Optimizing Production in Greece under GHG emission reduction constraints: a comparison of objective functions

D. Hristu-Varsakelis[a], S. Karagianni[b], M. Pempetzoglou[c], A. Sfetsos[d]

[a] Department of Applied Informatics, University of Macedonia, 156 Egnatia St., Thessaloniki 54006, Greece, dcv@uom.gr

[b] Department of Economics, University of Macedonia, 156 Egnatia St., Thessaloniki 54006, Greece, stelkar@uom.gr

[c] Department of Social Administration, Democritus University of Thrace, Panagi Tsaldari 1, Komotini, Greece, mariap@socadm.duth.gr

[d] Environmental Research Laboratory, INT-RP, NCSR Demokritos, Patriarhou Grigoriou, Agia Paraskevi, 15310, Greece, ts@ipta.demokritos.gr

Abstract

According to the Kyoto Protocol and the EU burden-sharing agreement, Greece is committed to limiting its 2008 – 2012 greenhouse gas (GHG) emissions to 25% over its 1990 levels. However, information derived from GHG emissions inventories has already shown an increase of approximately 28% between 1990 and 2005. Consequently, there is a pressing need to curtail emissions, after taking into consideration relevant economic and social parameters. Starting from an input-output model, this paper formulates a constrained optimization problem that could assist policy makers in maintaining optimal levels of economic (production) activity, while managing GHG emissions. We compare four alternative criteria: i) gross value added, ii) the product of gross value added and production value, iii) total production value, and iv) total GHG emissions – all put forth as possible objective functions to be used for optimizing production in Greece. The constraints placed on our model include bounds on fluctuations allowed in sectoral production and on overall demand that can be met. Our model, calibrated using the Greek environmental input-output matrix for 2005, indicates the maximization of total production value to be the superior criterion.

Keywords: GHG emissions, input-output analysis, optimization, Greece.

1. Introduction

The EU's Sixth Environment Action Programme (EAP), "Environment 2010: Our future, Our choice", includes Environment and Health as one of its four main target areas requiring greater effort. Air pollution is one of the main issues highlighted in that area, currently the focus of major interest both at the national and international level. The NAMEA (National Accounting Matrix Environmental Accounts) approach has gradually gained acceptance within the EU as an important part of the framework for environmental satellite accounts which are "attached" to national accounts, and which show the interactions between producer and consumer (household) activities, and the natural environment. These interrelationships occur as a consequence of the environmental requirements of economic activity, in terms of natural resource inputs and residual outputs. By providing economic and environmental data in a consistent Leontief-type framework (Leontief, 1972), the NAMEA is particularly suited for analysis purposes.

An especially relevant part of an economy's environmental impact concerns Greenhouse gases, which are regulated under the Kyoto protocol and have been connected with economic activity on a consistent basis (e.g., De Haan (2001), Roca and Serrano (2007), Tarancon Moran et. al. (2008)). Recently, input-output matrices have been employed as decision-making tools for sustainable development and planning in models incorporating the impact of air pollution and energy usage on a national or regional level. In the literature, there exist a number of studies applying multi-criteria optimization using variations of the input–output matrix, with particular emphasis on the macroeconomic variables of an economic entity. Examples include a three-criteria model of GDP maximization, minimization of the use of fuel-and-energy resources, and maximization of the foreign-trade balance, applied to the analysis of alternative development scenario for the national economy of Belarus, studied extensively by Kravtsov and Pashkevich (2004); the Olivera and Antuenes (2002) model of the Portuguese economy, using 45 activity sectors, coupling the maximization of employment and GDP with the minimization of energy imports and carbon dioxide (CO_2) emissions; and the Hsu and Chou (2000) multi-objective programming approach which uses a Leontief inter-industry model to evaluate the impact of energy conservation policy on the cost of reducing CO_2 emissions and industrial adjustment in Taiwan.

This paper combines environmental account data (NAMEA) with Greek input-output matrix in order to formulate and solve a constrained optimization problem that could assist policy makers in maintaining optimal levels of economic (production) activity, while curtailing GHG emissions. We examine and compare four alternative optimization criteria, including i) gross value added, ii) the product of gross value added and production value, iii) gross value of production, and iv) total GHG emissions – all put forth as possible objective functions used to optimize production levels for the Greek economy, based on the latest available (2005) data. Our results indicate the Gross Value of Production (GVP) to be the superior criterion. The remainder of this paper is structured as follows. In the next Section we discuss the development Greek environmental input-output matrix, from which we will later obtain the coefficients used to specify our model and optimization problem, in Section 3. Section 4 discusses the solution of the optimization problem under each criterion and makes comparisons in terms of their economic performance.

2. The Greek environmental input-output matrix

In order to be able to formulate optimization problems which explore the coupling between production and environmental impact within an economy, we require – among other things – a way of "attributing" environmental impact to the various kinds of economic activities in the form of an environmental input-output matrix. We go on to describe our methodology for doing so.

The NAMEA approach consists of a maintaining a National Accounting Matrix (NAM), extended to include Environmental Accounts. All such accounts are presented in matrix format. This format reconciles supply-use tables and sector accounts, creating a comprehensive accounting framework that can be presented at various levels of detail. The economic accounts in the NAM part of the NAMEA present the complete set of accounts of 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 input of natural resources and output of residuals for the national economy.

The data used for this study are based on the official data reported by the Greek Ministry of Environment and Public Works to fulfil the country's obligations within the EU. The data are based on the CORINAIR methodology and classified according to the Selected Nomenclature for sources of Air Pollution (SNAP). The original data were processed to derive a NAMEA-consistent total and to arrange process-oriented data in order to make them fit into the NACE-based classification, presently adopted for NAMEA. A hybrid approach was followed in order to attribute the SNAP-classified emissions to NACE-based economic activities or households' consumption functions: simple (direct) and complex allocations. Concerning the later, some SNAP processes emissions had to be split into several NAMEA activities. These emissions were attributed to NACE codes or households' consumption functions using fuel consumption data, technical data contained in CORINAIR, and expert knowledge or other data.

Recent studies concerning the structure of the Greek NAMEA (Economides et. al. (2008)) revealed that the only quantity with significant impact for production levels in Greece is GHG, an environmental stressor contributing to global climate change, and collectively represented by the Global Warming Potential, GWP = CO_2 + 310 * N_2O + 21 * CH_4. For this reason our analysis will focus on this pollutant. In order to study the effects of reallocating production on energy use, we obtained energy data from the EUROSTAT New Cronos database, for the same time period as with our environmental data. The energy expenditures were attributed to the economic activity data using a similar methodology as with the air emissions.

3. Problem Setup

Let $x \in R_*^{25}$ be the gross value of production vector, Y the final demand, M imports, and X the 25x25 input-output matrix. We have:

$$x = X\mathbb{E} + Y - M \ , \qquad (1)$$

where $\mathbb{E}^T = [1,1,...,1]^T$ and Y is assumed to be constant at this point. The matrix of technology coefficients is (assuming $x > 0$)

$$A_{ij} = X_{ij}/x_j , \qquad i, j = 1,...,25,$$

or, equivalently[1], $X = A \cdot diag(x)$, and $X\mathbb{E} = Ax$, so that

$$x = Ax + Y - M \Rightarrow (I - A)x = Y - M . \qquad (2)$$

Furthermore, we let the total intermediate consumption at market prices

$$x_T = X^T\mathbb{E} + T + S + V = diag(x)A^T\mathbb{E} + T + S + V , \qquad (3)$$

[1] For a vector x, $diag(x)$ denotes the diagonal matrix whose diagonal elements are those of x.

where $T \in R^{25}$ are taxes, $S \in R^{25}$ subsidies and $V \in R^{25}$ is VAT, all written as column-vectors, with S assumed constant. Taxes and VAT are taken to be linearly related to gross value of production, i.e.,

$$T = diag(a_T)X^T\mathbb{E} = diag(a_T)diag(x)A^T\mathbb{E},$$

and

$$V = diag(a_{VAT})X^T\mathbb{E} = diag(a_{VAT})diag(x)A^T\mathbb{E},$$

where the vectors a_T, a_{VAT} correspond to the model's tax and VAT coefficients, respectively.

The vector form of the Gross Value Added (GVA) is computed as

$$\begin{aligned} GVA &= x - x_T \\ &= x - diag(x)A^T\mathbb{E} - diag(a_T)diag(x)A^T\mathbb{E} - \\ &- diag(a_{VAT})diag(x)A^T\mathbb{E} - S \\ &= x - diag(x)(I + diag(a_T + a_{VAT}))A^T\mathbb{E} - S \end{aligned} \quad (4)$$

The GHG pollution production vector corresponding to x is

$$P = diag(a_{GHG})x, \quad (5)$$

where a_{GHG} is a vector of pollution coefficients (GHG emissions per unit of production).

The energy consumption vector corresponding to a production of x is

$$C = diag(a_e)x, \quad (6)$$

where a_e is a vector containing the energy coefficients for all sectors (energy use per unit of production).

Finally, the economy's total Gross Value of Production (GVP) is given by

$$GVP = \mathbb{E}^T x \tag{7}$$

3.1 Optimization Problem

Our goal is to draw comparisons between criteria and to identify, if possible, the superior criterion that may assist policy makers in maintaining optimal levels of production while reducing GHG. We will consider optimizing production expressed in four alternative objective functions:

i) total Gross Value Added, (4),

$J_1 = \mathbb{E}^T GVA = \mathbb{E}^T (x - diag(x)(I + diag(a_T + a_{VAT}))A^T \mathbb{E} - S)$

ii) the (inner) product of gross value added and production value,

$J_2 = x^T GVA$

iii) total production value, (7)

$J_3 = \mathbb{E}^T x$, and

iv) total GHG emissions (6)

$J_4 = diag(a_{GHG})x$,

all subject to the following constraints:

- $a_e^T x \le e_u$, where e_u is a (scalar) upper limit on energy used – set to 100% of the amount used in 2005.
- $a_{GHG}^T x \le p_u$, where p_u is a scalar upper limit on pollution.
- $\mathbb{E}^T (I - A)x \ge Y_l{}^T - M$, where Y_l is a lower bound on the total sum of demand met across all sectors – set to 97% of the 2005 total demand.

- $x_l \leq x \leq x_u$, where x_l, $x_u \in \mathbb{R}^{25}$ are lower and upper bounds on production, set to -10% below and +10% above 2005 levels, respectively.
- Non-negative production, $x \geq 0$.

4. Optimization Results

Before we present the results obtained with each criterion, we must clarify some of the terminology to be used in the sequel. In every case, we will make comparisons with the *initial status* (year 2005) of the economy, where no environmental policies or reallocation of production has occurred. We will first proceed with a *baseline* reallocation of production, in order to investigate the potential for improvements in the economy. This baseline case assumes no environmental restrictions and no emission alleviation targets; the fluctuations allowed in sectoral production are not to exceed ±10%, while overall demand must meet at least 97% of the 2005 level. A second, *final* scenario, will assume that the optimal production reallocation must also satisfy emission mitigation policies that restrict GHG emissions to up to 9%[2] . In each case, and for each candidate optimization criterion, we will examine the effects on various economic and environmental variables

4.1. Results using the 'total GVA' optimization criterion

This section discusses the use of the 'GVA' optimization criterion and its effects on the values of various macroeconomic variables at the aggregate level.

---

[2] Note: Based on our model, the maximum GHG emissions reduction that can be achieved is 9.9%. We chose to present data for a less-than-optimal reduction of 9% because that scenario is deedmed more interesting and viable. In fact, demanding *optimality* in GHG emissions (e.g., moving from a 9% cut to the maximum, 9.9%), is accompanied by a precipitous drop in all major economic variables examined here, to the values shown in Sec.4.4.

Table 4.1.1 indicates the nominal values of the variables for the initial status, as well as their optimal values in the baseline and final cases. The economic variables to be examined are: GHG emissions, GVP, total GVA (i.e., the sum of elements in the GVA vector in (4)), the inner product between GVA and production value (x^TGVA), total tax revenues, total value added tax (VAT), and total energy use.

[TABLE 4.1.1]

Table 4.1.2 shows the percentage changes in the economic variables under consideration, between the initial, baseline and final cases. The results indicate that without the implementation of emission mitigation policies, GVP could increase by 9.7%, tax revenues by 9.2%, VAT by 10%, and there is a slight decrease (-0.7%) in energy use. Additionally, a maximum increase in the value of GVA (9.5%) is achieved. The adoption of emission alleviation policies reduces the percentages attained at the base case, but still allows for positive changes in the economic variables, compared to the initial status. Specifically, GVP and GVA increase by 3.5% and 4.8%, respectively, tax revenues and VAT raise by 0.3% and 7.1%, respectively, and total energy use is restricted by 8.7%. At the same time, an emissions reduction of 9% is achieved.

[TABLE 4.1.2]

4.2. Results using the ‘product of GVA and production value’ optimization criterion[3]

Table 4.2.1 shows the nominal and optimal values of the “main” economic variables listed in the previous section, when optimizing based on the inner product of GVA and production vectors. Table 4.2.2 contains the percentage changes for the same variables.

[TABLE 4.2.1]

The results indicate no changes between the initial status and the baseline case under compared to our 1st optimization criterion (Sec. 4.1). However, the two criteria are differentiated in the final case. With an emissions reduction at 9%, GVP increases by 3.1%, GVA by 4.7%, the product of *x* and GVA by 14.6%, and VAT by 7.4%. Reductions are observed in tax revenues (-0.6%) and energy use (-8.9%).

[TABLE 4.2.2]

4.3. Results using the ‘total production value’ optimization criterion

Table 4.3.1 lists the nominal and optimal values of the main economic variables, at the aggregate level, when maximizing total production value.

[TABLE 4.3.1]

---

[3] The product x^TGVA does not have a specific economic meaning. It is only used as an optimization criterion. For this reason, the results concerning this variable are presented but not analysed in detail.

The corresponding percentage changes compared to the initial status are shown in Table 4.3.2. The results of the base case are identical to those from the previous two criteria, while the emissions reduction achieved is 9%. The table indicates that the reallocation of sectoral production allows for a 4.3% increase in GVP, a 4.8% increase in GVA, an 1.9% increase in tax revenues and a 6.5% increase in VAT. A reduction is observed only in energy use (-8.2%).

[TABLE 4.3.2]

4.4. Results using 'total GHG emissions' optimization criterion

When minimizing total GHG emissions considerable the solution (sectoral production levels) differs considerably from those obtained using the first three optimization criteria. Table 4.4.1 indicates the corresponding nominal and optimal values of the economic variables. Because the optimality criterion here is minimizing GHG emissions, the results for the baseline and finals cases coincide, so that there is no question of a "gradual" reduction of emissions, as with the previous three criteria.

[TABLE 4.4.1]

Table 4.4.2. includes the percentage changes in the values of the main variables. Both the reallocation of sectoral production and the minimization of emissions allow for a significant drop in emissions (-9.9%) as well as in energy use (-9.8%). However, the adoption of this criterion leads to important reductions in all economic variables: GVP is reduced by 4.7%, GVA by 3.8%, tax revenues by 6.8% and VAT by 7.1%.

[TABLE 4.4.2]

4.5. Comparisons between optimization criteria

We proceed to compare the four optimization criteria in terms of economic and environmental effectiveness. The curves shown in Figure 1 indicate the evolution of the first three optimization criteria (maximization of GVA, x^TGVA, and GVP) as GHG emissions are gradually restricted (from 0% to 9%), with the fourth criterion (minimum GHG) also shown for reference purposes.

[FIGURE 1]

As we have already mentioned, sectoral production fluctuations were limited to 10%, while overall demand met was not allowed to drop more than 3% over its 2005 level. The curves for the first three criteria begin at the same value (9.7% above 2005 levels), indicating that the reallocation of sectoral production, without the implementation of any emission mitigation policies, already allows for a significant increase in total GVP. The maximum GHG emissions cut possible is 9.9%, as indicated by the GHG-minimizing solution, at which point all four criteria would give the same solution.

Figure 1 also indicates that progressive cutbacks in emissions gradually restrict the maximum production possible to approximately 5% over 2005 levels. Production drops at a slow pace during the initial GHG emission restrictions, but the decline is much steeper when emissions abatement surpasses 9%. However, there are numerous combinations of optimized production and emission reduction levels that can be chosen without “suffering” in terms of production, i.e. a 9% restriction in emissions can simultaneously be achieved with a 4.4% (under the GVP criterion), a 3.3% (under the GVA criterion) and a 2.9% (under the x^TGVA criterion) increase in production.

As far as the GHG minimization criterion is concerned, it appears that a reallocation of production, both with and without the implementation of emission alleviation policies, cuts GVP down by 4.7%, compared to the initial status of production. The significant difference in total production value between this last criterion and the first three (at least for GHG emmissions cuts in the 0-9% range) suggests that this criterion might be too strict, in the sense that by demanding an extra 0.9% emissions cuts beyond the 9% level entails a significant drop in all major economic variables. Conversely, if one is satisfied with an “almost optimal” GHG emmissions cut of 9%, the economy gains significantly compared to a GHG-optimal scenario.

As far as other variables are concerned (Table 4.5.1), it appears that the implementation of emission abatement policies either increases GVA from 4.7% (2nd criterion) to 4.8% (1st and 3rd criterion) or decreases it by 3.8%; either increases tax revenues by 0.3% (1st criterion) and by 1.9% (3rd criterion) or decreases them by 0.6% (2nd criterion) and by 6.8% (4th criterion); either increases VAT by 6.5%, 7.1% and 7.4% (3rd , 1st and 2nd criterion, respectively) or decreases it by 7.1%; and decreases energy use by 8.2%, 8.7%, 8.9% and 9.8% (3rd , 1st, 2nd and 4th criterion), respectively.

[TABLE 4.5.1]

To summarize, all four criteria may provide a maximum 9.9% curtail in GHG emissions. GVP is the criterion that secures the highest possible GVP (as expected), as well and GVA and total tax revenues. However, this criterion leads to greater losses in terms of VAT revenues, and entails the least reduction in energy use. The total GVA optimization index comes in second place in terms of economics and environmental effectiveness, while the product of GVA and production seems to be much less effective. This is because the latter function involves purely negative tax revenues and lower GVP and GVA values, compared to the previous two criteria; moreover, it is not very effective in reducing energy use. The GHG emissions criterion is regarded as the most draconian; this study suggests that its use should be avoided because of its uniformly negative effect on all economic variables examined here.

5. Conclusions

In this paper, we have developed a input-output based model, calibrated using the Greek environmental input-output matrix for 2005, in order to specify the optimum criterion to be used to mitigate GHG emissions in Greece. The criteria compared are four and they include the maximization of total GVA, total GVP, x^TGVA, and the minimization of GHG emissions.

Our analysis indicates the maximization of total GVP to be the superior criterion, because it appears to yield the best performance in both economic and environmental variables. Specifically, the GVP criterion shows the maximum percentage increase over its 2005 value, compared to the other criteria; it also yields the maximum increase in total production value, and total tax revenues. The GVA and x^TGVA criteria come at the second and third place, respectively, while the GHG emissions minimization criterion appears to have a prohibitive economic cost.

References

De Haan M., 2001. A structural decomposition analysis of pollution in the Netherlands, Economic Systems Research 13 (2), 181-196.

Economidis, Ch., Keramidas, D., Demertzi, A., Stromplos, N., Sfetsos, A., Vlachogiannis, D., 2008. The compilation of a Greek Environmental Input Output matrix for 2005, and its application as a methodological framework for assessing emission reduction options, 17^{th} International Input-Output Conference, Seville, Spain.

Hsu, G.J.Y., Chou, F.-Y., 2000. Integrated planning for mitigating CO_2 emissions in Taiwan: A multi-objective programming approach , Energy Policy 28 (8), 519-523.

Kravtsov, M.K., Pashkevich, A.V., 2004. A multicriteria approach to optimization of the gross domestic product, Automation and Remote Control 65 (2), 337-345.

Leontief, W., Ford, D., 1972. Air pollution and the economic structure: Empirical results of input-output computations, Input-output Techniques. edited by A. Brody and A.P. Carter. Amsterdam: North-Holland.

Olivera, C. and Antuenes, C.H., 2002. An Input-Output Model for Decision Support in Energy-Economy Planning: a Multiobjective Interactive Approach, *Journal Syst. Anal. Modelling Simul.* 42 (5), 769-790.

Roca, J., Serrano, M., 2007. Income growth and atmospheric pollution in Spain: An input-output approach, Ecological Economics 63 (1), 230-242.

Tarancón Morán, M.A., del Río, P., Albiñana, F.C., 2008. Tracking the genealogy of CO2 emissions in the electricity sector: An intersectoral approach applied to the Spanish case. Energy Policy 36 (6), 1915-1926.

Tables

Table 4.1.1.: Nominal and optimal values of main economic variables according to the GVA optimization criterion

	Nominal (2005) values (*initial status*)	Optimal values without any emission mitigation policies adoption (*baseline case*)	Optimal values with 9% reduction in total GHG emissions (*final case*)
Total GHG emissions (kton)	102705	102705	93462
Total GVP (M€)	265712	291390	275106
Total GVA (M€)	160394	175696	168117
x^TGVA (M€)^2	3326238412	4016674317	3801110338
Total tax revenues (M€)	2726	2978	2733
Total VAT (M€)	3227	3550	3457
Total energy use (TJ)	950	943	867

Table 4.1.2: Percentage changes in the values of main economic variables according to the 'GVA' optimization criterion

	% changes in values without any emission mitigation policies adoption (*basline case compared to initial status*)	% changes with 9% reduction in total GHG emissions (*final case compared to initial status*)
Total GHG emissions (kton)	0%	-9%
Total GVP (M€)	9.7%	3.5%
Total GVA (M€)	9.5%	4.8%
x^TGVA (M€)^2	20.8%	14.3%
Total tax revenues (M€)	9.2%	0.3%
Total VAT (M€)	10%	7.1%
Total energy use (TJ)	-0.7%	-8.7%

Table 4.2.1: Nominal and optimal values of main economic variables according to the 'product of GVA and production value' optimization criterion

	Nominal (2005) values (*initial status*)	Optimal values without any emission mitigation policies adoption (*baseline case*)	Optimal values with 9% reduction in total GHG emissions (*final case*)
Total GHG emissions (kton)	102705	102705	93462
Total GVP (M€)	265712	291390	273870
Total GVA (M€)	160394	175696	167887
x^TGVA $(M€)^2$	3326238412	4016674317	3812764740
Total tax revenues (M€)	2726	2978	2709
Total VAT (M€)	3227	3550	3467
Total energy use (TJ)	950	943	865

Table 4.2.2: Percentage changes in the values of main economic variables according to the 'product of GVA and production value' optimization criterion

	% changes in values without any emission mitigation policies adoption (*baseline compared to initial status*)	% changes with 9% reduction in total GHG emissions (*final case compared to initial status*)
Total GHG emissions (kton)	0%	-9%
Total GVP (M€)	9.7%	3.1%
Total GVA (M€)	9.5%	4.7%
x^TGVA $(M€)^2$	20.8%	14.6%
Total tax revenues (M€)	9.2%	-0.6%
Total VAT (M€)	10%	7.4%
Total energy use (TJ)	-0.7%	-8.9%

Table 4.3.1.: Nominal and optimal values of main economic variables according to the ‘total production value’ optimization criterion

	Nominal (2005) values (*initial status*)	Optimal values without any emission mitigation policies adoption (*baseline case*)	Optimal values with 9% reduction in total GHG emissions (*final case*)
Total GHG emissions (kton)	102705	102705	93462
Total GVP (M€)	265712	291390	277117
Total GVA (M€)	160394	175696	168116
x^TGVA $(M€)^2$	3326238412	4016674317	3798946472
Total tax revenues (M€)	2726	2978	2778
Total VAT (M€)	3227	3550	3436
Total energy use (TJ)	950	943	872

Table 4.3.2: Percentage changes in the values of main economic variables according to the ‘total production value’ optimization criterion

	% changes in values without any emission mitigation policies adoption (*baseline compared to initial status*)	% changes with 9% reduction in total GHG emissions (*final case compared to initial status*)
Total GHG emissions (kton)	0%	-9%
Total GVP (M€)	9.7%	4.3%
Total GVA (M€)	9.5%	4.8%
x^TGVA $(M€)^2$	20.8%	14.2%
Total tax revenues (M€)	9.2%	1.9%
Total VAT (M€)	10%	6.5%
Total energy use (TJ)	-0.7%	-8.2%

Table 4.4.1.: Nominal and optimal values of main economic variables according to the ‘total GHG emissions’ optimization criterion

	Nominal (2005) values (*initial status*)	Optimal values both with and without any emission mitigation policies adoption (*baseline and final case*)
Total GHG emissions (kton)	102705	92524
Total GVP (M€)	265712	253154
Total GVA (M€)	160394	154350
x^TGVA (M€)^2	3326238412	3159103755
Total tax revenues (M€)	2726	2540
Total VAT (M€)	3227	2998
Total energy use (TJ)	950	857

Table 4.4.2: Percentage changes in the values of main economic variables according to the ‘total GHG emissions’ optimization criterion

	% changes in values with minimization of total GHG emissions (*baseline and final case, compared to initial status*)
Total GHG emissions (kton)	-9.9%
Total GVP (M€)	-4.7%
Total GVA (M€)	-3.8%
x^TGVA (M€)^2	5%
Total tax revenues (M€)	-6.8%
Total VAT (M€)	-7.1%
Total energy use (TJ)	-9.8%

Table 4.5.1: Percentage changes in the values of main economic variables at the aggregate level: comparison between criteria

	baseline compared to initial status				*Final case compared to initial status*			
	1st criterion	2nd criterion	3rd criterion	4th criterion	1st criterion	2nd criterion	3rd criterion	4th criterion
Total GHG emissions	0%	0%	0%	-9.9%	-9%	-9%	-9%	-9.9%
Total GVP	9.7%	9.7%	9.7%	-4.7%	3.5%	3.1%	4.3%	-4.7%
Total GVA	9.5%	9.5%	9.5%	-3.8%	4.8%	4.7%	4.8%	-3.8%
x^TGVA	20.8%	20.8%	20.8%	5%	14.3%	14.6%	14.2%	5%
Total tax revenues	9.2%	9.2%	9.2%	-6.8%	0.3%	-0.6%	1.9%	-6.8%
Total VAT	10%	10%	10%	-7.1%	7.1%	7.4%	6.5%	-7.1%
Total energy use	-0.7%	-0.7%	-0.7%	-9.8%	-8.7%	-8.9%	-8.2%	-9.8%

Figures

Figure 1: Total production achieved under the four optimization criteria under consideration, showing the decline of the first three (maximum sum of GVAs, maximum sum of GVA and GVP products, maximum sum of GVPs) versus the enforced reduction of GHG emissions. The GHG-minimizing solution is shown as a flat line for comparison.