbf{t} + \mathbf{s} + \mathbf{v} + \mathbf{g} = \mathbf{x_T} + \mathbf{g} \tag{5}$$

The GVA, **g**, is obtained indirectly by subtracting the value of total inputs in market prices from the gross value of production:

$$\mathrm{g} = \mathbf{x} - \mathbf{x_T} \tag{6}$$

3.1. Assumptions and Parameter Selection

In our analysis, subsidies are assumed to be exogenously determined and remain constant, while **t** and **v** are calculated as ratios of total intermediate inputs in basic prices, as indicated below:

$$\mathbf{t} = \mathrm{diag}(\mathbf{a_T})\mathbf{X}'\mathbf{u} = \mathrm{diag}(\mathbf{a_T})\mathrm{diag}(\mathrm{x})\mathbf{A}'\mathbf{u} \tag{7}$$

$$\mathbf{v} = \mathrm{diag}(\mathbf{a_v})\mathbf{X}'\mathbf{u} = \mathrm{diag}(\mathbf{a_v})\mathrm{diag}(\mathbf{x})\mathbf{A}'\mathbf{u} \tag{8}$$

The vectors $\mathbf{a_T}$ and $\mathbf{a_V}$ contain the (constant) technical coefficients between tax and VAT revenues and total intermediate inputs in basic prices, respectively. GHG emissions, **p**, and waste generation, **w**, are also assumed to be directly proportional to the total output of the corresponding branch:

$$\mathbf{p} = \mathrm{diag}(\mathbf{a_P})\mathbf{x} \tag{9}$$

$$\mathbf{w} = \mathrm{diag}(\mathbf{a_W})\mathbf{x} \tag{10}$$

where $\mathbf{a_P}$ and $\mathbf{a_w}$ are vectors containing air-pollution and waste generation coefficients, respectively. In the present setting, both vectors are taken to be constant, capturing the constant technical relationship that we have assumed between pollution variables and total output. We also assume a linear relation between each sector's energy consumption, **c**, and the gross value of production,

$$\mathbf{c} = \mathrm{diag}(\mathbf{a_e})\mathbf{x} \tag{11}$$

where $\mathbf{a_e}$ is a vector of energy coefficients. Finally, total GHG emissions, total waste pollution and total energy consumption are summed over all sectors, $i = 1, \ldots, 25$:

$$\sum_i p_i = \mathbf{u}'\,\mathrm{diag}(\mathbf{a_p})\mathbf{x} = \mathbf{a_p}'\mathbf{x} \tag{12}$$

$$\sum_i w_i = \mathbf{u}'\mathrm{diag}(\mathbf{a_w})\mathbf{x} = \mathbf{a_w}'\mathbf{x} \tag{13}$$

$$\sum_i c_i = \mathbf{u}'\,\mathrm{diag}(\mathbf{a_e})\mathbf{x} = \mathbf{a_e}'\mathbf{x} \tag{14}$$

The matrix of technical coefficients, **A**, was computed from the 2005 Greek NAMEA (Economidis et al., 2008). From the standard input–output table, extended to include both GHG emissions and solid, hazardous and non-hazardous waste, we calculated the coefficients $\mathbf{a_e}$, $\mathbf{a_W}$, $\mathbf{a_P}$, $\mathbf{a_V}$, and $\mathbf{a_T}$. The coefficients for energy consumption, $\mathbf{a_e}$, GHG emissions, $\mathbf{a_P}$, and solid waste generation, $\mathbf{a_W}$, were obtained by dividing the total quantity used or produced by each sector (listed in Table A2 in the Appendix) by that sector's production. The VAT ($\mathbf{a_V}$) and tax ($\mathbf{a_T}$) coefficients were calculated as the ratio of each sector's revenues to that sector's total intermediate inputs in basic prices.

3.2. Optimization Problem

Based on the above discussion, the problem we are concerned with is the maximization of the total GVP, subject to bounded fluctuations in sectoral production, while meeting final demand and pollution (GHG emissions and waste) targets. In our notation, we can formulate the following linear programming problem (Koopmans, 1951; Dorfman et al., 1958):

$$\max_{\mathbf{x}} \mathbf{u}'\mathbf{x} \tag{15}$$

subject to the constraints

- $\sum_i c_i = \mathbf{a}'_{\mathbf{e}}\mathbf{x} \leq l_u$, where l_u is a (scalar) upper limit on energy used. This will ensure that we only consider production vectors that do not exceed some energy usage threshold (e.g. 2005 levels).
- $\sum_i p_i = \mathbf{a}'_{\mathbf{P}}\mathbf{x} \leq l_P$, where l_P is an upper limit on GHG emissions. We will consider solutions in which l_P is set to approximately 0–9% lower than its 2005 level.
- $\sum_i w_i = \mathbf{a}'_{\mathbf{W}}\mathbf{x} \leq l_W$, where l_W is a scalar upper limit on solid waste produced. As with GHG, we will explore a range of l_W approximately 0–9% lower than its 2005 level.
- $\mathbf{u}'(\mathbf{I} - \mathbf{A})\mathbf{x} \geq \mathbf{u}'(\mathbf{y}_1 - \mathbf{m})$. By comparing with Equation (4), we observe that this constraint forces solutions that will meet a total demand of at least $\mathbf{u}'\mathbf{y}_1$ in value.
- $0 \leq \mathbf{x}_1 \leq \mathbf{x} \leq \mathbf{x}_\mathrm{u}$, where $\mathbf{x_1}$, $\mathbf{x_u} \in R^n$ are lower and upper bounds on production. The specific choices of upper and lower bounds will be addressed in the next section.

In the next section, we discuss the solutions of the optimization problem posed above, for a range of GHG and solid waste reduction targets deemed to be of practical significance. We chose GVP as our objective (instead of, say, GDP or national income) because it is considered to be a more ample indicator/measure of the value of a country's production output, and to describe more fully the state of the economy.[4] In addition, in a comparison with three other objectives, including GDP, GVP has been found to be somewhat superior in terms of economic performance (Hristu-Varsakelis et al., 2009). Apart from the maximization of total production, we are also interested in determining the corresponding levels of other economic and environmental variables, such as GVA, tax and VAT revenues, and energy use. Regarding, the constraint on final demand, $\mathbf{u}'(\mathbf{I} - \mathbf{A})\mathbf{x} \geq \mathbf{u}'(\mathbf{y}_1 - \mathbf{m})$, we note that it is equivalent to imposing a lower bound on the total value of final demand

[4] GVP includes both the value of the intermediate goods and services that have been used in the production process, and the payments that have been defrayed to the primary factors of production. By comparison, GDP is a more restrictive indicator since it does not include the value of the intermediate goods and services.

across all sectors, as opposed to constraining the demand for each sector separately. This was done in order to avoid restricting the problem too severely, thus allowing more room for meaningful solutions with respect to GHG and solid waste reductions. We also note that, because our analysis is based on monetary input–output tables, it is not possible to specify whether fluctuations in the value of final demand are to come about via fluctuations in physical units produced versus price changes.

4. PARAMETER SELECTION AND EMPIRICAL RESULTS

With respect to the constraints posed in Section 3.3, data from the European Environmental Agency, indicate that Greece's GHG production for the year 2005 had reached 139.2 Mt, an increase of 25.4% over 1990 levels.[5] The target set under the Kyoto protocol (2008–2012) was a cumulative increase of no more than 25% in GHG. In light of this, we focused our attention on a 0–9% range for both GHG and solid waste reductions relative to 2005, keeping in mind that any solutions to the optimization problem of Section 3 are to be viewed as 'targets', and that the time horizon within which they are to be implemented would be up to policy makers. We also assumed a maximum production fluctuation of 10% in each sector, a total production that can satisfy at least 97% of the total 2005 final demand (i.e. $\mathbf{y}_1 = 0.97\mathrm{y}_{\mathbf{2005}}$), with no more than baseline (2005) energy usage. These ranges are considered realistic for Greece, given the available data and expert opinion (Stromplos 2010).

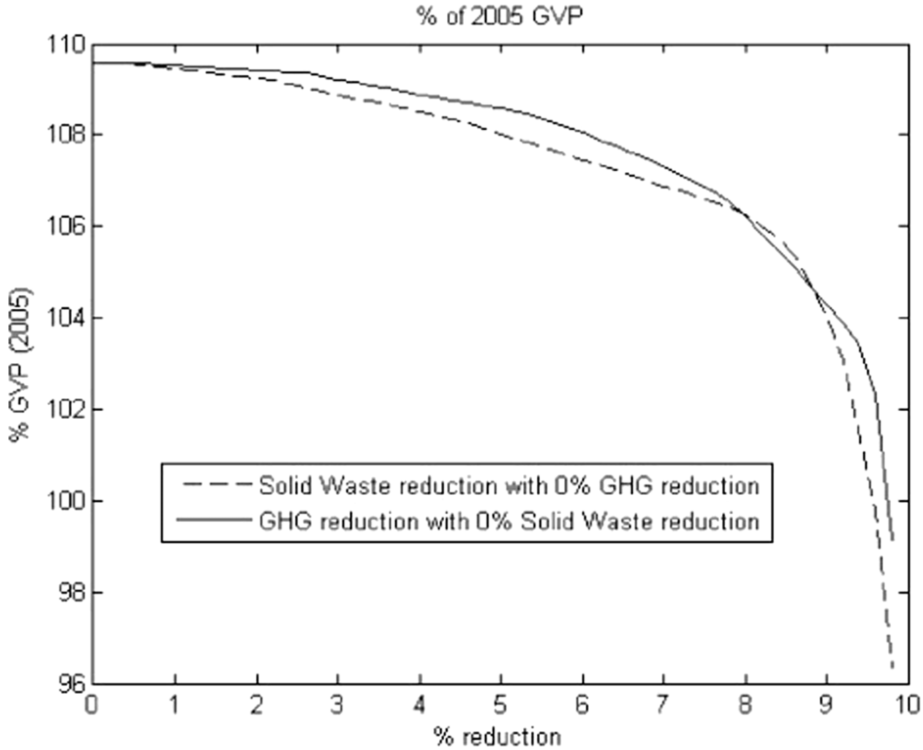
The optimization problem of Section 3 was solved using a linear solver in MATLAB. Figures 1 and 2 illustrate the relationship between the percentage change in GVP and the percentage reduction of pollutants, all compared against their 2005 levels. In Figure 1, we have solved the optimization problem separately for each category of pollutants. Figure 2, on the other hand, shows the maximum GVP that can be attained for any combination of GHG and solid waste reduction within the range of interest. The surface is concave everywhere, with a slope that points in the negative GVP direction. The latter indicates an inverse relationship between GVP and restrictions in pollutants' volume. This concavity (i.e. the fact that achieving pollution reductions requires increasingly lower levels of total production – Gruber, 2007) originates from the linear programming problem (which is informed by empirical data on the Greek economy) but is also consistent with the view of the Greek economy in the context of the EU Burden Sharing agreement. Specifically, Greece is one of the EU member states that were allowed to increase their CO_2 emissions (GMEPPPW and NOA, 2000) under the rationale that this is a requirement for economic development. In a sense, this is equivalent to stating that Greece lies on the upward sloping part of the environmental Kuznets curve.[6]

The concavity of the surface in Figure 2 indicates an increasing opportunity cost associated with pollution mitigation; that is, the higher the pollution abatement targets, the greater the marginal losses in production. From the data plotted in Figure 2, it is possible

[5] See http://www.eea.europa.eu/pressroom/newsreleases/eu-greenhouse-gas-emissions-decrease-in-2005

[6] For countries that lie on the upward sloping part of the environmental Kuznets curve, increased production comes with increased pollution, or, equivalently, the attainment of improved environmental conditions requires significant economic sacrifices.

FIGURE 1. Optimal GVP levels vs. percentage reduction in GHG emissions (solid curve) and solid waste (dashed curve).

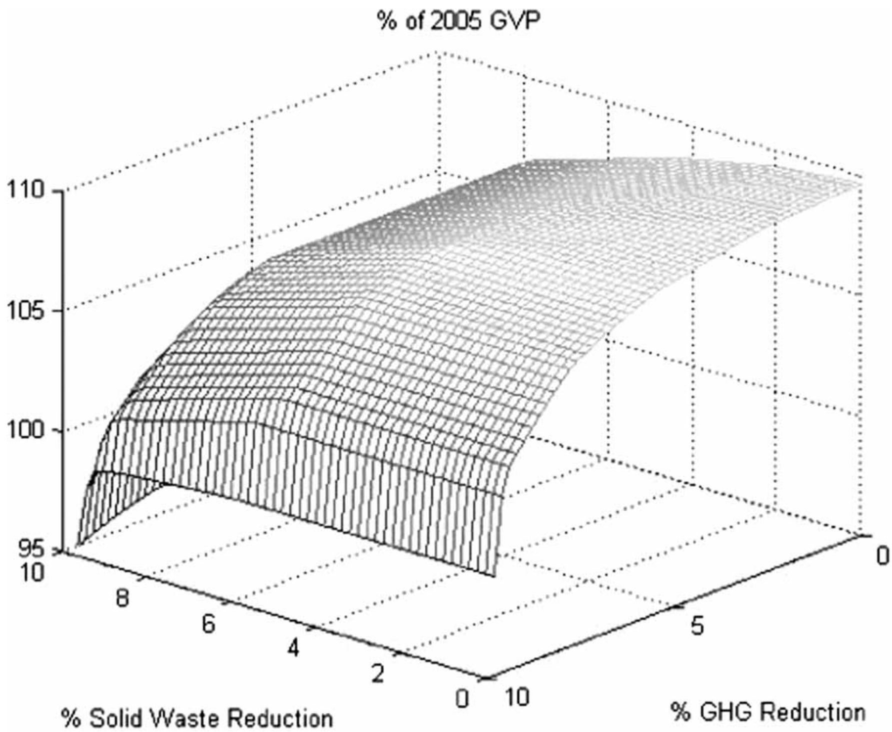


to calculate the marginal costs (in terms of GVP growth) incurred for each unit of pollution reduction at any point on the %GHG–%Waste reduction plane. We will not pursue this further here because of space considerations.

4.1. Some Remarks on the Optimal Solution(s)

By using GVP as our objective, we have in a sense deemed it to be the most 'important' variable (which it arguably is, from an economic perspective), and proceeded to explore what is possible with respect to GHG and solid waste, viewed as constraints. An alternative might be to take a multi-objective optimization approach and consider GVP, GHG, and waste as objectives, either by specifying the relative importance of the three, or by offering the decision maker a chance to proceed interactively (e.g. Oliveira and Antunes, 2009a). Our approach, however, is not wholly 'divorced' from multiobjective optimization; it is relatively straightforward to verify computationally that the GVP vs. GHG-and-waste surface of Figure 2 is a Pareto front, along which a decision-maker could make their selection(s) (and obtain the corresponding optimal solutions), being aware of the trade-offs between improving one quantity and worsening the other two. Finally, we note that the optimal solutions corresponding to each point of the graphs in Figures 1 and 2 were found to be unique (e.g. Mangasarian, 1979) to within ten significant digits. The same fact was verified for all scenarios examined in the remainder of the paper.

FIGURE 2. Optimal GVP (in percentage change relative to 2005) as a function of GHG emissions and solid waste reductions.



4.2. Effects of Optimal Production Reallocation on Macroeconomic Quantities

Table 1 presents the percentage changes (relative to 2005 levels) in a set of main economic and environmental variables, for various combinations of GHG and solid waste reduction targets. These targets were used to determine the bounds l_p, l_W, in the constraints of Section 3.3, and then the optimization problem was solved. The solutions obtained can be viewed as candidate policy targets where, for a given environmental goal (in some cases exceeding the country's commitments to international conventions such as the Kyoto protocol), we ask for an economy that produces at the highest possible level.

Scenario 1 corresponds to an optimal reallocation of sectoral production without imposing any pollution abatement measures, and yields a 0.54% reduction in energy use while simultaneously boosting GVP by 9.58%, GVA by 9.46%, tax revenues by 9.14% and VAT revenues by 10%. This solution leads to a slight decrease in emissions (−0.05%, indicating that the constraint on GHG is slack), but leaves waste volume unaffected; it is given here mainly for the sake of comparison. In the remaining scenarios, we reduced the allowed level of emissions and waste in two steps of 4.5% each. These curtailment rates are considered to be realistic targets given the country's economic potential (Stromplos, 2010).

Imposing a 4.5% reduction in emissions while leaving waste volume fixed (scenario 2) results in a more limited increase in GVP (8.73%), GVA (8.74%), tax (7.78%) and VAT revenues (8.47%), compared with scenario 1, but a more significant restriction in energy

TABLE 1. Percentage changes in main economic and environmental variables compared to their baseline (2005) values.

Scenario	1	2	3	4	5	6	7	8	9
% GHG emissions reduction	0.00	4.50	9.00	0.00	0.00	4.50	9.00	4.50	9.00
% solid waste reduction	0.00	0.00	0.00	4.50	9.00	4.50	4.50	9.00	9.00
Total GVP	9.58	8.73	4.29	8.31	4.06	8.27	4.29	4.06	2.00
Total GVA	9.46	8.74	4.81	8.45	5.55	8.43	4.81	5.55	3.17
Total tax revenues	9.14	7.78	1.92	7.55	1.22	7.45	1.92	1.22	−0.26
Total VAT	10.00	8.47	6.48	7.53	−3.54	7.75	6.48	−3.54	−6.01
Total energy use	−0.54	−2.87	−8.18	−3.20	−5.70	−3.54	−8.18	−5.70	−7.44
Total GHG emissions	−0.05	−4.50	−9.00	−3.76	−6.87	−4.50	−9.00	−6.87	−9.00
Solid Waste	0.00	−2.13	−5.17	−4.50	−9.00	−4.50	−5.17	−9.00	−9.00

use (−2.87%). This is in line with the fact that energy generation is the largest GHG contributor in Greece. Besides GHG emissions declining by the required 4.5%, solid waste is also reduced (−2.13%), indicating that the corresponding constraint is again slack. This is because GHGs and solid waste are not produced 'independently'; thus, in this case, the GHG restriction is tight enough to cause a reduction in the other pollutant's volume as well.

Further emissions restrictions (by 9%) without any waste constraints (scenario 3), lead to even lower gains in GVP (4.29%), GVA (4.81%), tax (1.92%) and VAT revenues (6.48%), while energy use is significantly limited (−8.18%). At the same time, a significant reduction in solid waste volume (−5.17%) is achieved. Scenario 4 prescribes a 4.5% restriction in solid waste only. In that case, GVP increases by 8.31%, GVA by 8.45%, tax and VAT revenues by 7.55% and 7.53%, respectively. These changes are of a slightly lower magnitude than in scenario 2, where the 4.5% reduction was applied to GHG emissions only. Total energy use decreases by 3.2%, and GHG emissions by 3.76%. If we must decide between either a 4.5% restriction in emissions or a 4.5% restriction in solid waste, it seems preferable to choose the former (scenario 2) if the criterion is economic performance, and the latter (scenario 4) if environmental considerations take precedence.

An additional restriction of solid waste up to 9% with no emission abatement policies (scenario 5), limits GVP to an increase of 4.06%, and tax revenues to 1.22%, again compared to 2005 levels. VAT revenues are now reduced by 3.54%, energy use by 5.7%, and emissions by 6.87%. These are more severe effects compared with scenario 3, as far as most economic variables are concerned, with the exception of GVA, which increases by 5.55%. A restriction of 4.5% in both emissions and waste (scenario 6) leads to an increase of 8.27% in GVP, 8.43% in GVA, 7.45% in tax and 7.75% in VAT revenues, and a decrease of 3.54% in energy use.

Keeping the solid waste restriction at 4.5% and lowering GHG emissions by 9% (scenario 7), yields the same results as in scenario 3, where the intention was solely the restriction of GHG emissions by 9%. Again, the coupling between GHG emissions and solid waste production is such that reducing emissions by 9% without considering waste, also reduces waste by 5.17%. This suggests that, rather than applying policies aimed at combating both pollutants, it might be simpler to focus on the abatement of one, in this case

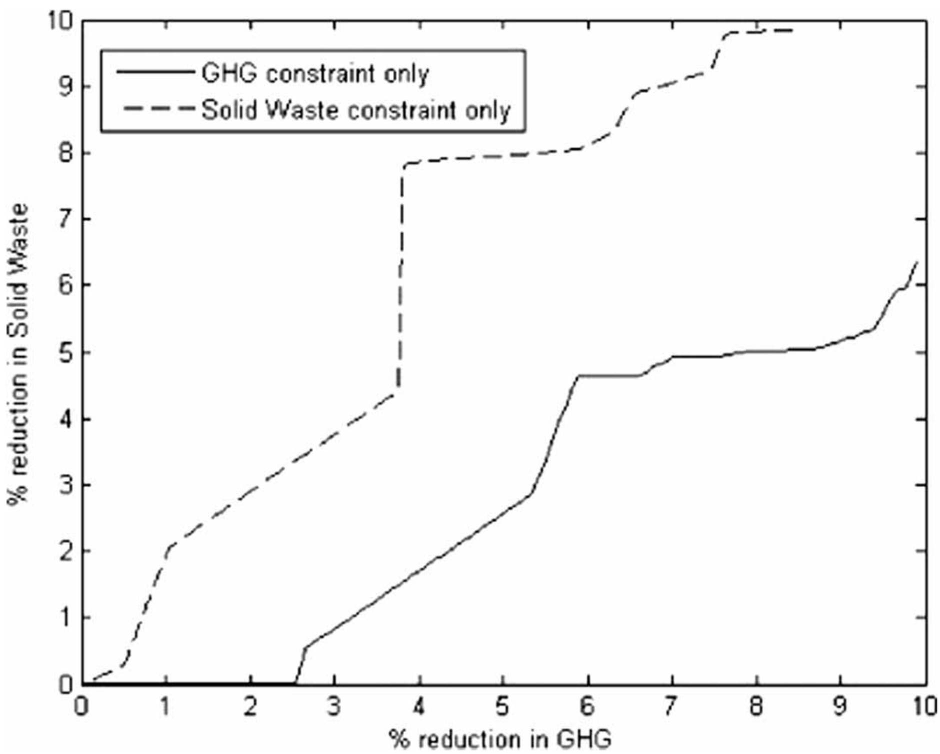
GHG emissions; the severe reduction rates of emissions lower the volume of other pollutants, without additional measures. We come to a similar conclusion when comparing scenarios 5 and 8 but now the roles of the pollutants are reversed: adopted policies should emphasise waste disposal restriction, disregarding emissions.

Finally, imposing a 9% reduction in both pollutants (scenario 9), leads to the harshest economic consequences among all scenarios examined here. The GVP's increase is limited to just 2%, GVA's to 3.17%. Taxes, and especially VAT revenues, decline to −0.26% and −6.01%, respectively. Energy use diminishes considerably (−7.44%) as well.

4.3. When Should Policy Explicitly Address Each Pollutant Separately?

The comparison between scenarios 3 and 7 (as well as 5 and 8) is worth exploring more fully; both cases are instances of the relationship illustrated in Figure 3. The solid curve shows the solid waste reduction that could be achieved if we were to ignore the solid waste constraint in the optimization problem of Section 3 and focus only on reducing GHG. Points under the solid curve (such as scenario 7) correspond to settings where the solid waste constraint is slack and can be ignored. Points above the curve correspond to

FIGURE 3. Solid curve: reduction in solid waste (as a percentage of its 2005 value) that is achieved by focusing solely on reducing GHG.



Dashed curve: reduction in GHG emissions (as a percentage of 2005 values) achieved by only mitigating solid waste.

reduction combinations in which the solid waste constraint is tight and its application comes at a cost in terms of GVP growth.

The dashed curve illustrates the converse situation, i.e. the GHG reduction that can be achieved (on the horizontal axis) if one were to optimize GVP while imposing only the solid waste constraint (at a level shown on the vertical axis). In all cases, we verified that the optimal solution was unique to within ten significant digits. We note that in both curves there are segments where the slope is near a 45° angle, thus optimizing GVP by considering only one of the two pollutants has the effect of also reducing the other. Also of interest are the near-horizontal and near-vertical areas of the curves. For example, if solid waste were the only concern, there is a range (approximately 4.2–7.7% on the vertical axis of Figure 3) where 'paying' for additional reductions (by somewhat reducing GVP – see Figure 2) has almost no effect on GHG emissions. An analogous situation occurs for GHG emissions at the 6–9% range.

Returning to the options considered in Section 4.2, the choice of the 'most effective' scenario would depend on the priorities of government. If the state is bound to strict environmental commitments, it may be obligated to adopt scenario 9, despite the fact that it entails the highest economic cost. Scenario 5 addresses solid waste restrictions only, with more adverse effects for the economy than scenario 3, which focuses solely on GHGs. In that sense, a policy that prioritizes emissions control over solid waste control in Greece (at the same, 9% target reduction) implies more favourable economic conditions, the most significant difference being in terms of VAT and energy usage, with a still significant reduction in solid waste. In general, whether reducing GHG is marginally preferable to reducing solid waste depends on which point on the surface shown in Figure 2 we choose to consider as 'reference'.

Specifically, for Greece – which currently faces binding GHG emission targets – scenario 3 seems to be the most appropriate if one is willing to make significant economic sacrifices. Otherwise, scenario 2 yields almost twice the growth rate for GVP, and a fourfold tax revenue increase, at a cost of lower environmental performance (approximately half of the reductions achieved under scenario 3). Scenario 4 does not appear particularly advantageous, as it entails lower levels of economic performance with small gains in environmental effectiveness.

4.4. Effects of Optimal Production Reallocation on Sectoral Production

Table 2 lists the percentage changes in the value of sectoral production under optimal reallocation, for each of the nine scenarios discussed in the previous section. We observe that sectoral production changes in every case (within the allowable range of $\pm 10\%$). However, results vary considerably both on a sector-by-sector basis, and across scenarios. Overall, the activities most severely affected belong to the primary and the secondary sectors of the economy. The most energy-intensive activities, i.e. mining and quarrying, electricity, gas and water supply, undergo major reductions in every case. The most 'privileged' sectors – those that are assigned higher production levels under all scenarios – are mainly from tertiary production: manufacture of textiles and textile products, manufacture of wood and wood products, wholesale and retail trade, repair of motor vehicles, motorcycles and personal and household goods, hotels and restaurants, financial intermediation, real estate, renting and business activities, education, health and social work and

TABLE 2. Percentage changes of sectoral production. The correspondence between sector numbers and NACE activities can be found in the Appendix.

Scenario		1	2	3	4	5	6	7	8	9
%GHG reduction		0.0	4.5	9.0	0.0	0.0	4.5	9.0	4.5	9.0
%Solid Waste reduction		0.0	0.0	0.0	4.5	9.0	4.5	4.5	9.0	9.0
Sector No	1	10.0	−3.8	−10.0	−10.0	−10.0	−10.0	−10.0	−10.0	−10.0
	2	10.0	10.0	−10.0	10.0	10.0	10.0	−10.0	10.0	−10.0
	3	−10.0	−10.0	−10.0	−10.0	−10.0	−10.0	−10.0	−10.0	−10.0
	4	10.0	10.0	10.0	10.0	−10.0	10.0	10.0	−10.0	5.1
	5	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
	6	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
	7	10.0	10.0	10.0	10.0	−10.0	10.0	10.0	−10.0	−10.0
	8	10.0	10.0	−10.0	10.0	10.0	10.0	−10.0	10.0	−10.0
	9	10.0	10.0	−10.0	10.0	−10.0	10.0	−10.0	−10.0	−10.0
	10	10.0	−10.0	−10.0	10.0	−10.0	3.0	−10.0	−10.0	−10.0
	11	10.0	10.0	−10.0	−10.0	−10.0	−10.0	−10.0	−10.0	−10.0
	12	10.0	10.0	−10.0	10.0	−10.0	10.0	−10.0	−10.0	−10.0
	13	10.0	10.0	−10.0	10.0	10.0	10.0	−10.0	10.0	−10.0
	14	10.0	10.0	−10.0	10.0	−10.0	10.0	−10.0	−10.0	−10.0
	15	−9.1	−10.0	−10.0	−10.0	−10.0	−10.0	−10.0	−10.0	−10.0
	16	10.0	10.0	10.0	9.5	−10.0	10.0	10.0	−10.0	−10.0
	17	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
	18	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
	19	10.0	10.0	−10.0	10.0	10.0	10.0	−10.0	10.0	2.8
	20	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
	21	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
	22	10.0	10.0	1.9	10.0	7.7	10.0	1.9	7.7	−10.0
	23	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
	24	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
	25	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0

activities of membership organizations n.e.c. In general, the stricter the scenario, the greater the number of sectors that undergo a reduction: 14 sectors in scenario 9, 12 sectors in scenarios 3 and 7, and 11 sectors in scenarios 5 and 8. In scenarios 2, 4 and 6, only four sectors decline.

We note that scenarios 3 and 7 display identical fluctuations in sectoral production. The same is true for scenarios 5 and 8. In the first case, the consequences are identical whether the environmental policy aims at a large reduction in GHG emissions and a modest reduction in waste volume, or at a large reduction in GHG emissions alone; thus, it is sufficient for policy to focus on emissions. In the second case (scenario 8) we are, in a sense, indifferent between either applying a strict waste restriction policy and a moderate GHG emissions mitigation policy, or a strict waste reduction policy alone; thus, if solid waste reduction is a priority, it seems more efficient to focus solely on that objective. Scenarios 2, 4 and 6 achieve moderate pollution reductions, mainly via significant declines in some of the most energy-intensive branches, i.e. agriculture, mining and quarrying, manufacture of other non-metallic mineral products, manufacture of basic metals and fabricated metal products and electricity, gas and water supply; all other branches undergo increases ranging from 3% to 10%.

5. CONCLUSIONS

We have examined the macroeconomic and sectoral effects of various possible policies aimed at mitigating GHG emissions and solid waste generation within the Greek economy. The main objectives of the study were: (i) to explore a set of feasible pollution abatement strategies in order to help meet the country's Kyoto obligations, as well as existing EU directives for solid waste management, and (ii) to determine when a separate policy is needed to mitigate one of the two pollutants, assuming that a policy is already in place for reducing the other. We constructed an input output-based constrained optimization problem and solved it for each policy scenario under consideration. The objective was to maximise total production under constraints on energy use, sectoral production and final demand fluctuations. The data used in the analysis were derived from the extended input–output Greek NAMEA for the year 2005 (latest available).

In each scenario, we determined the consequences for a set of macro-economic variables, including GVA, and tax revenues. It appears that the imposition of strict abatement policies for both pollutants (scenario 9) should be rejected, since it entails steep reductions for the economy, both at the aggregate and at the sectoral level. Scenarios 3 and 7 (as well as 5 and 8), lead to identical results, indicating that if the state decides to impose significant pollution restrictions, the focus should be on one of the pollutants rather than on both of them. This is because the two pollutants are not produced independently; thus, depending on the combination of GHG and solid waste target reductions, a significant decrease in one pollutant may reduce the other as well. Going beyond the nine scenarios analysed here, we computed a pair of 'separating' curves in the space of GHG versus solid waste reductions. Each curve effectively splits the set of all reduction targets into (a) a subset where policy must explicitly address each pollutant, and (b) a subset where mitigating one pollutant 'automatically' reduces the other, implying an opportunity for cost and bureaucracy savings.

Our results indicate that all sectors undergo production fluctuations, which vary depending on the scenario adopted and the pollution intensity of the specific sector. Activities belonging to the primary and the secondary sectors face the greatest restrictions, whereas activities in the tertiary sectors see a negligible effect. As expected, the more restrictive the scenario, the greater the number of sectors affected, and the more significant the effect.

To arrive at a final choice regarding which scenario to implement, one should take into account the state's commitments towards pollution abatement, the consequences for macroeconomic and environmental variables, and the broader (e.g. social or political) effects of adjusting production in specific economic sectors. In light of the country's Kyoto obligations, scenario 3 (9% reduction in GHG emissions, which in turn effects a 5.17% reduction in solid waste) seem to be the most appropriate to aim for. If, however, Greece is unable to afford the economic cost of this policy, scenario 6 (4.5% reduction both in GHG emissions and solid waste) might be the next best option to consider. Finally, it would be interesting to consider a 'dynamic' version of the problem addressed in this work, by allowing technology coefficients to vary in time. At this time, the main obstacle in that direction seems to be the lack of empirical data regarding the environmental input–output tables for Greece.

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APPENDIX

TABLE A1. Sector numbers, NACE (Nomenclature statistique des Activités économiques dans la Communauté Européenne) codes and activities in the 2005 Greek Input-Output Matrix.

Sector no	NACE Code	NACE Activity Rev. 1
1	01 & 02	Agriculture
2	5	Fisheries
3	10,11&12 / 13–14	Mining and quarrying
4	15–16	Manufacture of food products, beverages and tobacco
5	17–19	Manufacture of textiles and textile products
6	20A	Manufacture of wood and wood products
7	21–22	Manufacture of pulp, paper and paper products; publishing and printing
8	23	Manufacture of coke, refined petroleum products and nuclear fuel
9	24–25	Manufacture of chemicals, chemical products and man-made fibres
10	26	Manufacture of other non-metallic mineral products
11	27	Manufacture of basic metals and fabricated metal products
12	28	Manufacture of fabricated metal products, except machinery and equipment
13	29–36	Manufacture of machinery and equipment
14	37	Recycling
15	40–41	Electricity, gas and water supply
16	45	Construction
17	50–52	Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods
18	55	Hotels and restaurants
19	60–64	Transport, storage and communication
20	65–67	Financial intermediation
21	70–74	Real estate, renting and business activities
22	75&90	Public administration and defence; Sewage and refuse disposal
23	80–84	Education
24	85	Health and social work
25	91	Activities of membership organizations n.e.c.
26	92, 93, 95 & 99	Recreational, cultural and sporting activities; Activities of households; Extra-territorial organizations

Source: Economidis et al. (2008, p. 5)

TABLE A2. Quantities used to calculate the energy ($\mathbf{a_e}$), GHG ($\mathbf{a_P}$), solid waste ($\mathbf{a_W}$), VAT ($\mathbf{a_V}$), and tax revenue ($\mathbf{a_T}$), coefficient vectors in the main optimization problem of Section 3. See Section 2 for data sources.

Sector no	Energy usage (MW)	Solid waste generated (ktonne)	GHG generated (ktonne)	VAT revenue (M€)	Tax revenue (M€)
1	57.9	4707.0	13988.5	358.1	171.9
2	0	3.8	345.9	34.6	25.8
3	4.8	7494.6	1553.6	0	20.0
4	27.1	767.4	973.8	13.4	246.5
5	6.2	44.1	110.6	0	79.0
6	0.3	15.9	22.6	0	11.3
7	5.7	354.8	288.8	1.3	42.8
8	52.5	17.6	3736.7	0	77.8
9	25.7	562.3	2047.8	0	72.3
10	46.9	407.2	10829.9	0	61.4
11	44.6	3517.0	2728.9	0	30.5
12	3.1	113.9	950.4	0	14.7
13	4.8	19.3	2901.4	0	56.1
14	0.3	29.5	190.6	0	5.7
15	519.6	13028.8	52403.2	0	102.3
16	8.6	6829.2	285.7	1762.4	420.1
17	5.5	646.0	454.5	0	266.6
18	3.9	167.0	247.6	1.4	251.0
19	99.1	105.0	4491.4	3.0	429.9
20	0.3	150.0	27.6	167.8	108.1
21	0.3	182.0	61.1	172.1	52.0
22	11.2	566.0	3452.7	423.3	80.4
23	6.9	62.0	243.9	57.5	25.0
24	6.2	79.0	185.1	213.0	40.6
25	8.4	2.0	183.2	19.5	34.6