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Energy-environment sustainability - a multi-objective approach with uncertain data

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Abstract

Multiple objective programming models allow to consider explicitly distinct axes of evaluation, generally conflicting and non-commensurable. In particular, multiple objective linear programming models (MOLP) based on the linear inter/intra industrial linkages of production can be used to study the interactions between the economy, the energy system and the environment. This kind of models allows assessing the environmental impacts, resulting from changes in the level of the economic activities sustained by distinct policies. However, the uncertainty associated with these model's coefficients, namely derived from Input-Output (I-O) analysis, may lead to conclusions that are not robust regarding the changes of the input data. In this context, we propose a MOLP model based on I-O analysis with interval coefficients, which allows to assess impacts on the economy, the energy system and the environment, based on the levels of activity of economic sectors consistent with distinct policies.

Keywords: MOLP, Input-Output, Economy-Energy-Environment (E3) interactions, Interval coefficients.

1. Introduction

I-O analysis is an analytical tool, which allows evaluating the inter-relations between different economic activities being often applied to assess E3 interactions (Hawdon and Pearson, 1995). I-O analysis and linear programming (LP) are closely related. In its simplest form, with no substitute inputs, I-O analysis may be regarded as a simple particular case of LP (Dorfman *et al.*, 1958). The use of the I-O methodology in the framework of LP models allows obtaining value added information, which would not be possible to achieve with the separate use of both techniques. Inter/intra-sector relations embedded in I-O analysis allow designing the production possibility frontier. LP models allow choosing the optimum level of activities, which cope with a certain objective, respecting the productive relations imposed by I-O analysis.

Traditional studies, which use I-O analysis in the framework of LP, generally consider a single objective function to be maximized or minimized, usually an aggregated economic indicator. However, most real-world problems inherently incorporate multiple, conflicting and incommensurable axes of evaluation of the merit of potential solutions. In this context, mathematical programming models for decision support become more representative of reality if distinct aspects of evaluation are explicitly brought into consideration.

Generally, in most real-world situations, the necessary information to specify the exact model's coefficients is not available, because data is scarce, difficult to obtain, uncertain and the system being modelled may be subject to changes. Therefore, mathematical programming models for decision support must take explicitly into account, besides multiple and conflicting objective functions, the treatment of the uncertainty associated with the model coefficients.

Interval programming is one of the approaches to tackle uncertainty in mathematical programming models, which possesses some interesting characteristics, since it does not require the specification of the probabilistic distributions (as in stochastic programming) or the possibilistic distributions (as in fuzzy programming) of the model coefficients (Oliveira and Antunes, 2007). Interval programming just assumes that information about the range of variation of some (or all) of the coefficients is available, which allows to specify an interval mathematical programming model.

In this paper, we propose a MOLP model based on I-O analysis with interval coefficients to study E3 interactions. The model herein proposed is aimed at providing the decision-maker (DM) with information about robust solutions, that is, solutions with good performance for different model coefficient settings. In the next sections, a detailed description of the model is given. Finally, some illustrative results obtained using an algorithm developed to provide decision support in MOLP problems with interval coefficients are analysed.

2. The model

In what regards to previous studies (see Oliveira and Antunes (2004), Antunes *et al.* (2002)) the model incorporates:

- recent changes in the System of National Accounts consistent with the European System of Accounts (ESA95);
- 80 (real and artificial) activity branches;
- volume and price components of the economy;
- interval coefficients for the energy use within the I-O coefficients matrix (as well as in other constraints);
- emissions not only from the combustion processes but also from other sources;
- the acidification equivalent potential (AEP) and the tropospheric ozone potential (TOP), besides the global warming potential (GWP).

The main model variables are the production of the activity sectors, the Gross Added Value (GAV), the level of employment, imports and exports, the private consumption, GDP, the public administrations' global balance, the public debt, the GWP, the AEP and the TOP. The detailed description of the variables and coefficients of the model is given in appendix.

2.1. Constraints

The intermediate consumption and final demand of goods or services of each activity sector shall not exceed the total amount available from national production and competitive imports of that same good or service:

$$\mathrm{A}\mathbf{x} + \mathbf{a}_{\mathrm{cptf}}\,(\mathrm{cptf}) + \mathbf{a}_{\mathrm{csf}}\,(\mathrm{csf}) + \mathbf{a}_{\mathrm{g}}\,(\mathrm{g}) + \mathbf{a}_{\mathrm{fbcf}}\,(\mathrm{fbcf}) + \mathbf{a}_{\mathbf{sc}}\,(\mathrm{sc}) + \mathbf{a}_{\mathrm{acov}}\,(\mathrm{acov}) + \mathbf{a}_{\mathrm{exp}}\,(\mathrm{expstcif}) \leq \mathbf{x} + \mathbf{imp}^{\mathrm{c}}, \qquad (2.1)$$

$\mathrm{cptf} \leq \mathrm{cptf}^{*}$, $\mathrm{csf}^{L} \leq \mathrm{csf} \leq \mathrm{csf}^{U}$, $\mathrm{g}^{L} \leq \mathrm{g} \leq \mathrm{g}^{U}$, $\mathrm{fbcf}^{L} \leq \mathrm{fbcf} \leq \mathrm{fbcf}^{U}$, $\mathrm{sc}^{L} \leq \mathrm{sc} \leq \mathrm{sc}^{U}$, $\mathrm{acov}^{L} \leq \mathrm{acov} \leq \mathrm{acov}^{U}$, $\mathrm{expstcif} \geq \mathrm{expstcif}^{L}$.

The households' consumption on the territory corresponds to the consumption of the resident households plus the consumption of the non-resident households on the territory:

$$\mathrm{cptf} = \mathrm{cptfr} + \mathrm{cpe}, \qquad (2.2)$$

$\mathrm{cpe} \leq \mathrm{cpe}^{*}$.

The residents' (households and non-profit institutions serving households - NPISH) consumption is considered linearly dependent on the disposable income of the residents at constant prices (deflated by the price index for consumption):

$$\mathrm{cpr} = \beta_0 + \beta_1\,(\mathrm{yd} = \frac{\mathrm{ydcorr}}{\mathrm{pcpr}}), \qquad (2.3)$$

$\mathrm{cpr} \leq \mathrm{cpr}^{*}$, $\mathrm{yd} \leq \mathrm{yd}^{*}$.

The households' consumption on the territory is obtained after deducting from the residents's consumption the tourism imports and the consumption of the NPISH:

$$\mathrm{cptfr} = \mathrm{cpr} - \mathrm{cpm} - \mathrm{csf}, \qquad (2.4)$$

$\mathrm{cptfr} \leq \mathrm{cptfr}^{*}$, $\mathrm{cpm} \leq \mathrm{cpm}^{*}$.

The tourism imports are considered as a fixed proportion (exogenously defined) of the residents' consumption:

$$\mathrm{cpm} = (\alpha)\,(\mathrm{cpr}). \qquad (2.5)$$

Total exports at constant FOB (free on board) prices are obtained after deducting the CIF/FOB adjustment to the value of total exports at CIF (cost insurance and freight) prices:

$$\mathrm{expstfob} = \mathrm{expstcif} - (\mathrm{a}_{\mathrm{ciffob}})\,(\mathrm{impstcif}), \qquad (2.6)$$

$\mathrm{expstfob} \leq \mathrm{expstfob}^{*}$,

$\mathrm{impstcif} \geq \mathrm{impstcif}^{L}$.

Exports at constant purchasers' prices are obtained by adding to the exports at constant basic prices the corresponding net taxes:

$$\mathbf{expa} = \mathbf{a}_{\mathrm{exp}}\,(\mathrm{expstcif})\;\hat{\mathbf{p}}_{\mathrm{exp}} + \mathbf{a}_{\mathrm{expts}}\,(\mathrm{expstcif}). \qquad (2.7)$$

Total exports (excluding tourism) correspond to:

$$\mathrm{expstcif} = \mathbf{e}_1^{\mathrm{T}}\,\mathbf{expa}. \qquad (2.8)$$

Total exports (including tourism) are obtained from (2.6) by adding the tourism exports:

$$\mathrm{expfob} = \mathrm{expstfob} + \mathrm{cpe}, \qquad (2.9)$$

$\mathrm{expfob} \leq \mathrm{expfob}^*$.

Total imports are obtained by adding the imports of non-energetic goods and services to the (competitive and non-competitive) imports of energy in monetary units:

$$\mathrm{impstcif} = (\mathbf{p}_{\mathrm{impc}})^{\mathbf{T}}\, \mathbf{imp}^{c} + (\mathbf{p}_{\mathrm{impnc}})^{\mathbf{T}}\, (A_{m}^{nc}\mathbf{x} + \mathbf{a}_{sc}^{nc}\, \mathrm{sc}) + \mathbf{e}_{2}^{T} A_{m}\mathbf{x} + \mathbf{e}_{3}^{T}\, \mathbf{am}_{\mathrm{cptf}}\, (\mathrm{cptf}) + \mathbf{e}_{4}^{T}\, \mathbf{am}_{\mathrm{csf}}\, (\mathrm{csf}) + \mathbf{e}_{5}^{T}\, \mathbf{am}_{g}\, (\mathrm{g}) + \mathbf{e}_{6}^{T}\, \mathbf{am}_{\mathrm{fbcf}}\, (\mathrm{fbcf}) + \mathbf{e}_{7}^{T}\, \mathbf{am}_{\mathrm{sc}}\, (\mathrm{sc}) + \mathbf{e}_{8}^{T}\, \mathbf{am}_{\mathrm{acov}}\, (\mathrm{acov}), \qquad (2.10)$$

Total imports at FOB constant prices are obtained by deducting the CIF/FOB adjustment to the total imports at CIF constant prices:

$$\mathrm{mstfob} = \mathrm{impstcif}\, (1 - a_{\mathrm{ciffob}}), \qquad (2.11)$$

$\mathrm{mstfob} \leq \mathrm{mstfob}^*$.

Total imports (including tourism) are obtained from adding (2.11) to (2.5):

$$\mathrm{mfob} = \mathrm{mstfob} + \mathrm{cpm}, \qquad (2.12)$$

$\mathrm{mfob} \leq \mathrm{mfob}^*$.

The GAV for each activity branch is obtained by multiplying the corresponding output by a product's transformation coefficient.

$$\mathrm{vab} = \mathbf{a}_{\mathrm{rem}}^{T}\, \mathbf{x} + \mathbf{a}_{\mathrm{ot}}^{T}\, \mathbf{x} - \mathbf{a}_{\mathrm{os}}^{T}\, \mathbf{x} + \mathbf{a}_{\mathrm{ebermb}}^{T}\, \mathbf{x}. \qquad (2.13)$$

The employment level for each activity branch is obtained after dividing the output by the corresponding expected labour gross productivity for each branch.

$$\mathrm{emp} = \mathbf{l}^{\mathbf{T}}\, \mathbf{x}. \qquad (2.14)$$

Net taxes on products are computed by using net tax coefficients both on the intermediate consumption and on final demand flows:

$$\mathrm{ts} = \mathbf{e}_{9}^{T} A_{ts}\, \mathbf{x} + \mathbf{e}_{10}^{T}\, \mathbf{a}_{\mathrm{cptfts}}\, (\mathrm{cptf}) + \mathbf{e}_{11}^{T}\, \mathbf{a}_{\mathrm{csfts}}\, (\mathrm{csf}) + \mathbf{e}_{12}^{T}\, \mathbf{a}_{\mathrm{gts}}\, (\mathrm{g}) + \mathbf{e}_{13}^{T}\, \mathbf{a}_{\mathrm{fbcfts}}\, (\mathrm{fbcf}) + \mathbf{e}_{14}^{T}\, \mathbf{a}_{\mathrm{scts}}\, (\mathrm{sc}) + \mathbf{e}_{15}^{T}\, \mathbf{a}_{\mathrm{acovts}}\, (\mathrm{acov}) + \mathbf{e}_{16}^{T}\, \mathbf{a}_{\mathrm{exts}}\, (\mathrm{expstcif}) + {} + \mathbf{e}_{17}^{T}\, A_{ts}^{nc}\, \mathbf{x}, \qquad (2.15)$$

$\mathrm{ts} \geq \mathrm{ts}^{L}$.

GDP can be computed according to three distinct perspectives: income approach, production approach and expenditure approach. The first two approaches are similar and only the last two are herein considered, since the intrinsic coherence of the model does not guarantee that these two definitions lead to the same results. However, the use of interval coefficients leads to different results in these two approaches. Hence, we have considered that the lower bound of GDP according to the production approach should never exceed the upper bound according to the expenditure approach, assuming that there might be a slight deviation between the interval values obtained with both approaches.

$$\mathrm{pib}_{\mathrm{prod}} = \mathrm{vab} + \mathrm{ts}, \qquad (2.16)$$

$\mathrm{pib}^{L} \leq \mathrm{pib}_{\mathrm{prod}} \leq \mathrm{pib}^*$.

$$\mathrm{pib} = \mathrm{cpr} + \mathrm{g} + \mathrm{fbcf} + \mathrm{sc} + \mathrm{acov} + \mathrm{expfob} - \mathrm{mfob}, \qquad (2.17)$$

$\mathrm{pib}^{L} \leq \mathrm{pib} \leq \mathrm{pib}^*$.

The GDP at current prices is obtained from the distinct components of GDP at constant prices according to the expenditure approach, which are multiplied by the corresponding deflators:

$$\mathrm{pibcorr} = (\mathrm{cpr})\, (\mathrm{pcpr}) + \mathrm{gcorr} + \mathrm{fbcfcorr} + (\mathrm{sc})\, (\mathrm{psc}) + (\mathrm{acov})\, (\mathrm{pacov}) + (\mathrm{expfob})\, (\mathrm{pexpfob}) - (\mathrm{mfob})\, (\mathrm{pmfob}), \qquad (2.18)$$

$\mathrm{pibcorr} \leq \mathrm{pibcorr}^*$, $\mathrm{gcorr}^L \leq \mathrm{gcorr} \leq \mathrm{gcorr}^U$, $\mathrm{fbcfcorr}^L \leq \mathrm{fbcfcorr} \leq \mathrm{fbcfcorr}^U$.

The wages and salaries can be evaluated in real terms by deflating them with an index which reflects the prices of the products purchased.

$$\mathrm{remcorr} = \mathbf{a}_{\mathrm{rem}}^T \, \mathbf{x} \, (\mathrm{iucl}), \tag{2.19}$$

$\mathrm{remcorr} \leq \mathrm{remcorr}^*$.

The disposable income of households and NPISH equals the difference between the National Available Income and the sum of the available income of corporations and public administration. The available income of the corporations (savings) represents a given (exogenous) fixed proportion of GDP.

$$\mathrm{ydcorr} = \mathrm{pibcorr}\,(1 - \mathrm{pspibcorr}) + (\mathrm{rp}^+ - \mathrm{rp}^- + \mathrm{tisub} - (\mathrm{tisub})\,\mathrm{tigts}) + \mathrm{tre} - (\mathrm{rtdydcorr})\,\mathrm{ydcorr} - (\mathrm{tdscpibcorr})\,(\mathrm{pibcorr}) - (\mathrm{tcss})\,(\mathrm{remcorr}) - \mathrm{tisub} - (\mathrm{repgpibcorr})\,(\mathrm{pibcorr}) + \mathrm{trig}\,, \tag{2.20}$$

$\mathrm{ydcorr} \leq \mathrm{ydcorr}^*$, $\mathrm{rp}^+ - \mathrm{rp}^- \leq \mathrm{rp}^*$, $\mathrm{tisub} \leq \mathrm{tisub}^*$, $(\mathrm{tisub})\,\mathrm{tigts} \leq \mathrm{tisubg}^*$, $\mathrm{tre} \leq \mathrm{tre}^*$, $(\mathrm{rtdydcorr})\,\mathrm{ydcorr} \leq \mathrm{td}^*$, $(\mathrm{tdscpibcorr})\,(\mathrm{pibcorr}) \leq \mathrm{tdsc}^*$, $(\mathrm{tcss})\,(\mathrm{remcorr}) \leq \mathrm{css}^*$, $(\mathrm{repgpibcorr})\,(\mathrm{pibcorr}) \leq \mathrm{repg}^*$, $\mathrm{trig} \leq \mathrm{trig}^*$.

Net indirect taxes at current prices are computed by using the price deflator for the consumption of households and NPISH and an index for the evolution of the indirect fiscal burden:

$$\mathrm{tisub} = (\mathrm{a}_{\mathrm{ot}}\,\mathbf{x} - \mathbf{a}_{\mathrm{os}}\,\mathbf{x} + \mathrm{ts})\,(\mathrm{pcpr})\,(\mathrm{itis}). \tag{2.21}$$

Public debt results from accumulating the previous period debt with the symmetric value of the public administrations' global balance, plus one adjustment variable, which in turn results from the variation of the debts assumed by the Treasury, net of the privatization revenues.

$$\mathrm{div} = \mathrm{div}_{-1} - (\mathrm{sgg}^+ - \mathrm{sgg}^-) + \mathrm{dat}, \tag{2.22}$$

$\mathrm{div} \leq \mathrm{div}^*$, $\mathrm{div}_{-1} \geq \mathrm{div}_{-1}^*$, $(\mathrm{sgg}^+ - \mathrm{sgg}^-) \geq \mathrm{sgg}^*$, $\mathrm{dat} \geq \mathrm{dat}^*$.

Public administration's global balance is obtained after subtracting to the public administration's revenues the public administration's expenditures:

$$(\mathrm{sgg}^+ - \mathrm{sgg}^-) = (\mathrm{rtdydcorr})\,\mathrm{ydcorr} + (\mathrm{tdscpibcorr})\,(\mathrm{pibcorr}) + (\mathrm{tcss})\,(\mathrm{remcorr}) + (\mathrm{tisub})\,(\mathrm{tigts}) + (\mathrm{repgpibcorr})\,(\mathrm{pibcorr}) - \mathrm{gcorr} - \mathrm{trig} + \mathrm{treg} - \mathrm{rg}\,(\mathrm{div}_{-1} + \mathrm{div})/2 + (\mathrm{tkpibcorr})\,(\mathrm{pibcorr}) + \mathrm{trkg} - \mathrm{gfbcf}, \tag{2.23}$$

$\mathrm{treg} \leq \mathrm{treg}^*$, $\mathrm{rg}\,(\mathrm{div}_{-1} + \mathrm{div})/2 \leq \mathrm{jurg}^*$, $(\mathrm{tkpibcorr})\,(\mathrm{pibcorr}) \leq \mathrm{tk}^*$, $\mathrm{trkg} \leq \mathrm{trkg}^*$, $\mathrm{gfbcf} \geq \mathrm{gfbcf}^*$.

In the I-O table, the total fuel use is the total amount of fuel production plus imports. Nevertheless, the energy use for exports and investment shall not be taken into account in the emission computations (Proops *et al.*, 1993).

$$\mathbf{ecco}_{\mathbf{2}\mathrm{E}} = \mathbf{f\hat{c}tj}_{\mathrm{E}}\ \ \mathbf{f\hat{e}c}_{\mathrm{E}}\ \ \mathbf{f\hat{c}o}_{\mathrm{E}}\ [\mathrm{A}_{\mathrm{E}}\mathbf{x} + \mathbf{a}_{\mathrm{cptfE}}\,\mathrm{cptf} + \mathbf{a}_{\mathrm{csfE}}\,\mathrm{csf} + \mathbf{a}_{\mathrm{gE}}\,\mathrm{g}\ - \mathrm{N}_{\mathrm{E}}\mathbf{x} + \mathbf{a}_{\mathrm{ncptfE}}\,(\mathrm{cptf}) + \mathbf{a}_{\mathrm{ncsfE}}\,(\mathrm{csf}) + \mathbf{a}_{\mathrm{ngE}}\,(\mathrm{g})]\,\left(\tfrac{44}{12}\right)(10^{-3}). \tag{2.24}$$

Total CO_2 emissions from fuel combustion are obtained by summing up all the elements in (2.24):

$$\mathrm{ecco}_2 = \mathrm{e}_{18}^{\mathrm{T}}\ \mathbf{ecco}_{\mathbf{2}\mathrm{E}}. \tag{2.25}$$

The emission factors used in the computation of other pollutant emissions (CO, NO_x, N_2O, CH_4, NMVOC, NH_3 and SO_2) are highly dependent on the technology used. From this point onwards the pollutants emitted are designated by the letter w, where w = 1 = CO, 2 = NO_x, 3 = N_2O, 4 = CH_4, 5= NMVOC, 6 = SO_2, 7 = NH_3, 8 = CO_2.

Combustion emissions from electricity generation and co-generation are computed by considering that non-energetic oil products have null emission factors.

$$ecelect_w = (\mathbf{fecelect}_w)^T\,(\mathbf{f\hat{c}tj_E}\,(A_{Eelect}\,\mathbf{x}_{elect}))\,(10^{-9}). \tag{2.26}$$

$$eccog_w = (\mathbf{feccog}_w)^T\,(\mathbf{f\hat{c}tj_E}\,(\mathbf{A}_{E.cog}\,x_{cog}))\,(10^{-9}). \tag{2.27}$$

In the computation of combustion emissions from refining activities, only the energetic oil for the refineries’ own use is taken into account.

$$ecref_w = (\mathbf{fecref}_w)^T\,(\mathbf{f\hat{c}tj_E}\,(\mathbf{A}_{E.ref} - \mathbf{N}_{E.ref})\,x_{ref}))\,(10^{-9}). \tag{2.28}$$

Combustion emissions from the industrial and construction branches should be net of the use of oil products for non-energetic purposes.

$$ecind_w = (\mathbf{fecind}_w)^T\,(\mathbf{f\hat{c}tj_E}\,(A_{Eind} - N_{Eind})\mathbf{x}_{ind})\,(10^{-9}). \tag{2.29}$$

The computation of combustion emissions in the transportation branches is based on the IPCC (1996a, 1996b, 1996c, 2006) emission factors.

$$ectr_{tw} = (\mathbf{fectr}_{tw})^T\,(\mathbf{f\hat{c}tj_E}\,(\mathbf{A}_{E.t}\,x_t))\,(10^{-9}), \tag{2.30}$$

where t = 60, 61, 62 are activity branches of the I-O matrix.

Sulphur dioxide emissions are directly linked to the sulphur content of the fuels.

$$fectr_{ctw} = (2)\,(s)\,(\frac{1}{q})\,(10^{9})\,(1 - r)\,(1 - tred). \tag{2.31}$$

In the computation of combustion emissions from the agriculture and services branches, the non-energetic oil products have null emission factors.

$$ecos_{yw} = (\mathbf{fecos}_{yw})^T\,(\mathbf{f\hat{c}tj_E}\,(\mathbf{A}_{E.y}\,x_y))\,(10^{-9}), \tag{2.32}$$

where y = 1 = agriculture and catle 2 = forests, 5 = fishing, 41 = water capturing and distribution, 50 to 55 and 63 to 93 = services.

Combustion emissions from final consumption have null emission factors for non-energetic oil products.

$$eccp_w = (\mathbf{feccp}_w)^T\,(\mathbf{f\hat{c}tj_E}\,[(\mathbf{a}_{cptfE}\,cptf) + (\mathbf{a}_{cfsE}\,csf) + (\mathbf{a}_{gE}\,g)]\,(10^{-9}). \tag{2.33}$$

Total emissions of other pollutants from fuel combustion are obtained by summing up (2.26) to (2.30) and (2.32) to (2.33):

$$ec_w = ecelect_w + eccog_w + ecref_w + ecind_w + \sum_t ectr_{t\,w} + \sum_y ecos_{y\,w} + eccp_w, \tag{2.34}$$

Indexes t and y have the range of variation referred from (2.30) to (2.32).

Fugitive emissions obtained from the transportation of crude oil are computed considering as activity the crude oil consumption in the refining sector.

$$eftpb_w = (a_{pbref}\;x_{ref})\,(fct_{pb})\,(feftpb_w)\;(10^{-9}). \tag{2.35}$$

In the computation of the fugitive emissions from refining activities, the activity considered is the output of the refining sector.

$$efpp_w = (x_{ref})\,(fefpp_w)\,(10^{-9}). \tag{2.36}$$

According to the National Inventory Emissions Report (Ferreira *et al.*, 2006), the activity considered for computing fugitive emissions is the national output of gasoline refined both for domestic and foreign markets.

$$efdist_w = (x_{gasolina})\ (fct_{gasolina})(fefdist_w)\ (10^{-9}). \tag{2.37}$$

The emissions from vehicle supply of gasoline should only include the ones resulting from vehicle supply and eventual losses of gasoline. However, since the imported gasoline can also be exported we have considered the same activity of (2.37) for the emission computations.

$$efabast_w = (x_{gasolina})\ (fct_{gasolina})\ (fefabast_w)\ (10^{-9}). \tag{2.38}$$

The activity considered for the computation of fugitive emissions from natural gas transmission is the amount of natural gas transmitted/distributed.

$$efgn_w = (\mathbf{A}_{Egn.}\ \mathbf{x} + a_{cptfgn}\, cptf + a_{csfgn}\, csf + a_{ggn}\ g)\ (fctj_{gn})\ (fefgn_w)\ (10^{-9}). \tag{2.39}$$

The activity considered for venting and flaring in the refining sector is the output level of this activity branch.

$$efvent_w = (fevent_w)\ (x_{ref})\ (10^{-9}). \tag{2.40}$$

The activity considered for computing fugitive emissions from geothermal energy is the amount of geothermal energy produced.

$$efgeot_w = (fegeot_w)\ (fctj_{geot})\ (x_{geot})\ (10^{-9}). \tag{2.41}$$

Total fugitive emissions are obtained by summing up (2.35) to (2.41):

$$ef_w = eftpb_w + efpp_w + efdist_w + efabast_w + efgn_w + efvent_w + efgeot_w. \tag{2.42}$$

The activity considered for computing emissions from industrial processes is the output level of the activity sectors.

$$epr_{jw} = (fepr_{jw})\ (x_j)\ (10^{-9}). \tag{2.43}$$

Total emissions from industrial processes are obtained by summing up the emissions of pollutant w in the different activity branches:

$$epr_w = \sum_j epr_{jw}\ . \tag{2.44}$$

Emissions referring to the use solvents (non-energetic oil) are obtained in the following way:

$$efsolv_w = (\mathbf{A}_{Esolv.}\ \mathbf{x} + a_{cptfsolv}\ cptf + a_{csfsolv}\ csf + a_{gsolv}\ g)\ (fct_{solv})\ (fefsolv_w)\ (10^{-9}). \tag{2.45}$$

Emissions regarding other products use (paint application and others) are computed according to the output levels of the activity sectors which use them.

$$efout_{jw} = (fefout_{jw})\ (x_j)\ (10^{-9}). \tag{2.46}$$

Total emissions from solvent and other products use are obtained by summing up the emissions of pollutant w in the different activity branches:

$$efsolvout_w = efsolv_w + \sum_j efout_{jw}\ . \tag{2.47}$$

The computation of emissions (where w = 1, 2, 3, 5, 6 and the components of the constraints only assume non-null values for w = 3) from manure management takes into account the system of animal waste management used:

$$egte_{rw} = (aest_{r})\ (apec_{r}\ x_{y})\ (\mathbf{agte}_{gr})^{T}\ (\mathbf{fegte}_{wg})\ (10^{-3}), \tag{2.48}$$

where r = 1 = dairy cattle, 2 = non-dairy cattle, 3 = swine for reproduction, 4 = swine, 5 = poultry, 6 = other poultry, 7 = sheep, 8 = goats, 9 = horses, 10 = mules and asses, 12 = rabbits for reproduction, g = 1 = anearobic lagoon, 2 = liquid system, 3 = solid storage, 4 = pasture range padock and y = 1.

The computation of NH_3 and CH_4 emissions (where w = 4, 7) from manure management corresponds to:

$$egte_{rw} = (fegte_{rw})\ (apec_{r}\ x_{y})\ (10^{-3}). \tag{2.49}$$

The computation of CH_4 emissions from enteric fermentation is obtained from (where the elements of the constraints have only non-null values for w = 4):

$$efent_{rw} = (fefent_{rw})\ (apec_{r}\ x_{y})\ (10^{-3}). \tag{2.50}$$

In order to obtain the NMVOC emissions from the burning of agriculture residues, the emission factors are multiplied by the total amount of agricultural residues; for the other emissions, only the dry matter fraction of agricultural residues must be taken into account.

$$eqra_{aw} = (ara_{a})\ (fseca_{a})\ (apa_{a}\ x_{y})\ (aqra_{a})\ (feqra_{aw})\ (10^{-9}), \tag{2.51}$$

where a = 1 = vineyard; 2 = orchards and fresh products, 3 = olive orchards, 4 = rice.

The emissions from the use of nitrogen fertilizers are directly linked to the application pattern of nitrogen fertilizers, according to the total cultivated area.

$$efn_{dw} = (fefn_{dw})\ (afn_{d})\ (\sum_{a=1}^{4} apa_{a}\, x_{y}\ )\ (10^{-9}). \tag{2.52}$$

where d = 1 = direct deposition, 2 = atmospheric deposition, 3 = nitrogen leaching.

Total emissions from agriculture are obtained from expressions (2.48) to (2.52).

$$eagric_{w} = \sum_{r} egte_{rw} + \sum_{r} efent_{rw} + \sum_{a} eqra_{aw} + \sum_{d} efn_{dw}\ . \tag{2.53}$$

Indexes r, a and d have the range of variation referred from (2.48) to (2.52).

Municipal solid wastes (MSW) are produced, in general, by the households and by the commerce and services sectors.

$$rsu = (arsudom)\ (cptf + csf) + (arsucomserv)\ \mathbf{e}_{19}^{T}\ (\mathbf{x}_{comserv}) + (arsu90)\ (x_{y}). \tag{2.54}$$

The amount of MSW, which goes to solid waste disposal sites (SWDS) is computed according to a fixed proportion defined exogenously:

$$rsuaterro_{u} = (rsu)\ (frsuaterro)(aresiduo_{u}). \tag{2.55}$$

where u = 1 = organic waste , 2 = paper and card, 3 = plastic, 4 = wood, 5 = glass, 6 = metals, 7 = textiles, 8 = other inerts.

Within constant conditions, the rate of CH_4 generation depends on the carbon content of the waste being disposed. NH_3 emissions are computed by replacing the CH_4 generation potential by the corresponding generation potential of NH_3 (Instituto do Ambiente *et al.*, 2004).

$$ersuaterro_{uw} = \sum_{n} [(1 - e^{-k_u})\ (rsuaterro_{un})\ (mfcrsu_{u})\ (docrsu_{u})\ (docfrsu_{u})\ (f_{w})\ (\tfrac{16}{12})\ (1 - e^{-k_u(2010-n)})](10^{-3}), \tag{2.56}$$

where w = 1, 2, 3, 5, 6, 7 and the components of the constraints only assume non-null values for w = 4, 7 and u = 1, …, 8.

NMVOC emissions are computed using the amount of CH_4 emissions generated from SWDS and the concentration of non-methane organic compounds. No co-deposition was considered for 2010.

$$\text{ersuaterro}_{uw} = [(2)\ (\text{ersuaterro}_{4u}/\text{densch4})\ (10^{6})\ (\text{cconm})\ (10^{-6})\ (\frac{(86.18)(\text{pop})}{(8.205)(10^{-5})(1000)(273+\text{top})})]\ (\text{covnm})\ (10^{-6}). \tag{2.57}$$

Since there is no data available about the amount of waste of each type assigned to anaerobic digestion, an exogenous fraction is defined for this system of waste treatment.

$$\text{ersucomp}_{w} = (\text{rsu})\ (\text{frsucomp})\ (\text{fersucomp}_{w})\ (1 - \text{redemrsu}_{w})\ (10^{-6}). \tag{2.58}$$

Only non-hazardous industrial waste is accounted for (see Insituto do Ambiente *et al.* (2004)). In what concerns to NH_3 emissions we have applied a proportionality factor between these emissions and CH_4 (similarly to Instituto do Ambiente *et al.* (2004)).

$$\text{eriborgaterro}_{w} = (\text{feriborg}_{w})\ [(\sum_{j} (\text{ari}_{j})\ (x_{j})\ (1 - \text{fripri})\ )\ (\text{fribaterro})\ (\text{friborgaterro})]\ (10^{-6}), \tag{2.59}$$

where w = 1, 2, 3, 4, 6, 7, 8 and the components of the constraints only assume non-null values for w = 4, 7 and j = 15 to 37 (activity branches of the I-O matrix).

NMVOC emissions from industrial organic waste deposition on SWDS are computed analogously to (2.57).

$$\text{eriborgaterro}_{w} = [(2)(\text{eriborgaterro}_{4}/\text{densch4})(10^{6})(\text{cconm})(10^{-6})\ (\frac{(86.18)(\text{pop})}{(8.205)(10^{-5})(1000)(273+\text{top})})]\ (\text{covnm})\ (10^{-6}), \tag{2.60}$$

where w = 5.

We have only considered the non-hazardous industrial waste incineration without energetic use, since its combustion with energetic purpose has already been considered in the electricity and co-generation combustion emissions.

$$\text{eribincin}_{w} = [(\sum_{j} (\text{ari}_{j})\ (x_{j})\ (1 - \text{fripri}))\ (\text{fribincinsve})]\ (\text{feribincin}_{w})\ (10^{-6}). \tag{2.61}$$

Emissions regarding the incineration of hospital waste are computed according to the total amount of hospital waste incinerated per unit of output of activity branch 85 (health services).

$$\text{erhincin}_{w} = (\text{arhincin}_{85})\ (x_{y})\ (\text{ferhincin}_{w})\ (10^{-6}), \tag{2.62}$$

where y = 85 and each constraint component has a null value for w = 8.

The computation of CO_2 emissions regarding waste incineration should only refer to the amount of non-biogenic waste incinerated, having mainly into account the carbon content of the waste (*e.g.* plastics and synthetic textiles).

$$\text{eresincin}_{w} = [((\text{rsu})(\text{frsuincin}) + (\sum_{j} (\text{ari}_{j})\ (x_{j})\ (1 - \text{fripri}))\ (\text{fribincin}))\ (\text{ccrsurib})\ (\text{fcfrsurib}) + (\text{arhincin}_{85})\ (x_{y})\ (\text{ccrh})\ (\text{fcfrh})]\ (\tfrac{44}{12})\ (\text{efqueima})\ (10^{-3}), \tag{2.63}$$

where each constraint component has non-null values only for w = 8.

Total emissions from waste management are obtained from (2.54) to (2.65)

$$\mathrm{eres}_{w} = \sum_{u} \mathrm{ersuaterro}_{u\,w} + \mathrm{ersucomp}_{w} + \mathrm{eriborgaterro}_{w} + \mathrm{eribincin}_{w} + {} + \mathrm{erhincin}_{w} + \mathrm{eresincin}_{w}. \tag{2.64}$$

Index u varies in the range referred in (2.55).

The computation of the degradable organic component (DOC) in domestic waste water is based on the *per capita* biochemical oxygen demand.

$$\mathrm{tow} = (\mathrm{p})\,(\mathrm{bod}). \tag{2.65}$$

In order to compute the emissions of CH_4 regarding domestic waste water handling, an emission factor per unit of DOC is applied (Ferreira *et al*., 2006).

$$\mathrm{eagdds}_{w} = (\mathrm{feagd1}_{w})\,(\mathrm{tow} - (\mathrm{ds})\,(\mathrm{tow}))\,(1 - \mathrm{recagdt}_{w}) + (\mathrm{fesd}_{w})\,(\mathrm{ds})\,(\mathrm{tow})\,(1 - \mathrm{recds}_{w})\,(10^{-6}), \tag{2.66}$$

where w = 1, 2, 4, 6 and each component has only non-null values for w = 4.

The computation of NH_3 and N_2O emissions regarding domestic waste water handling is based on the application of an emission factor per unit of Nitrogen (N) (Instituto do Ambiente *et. al*, 2004).

$$\mathrm{eagdds}_{w} = (\mathrm{feagd2}_{w})\,(\mathrm{p})\,(\mathrm{cprot})\,(\mathrm{fnpr})\,(\mathrm{fsepticas})\,(10^{-6}), \tag{2.67}$$

where w = 3, 7.

NMVOC emissions regarding domestic waste water handling are computed through the application of an emission factor per volume of waste water handled.

$$\mathrm{eagdds}_{w} = (\mathrm{feagd3}_{w})\,(\mathrm{p})\,(\mathrm{cagd})\,(\mathrm{fsaneamento})\,(10^{-6}), \tag{2.68}$$

where w = 5.

The computation of N_2O, CH_4 and NMVOC emissions from industrial waste water handling is based on a DOC value constant between 1993 and 2000, and assumed to be 33 000 in thousands of inhabitants equivalent until 2010 (see Instituto do Ambiente *et al.* (2004)).

$$\mathrm{eagind}_{w} = (\mathrm{dcind})\,(\mathrm{feagind}_{w})\,(10^{-6}), \tag{2.69}$$

where each element assumes non-null values only for w = 3, 4, 5.

Total emissions of CO

$$\mathrm{etco} = \mathrm{ec}_{w} + \mathrm{ef}_{w} + \mathrm{epr}_{w} + \mathrm{efsolvout}_{w} + \mathrm{eagric}_{w} + \mathrm{eres}_{w} + \mathrm{eagdds}_{w} + {} + \mathrm{eagind}_{w}, \tag{2.70}$$

$\mathrm{etco} \le \mathrm{etco}^{U}$,

where w = 1.

Total emissions of NO_x

$$\mathrm{etnox} = \mathrm{ec}_{w} + \mathrm{ef}_{w} + \mathrm{epr}_{w} + \mathrm{efsolvout}_{w} + \mathrm{eagric}_{w} + \mathrm{eres}_{w} + \mathrm{eagdds}_{w} + {} + \mathrm{eagind}_{w} \tag{2.71}$$

$\mathrm{etnox} \le \mathrm{etnox}^{U}$,

where w = 2.

Total emissions of N_2O

$$\mathrm{etn2o} = \mathrm{ec}_{w} + \mathrm{ef}_{w} + \mathrm{epr}_{w} + \mathrm{efsolvout}_{w} + \mathrm{eagric}_{w} + \mathrm{eres}_{w} + \mathrm{eagdds}_{w} + {} + \mathrm{eagind}_{w}, \tag{2.72}$$

$etn2o \leq etn2o^U$,

where $w = 3$.

Total emissions of *CH_4*

$$etch4 = ec_w + ef_w + epr_w + efsolvout_w + eagric_w + eres_w + eagdds_w + \\ + eagind_w, \tag{2.73}$$

$etch4 \leq etch4^U$,

where $w = 4$.

Total emissions of *NMVOC*

$$etcovnm = ec_w + ef_w + epr_w + efsolvout_w + eagric_w + eres_w + eagdds_w + \\ + eagind_w, \tag{2.74}$$

$etcovnm \leq etcovnm^U$,

where $w = 5$.

Total emissions of *SO_2*

$$etso2 = ec_w + ef_w + epr_w + efsolvout_w + eagric_w + eres_w + eagdds_w + \\ + eagind_w, \tag{2.75}$$

$etso2 \leq etso2^U$,

where $w = 6$.

Total emissions of *NH_3*

$$etnh3 = ec_w + ef_w + epr_w + efsolvout_w + eagric_w + eres_w + eagdds_w + \\ + eagind_w, \tag{2.76}$$

$etnh3 \leq etnh3^U$,

where $w = 7$.

Total emissions of *CO_2*

$$etco_2 = ecco_2 + ef_w + epr_w + efsolvout_w + eres_w, \tag{2.77}$$

$etco_2 \leq etco2^U$,

where $w = 8$.

The most relevant gases leading to GHG emissions (CO_2, CH_4 e N_2O) and excluding land use changes, are obtained in the following way (Instituto do Ambiente, 2005):

$$pag = etco2 + (310)\ (etn2o) + (21)\ (etch4), \tag{2.78}$$

$pag \leq pag^U$.

SO_2, NO_x and NH_3 emissions are aggregated in an "equivalent acid" indicator after assigning each specific pollutant to a certain weight factor (Instituto do Ambiente, 2005):

$$eac = (21.74)\ etnox + (31.25)\ etso2 + (58.82)\ etnh3, \tag{2.79}$$

$eac \leq eac^U$.

The tropospheric ozone is an indicator which allows the aggregation of NO_x, NMVOC, CO and CH_4 emissions after assigning to each one of them a specific weight factor, being measured in NMVOC equivalent (Instituto do Ambiente, 2005).

$$pfot = (1.22)\ (etnox) + etcovnm + (0.11)(etco) + (0.014)\ (etch4), \tag{2.80}$$

$pfot \leq pfot^U$.

2.2. Objective functions

The allocation of energetic resources should be made having in mind that the energy sector is a part of the economic system as a whole and that energy planning requires the incorporation of economic, social, energetic and environmental objectives. In this way, the model herein proposed considers the following objective functions.

GDP can be seen as a measure of the economic performance to be maximized:

$$\max Z_1 = \mathrm{pib}. \tag{2.81}$$

The total level of employment in the economy might be faced as a measure of social well-being to be maximized:

$$\max Z_2 = \mathrm{emp}. \tag{2.82}$$

The minimization of the impact of economic activities in the GWP, measured through the emission of GHG, leads to the consideration of the following objective function:

$$\min Z_3 = \mathrm{pag}. \tag{2.83}$$

Since the country presents a strong foreighn energy dependency, the minimization of energy imports has been considered:

$$\min Z_4 = (\mathbf{e}_{20})^{\mathbf{T}}\, \mathbf{imp}^{\mathrm{c}} + (\mathbf{e}_{21})^{\mathbf{T}}\, (\mathrm{A}_{\mathrm{m}}{}^{\mathrm{nc}}\mathbf{x} + \mathbf{a}_{\mathrm{sc}}{}^{\mathrm{nc}}\ \mathrm{sc}). \tag{2.84}$$

3. The interactive method

The interactive approach used to obtain compromise solutions to the MOLP model based on I-O analysis with interval coefficients herein suggested is based on Oliveira and Antunes (2009).

Let the MOLP problem with interval coefficients be given, without loss of generality, by:

$$\begin{aligned}
&\max \mathrm{Z}_{\mathrm{k}}(\mathbf{x}) = \sum_{\mathrm{j}=1}^{\mathrm{n}} \left[c_{\mathrm{kj}}^{\mathrm{L}},\ c_{\mathrm{kj}}^{\mathrm{U}}\right] \mathrm{x}_{\mathrm{j}},\ \mathrm{k} = 1, \ldots, \mathrm{p},\\
&\text{s.t. } \sum_{\mathrm{j}=1}^{\mathrm{n}} \left[a_{\mathrm{ij}}^{\mathrm{L}},\ a_{\mathrm{ij}}^{\mathrm{U}}\right] \mathrm{x}_{\mathrm{j}} \le \left[b_{\mathrm{i}}^{\mathrm{L}},\ b_{\mathrm{i}}^{\mathrm{U}}\right],\ \mathrm{i} = 1, \ldots, \mathrm{m},\\
&\mathrm{x}_{\mathrm{j}} \ge 0,\ \mathrm{j} = 1, \ldots, \mathrm{n},
\end{aligned} \tag{2.85}$$

where $\left[c_{\mathrm{kj}}^{\mathrm{L}},\ c_{\mathrm{kj}}^{\mathrm{U}}\right]$, $\left[a_{\mathrm{ij}}^{\mathrm{L}},\ a_{\mathrm{ij}}^{\mathrm{U}}\right]$ and $\left[b_{\mathrm{i}}^{\mathrm{L}},\ b_{\mathrm{i}}^{\mathrm{U}}\right]$, k = 1, …, p, j = 1, …, n and i = 1, …, m, are closed intervals.

The method starts by obtaining two surrogate deterministic problems, by considering the minimization of the worst possible deviation of the interval objective functions from their corresponding interval ideal solutions (see Inuiguchi and Kume (1991)) and considering satisfaction levels on the constraints (see Urli and Nadeau (1992)). The interval ideal solutions are computed considering both the extreme versions of the objective functions and of the feasible region (Chinneck and Ramadan, 2000). Hence, the surrogate problem is:

$$\begin{aligned}
&\min \max_{\mathrm{k}=1,\ldots,\mathrm{p}} \lambda_{\mathrm{k}}\, \mathrm{D}_{\mathrm{k}}(\mathbf{x}),\\
&\text{s.t. } \sum_{\mathrm{j}=1}^{\mathrm{n}} (a_{\mathrm{ij}}^{\mathrm{L}} + \alpha_{\mathrm{i}}(a_{\mathrm{ij}}^{\mathrm{U}} - a_{\mathrm{ij}}^{\mathrm{L}}))\, \mathrm{x}_{\mathrm{j}} \le b_{\mathrm{i}}^{\mathrm{U}} - \alpha_{\mathrm{i}}(b_{\mathrm{i}}^{\mathrm{U}} - b_{\mathrm{i}}^{\mathrm{L}}),\ \mathrm{i} = 1, \ldots, \mathrm{m},\\
&\mathrm{x}_{\mathrm{j}} \ge 0,\ \mathrm{j} = 1, \ldots, \mathrm{n},
\end{aligned} \tag{2.86}$$

where $D_k(\mathbf{x}) = |[Z_k^{L^*} - Z_k^U(\mathbf{x}), Z_k^{U^*} - Z_k^L(\mathbf{x})]|$, $Z_k^{L^*}$ is the optimum with the worst set of coefficients and $Z_k^{U^*}$ is the optimum with the best set of coefficients for $Z_k(\mathbf{x})$, $Z_k^U(\mathbf{x})$ and $Z_k^L(\mathbf{x})$ are the upper and lower bounds of $Z_k(\mathbf{x})$, respectively, and λ_k is a coefficient to take into account the different orders of magnitude of the objective function values. The expanded trade-off table is composed of two parts: one for $\alpha_i = 0$ ($\forall_i$, i.e. the broadest feasible region) and another for $\alpha_i = 1$ ($\forall_i$, i.e. the narrowest feasible region).

Let $\varepsilon_k = Z_k^{L^*} - Z_k^U(\mathbf{x})$ and $\varepsilon_k = \varepsilon_k^+ - \varepsilon_k^-$, $\varepsilon_k^+, \varepsilon_k^- \geq 0$. In order to obtain the first compromise solution, the DM starts by considering the most constraining feasible region. Let the first compromise solutions be given by $\mathbf{x}^{1U'}$ and $\mathbf{x}^{1U''}$, which are obtained from the two surrogate deterministic problems obtained from (2.85), according to pessimistic or optimistic perspectives, in case the DM wants to minimize the upper bound or the lower bound of the worst possible deviation, respectively. If the first compromise solution satisfies the DM, then the algorithm stops and the solution $\mathbf{x}^{1U'}$ or $\mathbf{x}^{1U''}$ is chosen; otherwise, the algorithm proceeds. The other compromise solutions are given by $\mathbf{x}^m = \mathbf{x}^{mU'}$ and/or $\mathbf{x}^{mU''}$. The interactive phases are described next.

For each compromise solution obtained, the following data is shown to the DM:

1) $Z_k(\mathbf{x}^m)$, $m[Z_k(\mathbf{x}^m)] = \frac{(Z_k^U(\mathbf{x}^m)+Z_k^L(\mathbf{x}^m))}{2}$ (the centre of the interval) and $w[Z_k(\mathbf{x}^m)] = Z_k^U(\mathbf{x}^m) - Z_k^L(\mathbf{x}^m)$ (the width of the interval);

2) $d(Z_k^*, Z_k(\mathbf{x}^m)) = \text{Max}\,(|Z_k^L{}^* - Z_k^L(\mathbf{x}^m)|, |Z_k^U{}^* - Z_k^U(\mathbf{x}^m)|)$, $k = 1, \ldots, p$, and the "acceptability index" (see Sengupta e Pal (2000)) of $Z_k(\mathbf{x})$ being inferior to Z_k^*, $A\,(Z_k(\mathbf{x}^m) \prec Z_k^*) = \frac{(m[Z_k^{L*}] - m[Z_k(\mathbf{x}^m)])}{(\frac{w[Z_k^{L*}]}{2} + \frac{w[Z_k(\mathbf{x}^m)]}{2})}$. When $A\,(Z_k(\mathbf{x}^m) \prec Z_k^*)$ and $d(Z_k^*, Z_k(\mathbf{x}^m))$ are close to zero, $Z_k(\mathbf{x}^m)$ is closer to Z_k^*.

3) The achievement rate of $Z_k(\mathbf{x}^m)$ and $Z_k(\mathbf{x}^m)$ with respect to Z_k^*. The achievement rate is $tc_k^L = 1 - \frac{(Z_k^{L*} - Z_k^L(\mathbf{x}^m))}{(Z_k^{L*} - m_k^L)}$, with respect to $Z_k^L(\mathbf{x}^m)$, and it is $tc_k^U = 1 - \frac{(Z_k^{U*} - Z_k^U(\mathbf{x}^m))}{(Z_k^{U*} - m_k^U)}$, with respect to $Z_k^U(\mathbf{x}^m)$, where m_k^L and m_k^U are the worst optimum values obtained in the expanded trade-off table. The closer the values of tc_k^L and tc_k^U are to 1 the closer the DM is to meet its aspiration level Z_k^*. In general, $0 < tc_k^U < 1$; however, tc_k^L may be greater than 1, namely when α_i is relaxed. In this situation, a value superior to 1 corresponds to a deviation from the goal considered and not to an improvement of the achievement rate solution.

4) The impact of different values for α_i on the compromise solution.

After providing this information to the DM, he/she is asked to reveal his/her satisfaction regarding the solution being analysed. If the DM is not yet satisfied with the solution obtained, then the algorithm proceeds. The DM is then asked to choose the objective function he/she wishes to improve. If the problem obtained with the additional constraints has an empty feasible region, then information is provided on the amount he/she should relax the different objective reference values, in order to restore feasibility (see Chinneck and Dravnieks (1991)). In this phase the DM can also choose the objective function(s) he/she is willing to relax in order to improve the other objective function(s) and solve the problem with the additional constraints. If the DM wants to have a sensitivity measure of the efficient basis obtained for simultaneous and independent changes of the reference values considered for the objective functions, then the ranges of variation of these reference values should be computed according to the individual tolerance range approach (Wondolowski, 1991). On the other hand, if the DM wishes to have a sensitivity measure of the efficient basis obtained when changes occur in only one reference value for one objective function, then the range of variation of this reference value should be computed according to sensitivity analysis techniques (see Gal (1979)). In each case, the DM might choose new reference values within the ranges of variation computed or outside these ranges, knowing that in the last option the efficient basis will be changed. The main advantage of these procedures lies on the fact that it is no longer necessary to solve the entire problem all over again in order to obtain a new solution. The impacts of different thresholds on the constraints on the compromise solution may also be shown, allowing the DM to analyse distinct solutions with different coefficient settings. The exhaustiveness of the solution search process depends on the DM, who may decide to end the procedure when he/she considers to have gathered enough information about the problem.

4. Some illustrative results

In order to obtain the compromise solutions which best suit the preference structure of a real or hipothetical DM, we have started our analysis by computing the individual optima of each objective function with the best and worst case scenarios, respectively. The solutions obtained are given by $\mathbf{x}_k^\beta$, k = 1, 2, ..., 4 and $\beta = 0, 1$. This information is then displayed in Table 1.

Table. 1. Values of $Z_k^L(\mathbf{x}_k^\beta)$ e $Z_k^U(\mathbf{x}_k^\beta)$.

	$\mathbf{x}_1^0$	$\mathbf{x}_1^1$	$\mathbf{x}_2^0$	$\mathbf{x}_2^1$	$\mathbf{x}_3^0$	$\mathbf{x}_3^1$	$\mathbf{x}_4^0$	$\mathbf{x}_4^1$
$Z_1^U(\mathbf{x}_k^\beta)$	**130 351**	117 263	112 171	115 204	108 030	114 962	108 030	114 962
$Z_1^L(\mathbf{x}_k^\beta)$	122 134	**110 316**	105 147	108 030	101 272	108 030	101 302	108 030
$Z_2^U(\mathbf{x}_k^\beta)$	4 596	4 472	**5 641**	4 591	4 961	4 419	4 897	4 419
$Z_2^L(\mathbf{x}_k^\beta)$	4 596	4 472	5 641	**4 591**	4 961	4 419	4 897	4 419
$Z_3^U(\mathbf{x}_k^\beta)$	-69 061	-66 151	-61 974	-65 390	**-55 588**	-64 388	-55 594	-64 388
$Z_3^L(\mathbf{x}_k^\beta)$	-85 313	-82 024	-75 870	-81 243	-68 408	**-79 790**	-68 414	-79 790
$Z_4^U(\mathbf{x}_k^\beta)$	-22 787 991	-25 528 036	-20 025 728	-25 329 726	-18 881 045	-24 811 733	**-18 880 820**	-24 811 733
$Z_4^L(\mathbf{x}_k^\beta)$	-22 787 991	-25 528 036	-20 025 728	-25 329 726	-18 881 045	-24 811 733	-18 880 820	**-24 811 733**

The surrogate model of the original interval MOLP model is obtained by considering the minimization of the worst possible deviation of each interval objective function regarding each interval ideal solution (see the diagonal values on Table 1). The solution search process was driven by a hypothetical DM, which has a conservative stance and starts the solution search process by considering the model formulation which minimizes the upper bound of the worst possible deviation.

In order to obtain a global overview of the model with this formulation we have started our analysis by considering four coefficient settings with satisfaction thresholds on the constraints of 1, 0.8, 0.5 and 0, respectively.

The solutions obtained are briefly characterized as follows.

Solution $\mathbf{x}^{1U''}$, obtained with the most constrained version of the feasible region, allows achieving the worst optimum of GWP and energy imports (solutions $\mathbf{x}_3^1$ and $\mathbf{x}_4^1$).

Solution $\mathbf{x}^{2U''}$, obtained with a relatively constrained coefficients setting, allows improving the upper bounds on the environment and energy objectives (regarding the previous solution). However, the lower bounds of these objective functions are now farther from the lower bounds of the corresponding interval ideal solutions (the achievement rates of the lower bounds of these objective functions are now higher than one). Nevertheless, from the acceptability index and the distance between intervals, it might be concluded that the interval objective functions regarding energetic and environmental concerns (GWP) and the corresponding interval ideal solutions are now closer. On the other hand, the economic (GDP) and social (employment) axes of evaluation have lower values, having in the last situation both achievement rates with negative values (Table 2). This situation might occur, since the minimum of each objective function in the trade-off table is a convenient minimum and it might not be the real minimum of the objective function in the feasible region.

Table 2. Information regarding solution $\mathbf{x}^{2U''}$.

	$Z_k^L(\mathbf{x}^{2U''})$	$Z_k^U(\mathbf{x}^{2U''})$	$m[Z_k(\mathbf{x}^{2U''})]$	$w[Z_k(\mathbf{x}^{2U''})]$	$\mathcal{A}(Z_k(\mathbf{x}^{2U''}) \prec Z_k^*)$	$d(Z_k^*, Z_k(\mathbf{x}^{2U''}))$	tc_k^L	tc_k^U
Z_1	106 668	113 478	110 073	6 810	0.76	16 872.82	0.60	0.24
Z_2	4 363	4 363	4 363	0	1.43	1 278.36	-0.33	-0.05
Z_3	-77 116	-62 362	-69 739	14 753	0.11	6 774.39	1.48	0.50
Z_4	-23 399 299	-23 399 299	-23 399 299	0	0.52	4 518 479.40	2.97	0.32

Solution $\mathbf{x}^{3U''}$, obtained with an intermediate coefficients setting, allows improving the upper bounds of the environmental and energetic objectives, regarding the two solutions previously analysed. However, the lower bounds of these objective functions regarding the lower bounds of their corresponding interval ideal solutions are now more distant. Nevertheless, from the acceptability index (with values near zero) and the distance between intervals, we may conclude that the interval objective functions and the corresponding interval ideal solutions are closer. On the other hand, the economic and social axes of evaluation are worsened (Table 3).

Table 3. Information regarding solution $\mathbf{x}^{3U''}$.

	$Z_k^L(\mathbf{x}^{3U''})$	$Z_k^U(\mathbf{x}^{3U''})$	$m[Z_k(\mathbf{x}^{3U''})]$	$w[Z_k(\mathbf{x}^{3U''})]$	$\mathcal{A}(Z_k(\mathbf{x}^{3U''}) \prec Z_k^*)$	$d(Z_k^*, Z_k(\mathbf{x}^{3U''}))$	Tc_k^L	tc_k^U
Z_1	104 534	111 526	108 030	6 992	0.91	18 825.05	0.36	0.16
Z_2	4 263	4 263	4 263	0	1.63	1 378.33	-0.91	-0.13
Z_3	-74 710	-60 669	-67 689	14 041	0.00	5 080.98	1.92	0.62
Z_4	-21 662 240	-21 662 240	-21 662 240	0	-0.06	3 149 962.63	5.40	0.58

Solution $\mathbf{x}^{4U''}$, obtained with a less constrained coefficients setting, allows improving the upper and lower bounds of GDP, regarding the previous solutions, enabling it to be closer to its interval ideal solution (the values of the acceptability index and of the distance between intervals are now lower – see Table 4). On the other hand, the level of employment reaches its worst optimum value (optimum value obtained with the worst coefficients setting), leading to an improvement of both achievement rates. Nevertheless, these solutions are not dominated from the point of view of the achievement rates of the objective functions. In fact, in what concerns the results obtained in solution $\mathbf{x}^{4U''}$, in solution $\mathbf{x}_2^1$, the achievement rates of GDP are deteriorated in both bounds; however, the achievement rates of the lower bounds of GWP (0.74) and energy imports (0.28) are now closer to one in absolute terms.

Table 4. Information regarding solution $\mathbf{x}^{4U''}$.

	$Z_k^L(\mathbf{x}^{4U''})$	$Z_k^U(\mathbf{x}^{4U''})$	$m[Z_k(\mathbf{x}^{4U''})]$	$w[Z_k(\mathbf{x}^{4U''})]$	$\mathcal{A}(Z_k(\mathbf{x}^{4U''}) \prec Z_k^*)$	$d(Z_k^*, Z_k(\mathbf{x}^{4U''}))$	tc_k^L	tc_k^U
Z_1	109 544	116 213	112 879	6 669	0.56	14 137.66	0.91	0.37
Z_2	4 591	4 591	4 591	0	1.00	1 049.56	1.00	0.14
Z_3	-77 296	-62 098	-69 697	15 198	0.10	6 510.49	1.45	0.52
Z_4	-21 935 126	-21 935 126	-21 935 126	0	0.03	3 054 306.36	5.02	0.54

Admitting that the DM does not consider any of the solutions obtained so far as satisfactory, the quest for new solution continues. Suppose that the DM wants to evaluate what would happen if he/she adopts a more optimistic stance. Hence, new solutions are obtained by considering three coefficient settings with the following thresholds on the constraints: 1, 0.5 and 0, corresponding to $\mathbf{x}^{1U'}$, $\mathbf{x}^{2U'}$ and $\mathbf{x}^{3U'}$, respectively. Regarding these solutions: solution $\mathbf{x}^{1U'}$ is the one with the best environmental results and the worst energy imports, economic and social results; solution $\mathbf{x}^{2U'}$ allows obtaining the worst environmental outcomes (particularly in what concerns to AEP, TOP and to GWP with the most favorable version of the coefficients setting) and the worst performance of the public global balance, but the best economic and social effects; solution $\mathbf{x}^{3U'}$ is the one which allows the best performance for the public global balance and the worst values for GWP in its less favorable version and the lower level of energy imports.

Suppose that the DM wishes to analyse the solutions obtained by combining situations more/less favorable in the scope of the energy coefficients settings (reduction/increase of the energy consumption coefficients) with the environmental and economic coefficients at their central values. Solution $\mathbf{x}^{4U'}$ and solution $\mathbf{x}^{5U'}$ are obtained with the most and less favorable version of energy consumption coefficients, respectively. The results obtained in these solutions indicate that the reduction of the energy consumption coefficients (therefore, the improvement of energy consumption efficiency) leads to a positive impulse on the economic growth (with the corresponding environmental impacts) and on the employment in a more energy efficient way, that is with a lower requirement for energy imports.

Let us now suppose that the DM wants to review its solution search process, by adopting once more a conservative stance, but imposing minimum values to the lower bounds of GDP, GWP and energy imports with the coefficients setting of solution $\mathbf{x}^{3U''}$ (threshold on the constraints of 0.5). Hence, the following constraints are added to the model:

$Z_1^L(\mathbf{x}) \geq 120\,000$, $Z_3^L(\mathbf{x}) \geq -76\,022$, $Z_4^L(\mathbf{x}) \geq -18\,881$.

With this coefficients setting, the additional constraints lead to an empty feasible region. Hence, an elastic LP problem is solved and a new solution ($\mathbf{x}^{5U''}$) is obtained. Thus, regarding solution $\mathbf{x}^{3U''}$ there is a slight improvement of the lower bound of GDP, of the level of employment (which has the same value of its worst optimum), of the upper bound of GWP and of the upper bound of energy imports. Although this solution allows obtaining the individual optimum of the level of employment with the less favorable version of the coefficients of the model, this solution is not dominated from the point of view of the achievement rates of the objective functions (the same might be said about $\mathbf{x}^{4U''}$) since it corresponds to higher outcomes on the environmental and energetic plans. On the other hand, the best results of GWP and energy imports are obtained when compared to the other solutions analysed so far (see Figure 1).

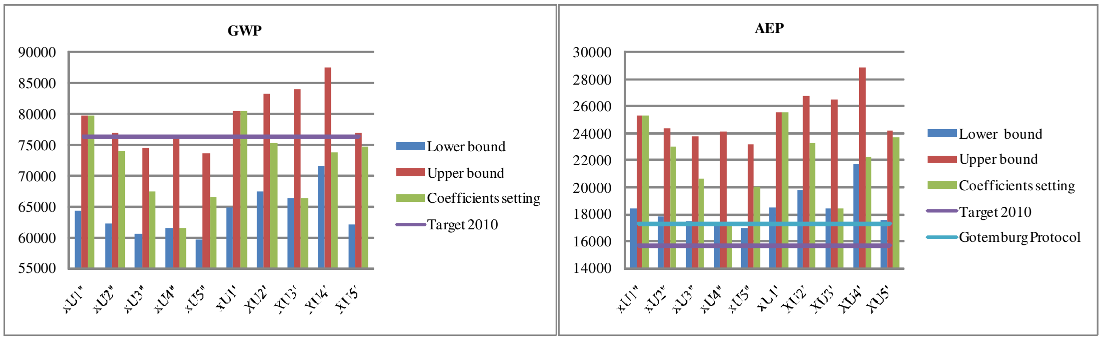

Figure 1. Ranges of variation GWP and AEP in the solutions analysed.

The solution search process stops when the DM considers to have gathered enough information on the problem.

5. Final remarks

Traditionally the I-O modeling approach has omitted any sources of uncertainty. The inter/intra industrial linkages have generally been viewed as static and deterministic. This paper proposes a MOLP model based on I-O analysis, which allows the analysts/DMs to assess impacts on the economy at a macroeconomic level, the environment and the energy system, based on the levels of activity of industrial sectors, in a situation of uncertain data modeled through interval coefficients. The aim is to provide information regarding robust solutions, that is, efficient solutions which attain desired levels for the objective functions across a set of plausible scenarios. The solution search process has been driven by considering a hypothetical DM which expresses his/her preferences regarding the information presented. In this case, we have opted to perform the solution search process by considering distinct decision alternatives according to a more or less conservative stance of the DM. By analyzing globally the solutions obtained with both formulations we can conclude that, in general, the more conservative stance allows obtaining better results for the energetic and environmental objectives; on the other hand, with the less conservative stance better outcomes are obtained for the economic and social concerns. All the solutions obtained indicate the need to reduce the energy intensity of the economy in order to overcome the deficit regarding the Kyoto Protocol fulfillment. Then again, it might be said that the improvement of energy efficiency is not enough to attain the necessary emissions reduction in order to achieve the targets imposed on the acidifying substances, being necessary to operate substantial changes namely on the electricity generation sector.

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Appendix

Variable	Description	Unit	Expression
x	Vector of total output for each branch.	10^6 euros (at constant basic prices) or toe.	(2.1), (2.10), (2.13), (2.14), (2.15), (2.19), (2.21), (2.24), (2.39), (2.45), (2.84)
imp^c	Vector of competitive imports. The elements which correspond to non-energetic goods or services have null value.	toe	(2.1), (2.10), (2.84)
cptf	Total consumption of the resident and non-resident households on the territory.	10^6 euros (at constant purchasers' prices).	(2.1), (2.2), (2.10), (2.15), (2.24), (2.33), (2.39), (2.45), (2.54)
csf	Total consumption of the NPISH.	10^6 euros (at constant purchasers' prices).	(2.1), (2.4), (2.10), (2.15), (2.24), (2.33), (2.39), (2.45), (2.54)
g	Total public consumption	10^6 euros (at constant purchasers' prices).	(2.1), (2.10), (2.15), (2.17), (2.24), (2.33), (2.39), (2.45)
fbcf	Total gross fixed capital formation – GFCF.	10^6 euros (at constant purchasers' prices).	(2.1), (2.10), (2.15), (2.17)
sc	Total changes in inventories.	10^6 euros (at constant purchasers' prices).	(2.1), (2.10), (2.15), (2.17), (2.18), (2.84)
acov	Acquisitions less disposals of valuables – ALDV.	10^6 euros (at constant purchasers' prices).	(2.1), (2.10), (2.15), (2.17), (2.18)
expstcif	Total exports at purchasers' CIF prices (excluding tourism).	10^6 euros (at CIF constant prices).	(2.1), (2.6), (2.7), (2.8), (2.15)
cptfr	Total consumption of the resident households on the territory.	10^6 euros (at constant purchasers' prices).	(2.2), (2.4)
cpe	Total consumption of the non-resident households on the territory (tourism exports).	10^6 euros (at constant prices).	(2.2), (2.9)
cpr	Total consumption of resident households and NPISH.	10^6 euros (at constant purchasers' prices).	(2.3), (2.4), (2.5), (2.17), (2.18)
yd	Disposable income of the households and NPISH.	10^6 euros (at constant prices).	(2.3)
ydcorr	Disposable income of the households and NPISH.	10^6 euros (at current prices).	(2.3), (2.20), (2.23)
pcpr	Price deflator for the consumption of households and NPISH (interval exogenous variable).	Allows converting constant prices into current prices	(2.3), (2.18), (2.21)
cpm	Private consumption of the resident households out of the territory (tourism imports).	10^6 euros (at constant prices).	(2.4), (2.5), (2.12)
expstfob	Total exports at FOB purchasers' prices (excluding tourism).	10^6 euros (at constant FOB prices).	(2.6), (2.9)
impstcif	Total imports at CIF basic prices (excluding tourism).	10^6 euros (at constant CIF prices).	(2.6), (2.10), (2.11)
expa	Vector of exports of goods or services (excluding tourism) at CIF purchasers' prices.	10^6 euros (at constant CIF prices).	(2.7), (2.8)
expfob	Total exports at FOB purchasers' prices (including tourism).	10^6 euros (at constant FOB prices).	(2.9), (2.17), (2.18)
mstfob	Total imports at FOB prices (excluding tourism).	10^6 euros (at constant FOB prices).	(2.11), (2.12)
mfob	Total imports at FOB prices (including tourism).	10^6 euros (at constant FOB prices).	(2.12), (2.17), (2.18)
vab	Gross Added Value (GAV).	10^6 euros (at basic constant prices).	(2.13), (2.16)
emp	Employment level.	10^3 full-time equivalent persons.	(2.14), (2.82)
ts	Net taxes on goods and services.	10^6 euros (at constant prices).	(2.15), (2.16), (2.21)
pib$_{prod}$	GDP at constant market prices (production approach).	10^6 euros (at constant prices).	(2.16)
pib	GDP at constant market prices (expenditure approach).	10^6 euros (at constant prices).	(2.17), (2.81)
pibcorr	GDP at current market prices.	10^6 euros (at current prices).	(2.18), (2.20), (2.23)
gcorr	Public consumption	10^6 euros (at current prices).	(2.18), (2.23)
fbcfcorr	GFCF.	10^6 euros (at current prices).	(2.18)
psc	Price deflator for changes in inventories (interval exogenous variable).	n.a.	(2.18)
pacov	Price deflator for ALDV (interval exogenous variable).	n.a.	(2.18)

Variable	Description	Unit	Expression
pexpfob	Price deflator for total exports at FOB prices (interval exogenous variable).	n.a.	(2.18)
pmfob	Price deflator for total imports at FOB prices (interval exogenous variable).	n.a.	(2.18)
remcorr	Wages and salaries.	10^6 euros (at current prices).	(2.19), (2.20), (2.23)
iucl	Index of the unitary labor costs (interval exogenous variable).	n.a.	(2.19)
$rp^+ - rp^-$	Balance of primary incomes with the rest of the world.	10^6 euros (at current prices).	(2.20)
tisub	Total indirect taxes.	10^6 euros (at current prices).	(2.20), (2.21), (2.23)
tre	Balance of private transfers with the rest of the world.	10^6 euros (at current prices).	(2.20)
trig	Balance of internal transfers from the public administrations to households.	10^6 euros (at current prices).	(2.20), (2.23)
itis	Index of the average indirect tax rate (exogenous interval variable).	n.a.	(2.21)
div	Public debt.	10^6 euros (at current prices).	(2.22), (2.23)
div_{-1}	Public debt of the previous period.	10^6 euros (at current prices).	(2.22), (2.23)
$(sgg^+ - sgg^-)$	Public balance.	10^6 euros (at current prices).	(2.22), (2.23)
dat	Public debt adjustment.	10^6 euros (at current prices).	(2.22)
rg	Public debt interest rate (exogenous interval variable)	%	(2.23)
treg	Balance of public transfers with the rest of the world.	10^6 euros (at current prices).	(2.23)
trkg	Balance of the public capital transfers.	10^6 euros (at current prices).	(2.23)
gfbcf	Public investment on GFCF.	10^6 euros (at current prices).	(2.23)
$\mathbf{ecco_{2E}}$	Vector of total CO_2 emissions from fuel combustion by energy type.	Gg.	(2.24), (2.25)
$ecco_2$	Total CO_2 emissions from fuel combustion.	Gg	(2.25), (2.77)
$ecelect_w$	Total emissions of pollutant w (excluding CO_2) from energy combustion in electricity generation.	Gg	(2.26), (2.34)
$\mathbf{x}_{elect}$	Sub-vector of **x** with the output of electricity for each electricity generation type (excluding co-generation).	toe	(2.26)
$eccog_w$	Total emissions of pollutant w (excluding CO_2) from energy combustion in co-generation.	Gg	(2.27), (2.34)
x_{cog}	Element of **x** with the output of co-generation.	toe	(2.27)
$ecref_w$	Total emissions of pollutant w (excluding CO_2) from energy combustion in refineries.	Gg	(2.28), (2.34)
x_{ref}	Element of **x** with the output of refineries.	toe	(2.28), (2.35), (2.36), (2.40)
$ecind_w$	Total emissions of pollutant w (excluding CO_2) from energy combustion in the industrial and construction branches.	Gg	(2.29), (2.34)
$\mathbf{x}_{ind}$	Sub-vector of **x** with the output of industrial and construction branches.	10^6 euros (at constant basic prices).	(2.29)
$ectr_{tw}$	Emissions of pollutant w (excluding CO_2) from energy combustion in the transportation branches t (t = 60 = road and rail, 61 = maritime, 62 = air).	Gg	(2.30), (2.34)
x_t	Element of **x** with the output of transportation branch t.	10^6 euros (at constant basic prices).	(2.30)
$ecos_{yw}$	Emissions of pollutant w (excluding CO_2) from energy combustion in branch y.	Gg	(2.32), (2.34)
x_y	Element of **x** with the output of branch y.	10^6 euros (at constant basic prices).	(2.32), (2.48), (2.49), (2.50), (2.51), (2.52), (2.54), (2.62), (2.63)
$eccp_w$	Emissions of pollutant w (excluding CO_2) from energy combustion in final consumption.	Gg	(2.33), (2.34)
ec_w	Total emissions of pollutant w (excluding CO_2) from energy combustion.	Gg.	(2.34), (2.70), (2.71), (2.72), (2.73), (2.74), (2.75), (2.76)
$eftpb_w$	Fugitive emissions of pollutant w from the distribution, storage and processing of crude oil.	Gg	(2.35), (2.42)
$efpp_w$	Fugitive emissions of pollutant w from the processing of oil products.	Gg	(2.36), (2.42)
$efdist_w$	Fugitive emissions of pollutant w from the sales of gasoline.	Gg	(2.37), (2.42)
$x_{gasolina}$	Element of **x** with the output of gasoline.	toe	(2.37), (2.38)

Variable	Description	Unit	Expression
$efabast_w$	Fugitive emissions of pollutant w from vehicle supply.	Gg	(2.38), (2.42)
$efgn_w$	Fugitive emissions of pollutant w from the transmission/distribution of natural gas.	Gg	(2.39), (2.42)
$efvent_w$	Fugitive emissions of pollutant w from venting and flaring in the refining sector.	Gg	(2.40), (2.42)
$efgeot_w$	Fugitive emissions of pollutant w from geothermal energy.	Gg	(2.41), (2.42)
x_{geot}	Element of **x** with the output of geothermal energy.	tep	(2.41)
ef_w	Total fugitive emission of pollutant w.	Gg	(2.42), (2.70), (2.71), (2.72), (2.73), (2.74), (2.75), (2.76), (2.77)
epr_{jw}	Fugitive emissions of pollutant w from industrial processes in branch j.	Gg	(2.43), (2.44)
x_j	Element of **x** with the output of branch j.	10^6 euros (at constant basic prices).	(2.43), (2.46), (2.59), (2.61), (2.63)
epr_w	Total emissions of pollutant w from industrial processes.	Gg	(2.44), (2.70), (2.71), (2.72), (2.73), (2.74), (2.75), (2.76), (2.77)
$efsolv_w$	Fugitive emissions of pollutant w referring to the use of solvents (non-energetic oil).	Gg	(2.45), (2.47)
$efout_{jw}$	Fugitive emissions of pollutant w referring to the use of other products in branch j.	Gg	(2.46), (2.47)
$efsolvout_w$	Total fugitive emissions of pollutant w referring to the use of solvents and other products.	Gg	(2.47), (2.70), (2.71), (2.72), (2.73), (2.74), (2.75), (2.76), (2.77)
$egte_{rw}$	Emissions of pollutant w (excluding CO_2) regarding animal type, r, in branch 1.	Gg	(2.48), (2.49), (2.53)
$efent_{rw}$	Emissions of CH_4 from enteric fermentation, for each animal type, r, in branch 1.	Gg	(2.50), (2.53)
$eqra_{aw}$	Emissions of pollutant w (excluding CO_2) from de burning of agricultural residues according to crop production, a.	Gg	(2.51), (2.53)
efn_{dw}	Emissions of pollutant w (excluding CO2) from the use of nitrogen fertilizers according to their handling type, d.	Gg	(2.52), (2.53)
$eagric_w$	Total emissions of pollutant w (excluding CO_2) from agriculture activities.	Gg	(2.53), (2.70), (2.71), (2.72), (2.73), (2.74), (2.75), (2.76)
rsu	Total generation of MSW in the territory.	t	(2.54), (2.55), (2.58), (2.63)
$\mathbf{x}_{comserv}$	Sub-vector of **x** with the *output* of the service branches (excluding sanitation, public hygiene and similar services).	10^6 euros (at constant basic prices).	(2.54)
$rsuaterro_u$	Total amount of MSW of the type u going to SWDS.	t	(2.55)
$ersuaterro_{uw}$	Emission of pollutant w (excluding CO_2) from waste of type u going to SWDS.	Gg	(2.56), (2.57), (2.64)
$rsuaterro_{un}$	Total amount of MSW of the type u going to SWDS in year n (exogenous variable from 1989 to 2009).	t	(2.56)
$ersucomp_w$	Emission of pollutant w (excluding CO_2) from anaerobic digestion.	Gg	(2.58), (2.64)
$eriborgaterro_w$	Emission of pollutant w (excluding CO_2) from industrial waste going to SWDS.	Gg	(2.59), (2.60), (2.64)
$eribincin_w$	Emission of pollutant w from industrial waste incineration.	Gg	(2.61), (2.64)
$erhincin_w$	Total emissions of pollutant w from hospital waste incineration.	Gg	(2.62), (2.64)
$eresincin_w$	Total emissions of pollutant w from waste incineration.	Gg	(2.63), (2.64)
$eres_w$	Total emissions of pollutant w from waste management.	Gg	(2.64), (2.70), (2.71), (2.72), (2.73), (2.74), (2.75), (2.76), (2.77)
tow	Total degradable organic component in waste water.	kg bod (*biochemical oxygen demand*) /year	(2.65), (2.66)
p	Estimated population of the country for the planning year (exogenous variable).	10^3 inhabitants	(2.65), (2.67), (2.68)
$eagdds_w$	Total emissions of pollutant w (excluding CO_2 emissions) from domestic waste water and sludge.	Gg	(2.66), (2.67), (2.68), (2.70), (2.71), (2.72), (2.73), (2.74), (2.75), (2.76)
$eagind_w$	Total emissions of pollutant w (excluding CO_2 emissions) from industrial waste water handling.	Gg	(2.69), (2.70), (2.71), (2.72), (2.73), (2.74), (2.75), (2.76)
dcind	Degradable organic component of industrial waste water (exogenous variable).	10^3 inhabitants equivalent	(2.69)
etco	Total emissions of CO.	Gg	(2.70), (2.80)
etnox	Total emissions of NO_x.	Gg	(2.71), (2.79), (2.80)
etn2o	Total emissions of N_2O.	Gg	(2.72), (2.78)
etch4	Total emissions of CH_4.	Gg	(2.73), (2.78), (2.80)

Variable	Description	Unit	Expression
etcovnm	Total emissions of NMVOC.	Gg	(2.74), (2.80)
etso2	Total emissions of SO_2.	Gg	(2.75), (2.79)
etnh3	Total emissions of NH_3.	Gg	(2.76), (2.79)
etco2	Total emissions of CO_2.	Gg	(2.77), (2.78)
pag	Global warming potential.	Gg of CO_2 equivalent	(2.78), (2.83)
eac	Acid equivalent potential.	Gg of acid equivalent	(2.79)
pfot	Tropospheric ozone generating potential..	Gg of NMVOC equivalent	(2.80)

Coefficient	Description	Unit	Expression
A	Technical coefficients matrix (product-by-product). Each element, a_{ij}, is the amount of good or service i needed to produce a unit of good or service j. This matrix has interval coefficients.	10^6 euros (at constant basic prices)/10^6 euros (at constant basic prices) for flows between non-energetic branches; 10^6 euros (at constant basic prices)/toe for flows between non-energetic and energetic branches; toe/10^6 euros (at constant basic prices) for flows between energetic and non-energetic branches; toe/toe for flows between energetic branches.	(2.1)
$\mathbf{a}_{cptf}$	Vector with the weight of each good or service aimed at household consumption on the total household consumption. This vector has interval coefficients.	10^6 euros (at constant basic prices) or toe, whether it is an energetic or non-energetic branch, respectively/10^6 euros (at constant purchasers' prices).	(2.1)
$\mathbf{a}_{csf}$	Vector with the weight of each good or service aimed at NPISH consumption on the total NPISH consumption.	10^6 euros (at constant basic prices) or toe, whether it is an energetic or non-energetic branch, respectively/10^6 euros (at constant purchasers' prices).	(2.1)
$\mathbf{a}_{g}$	Vector with the weight of each good or service aimed at public consumption on the total public consumption.	10^6 euros (at constant basic prices) or toe, whether it is an energetic or non-energetic branch, respectively/10^6 euros (at constant purchasers' prices).	(2.1)
$\mathbf{a}_{fbcf}$	Vector with the weight of each good or service aimed at GFCF on the total GFCF.	10^6 euros (at constant basic prices) or toe, whether it is an energetic or non-energetic branch, respectively/10^6 euros (at constant purchasers' prices).	(2.1)
$\mathbf{a}_{sc}$	Vector with the weight of each good or service aimed at changes in inventories on the total changes in inventories.	10^6 euros (at constant basic prices) or toe, whether it is an energetic or non-energetic branch, respectively/10^6 euros (at constant purchasers' prices).	(2.1)
$\mathbf{a}_{acov}$	Vector with the weight of each good or service aimed at ALDV on the total ALDV.	10^6 euros (at constant basic prices) or toe, whether it is an energetic or non-energetic branch, respectively/10^6 euros (at constant purchasers' prices).	(2.1)
$\mathbf{a}_{exp}$	Vector with the weight of each good or service aimed at exports at CIF prices on the total exports (excluding tourism).	10^6 euros (at constant basic prices) or toe, whether it is an energetic or non-energetic branch, respectively/10^6 euros (at constant purchasers' prices).	(2.1), (2.7)
cptf*	Upper interval bound on the household consumption on the territory.	10^6 euros (at constant purchasers' prices)	(2.1)
csf^L, csf^U	Upper and lower bounds on NPISH consumption.	10^6 euros (at constant purchasers' prices)	(2.1)
g^L, g^U	Upper and lower bounds on public consumption.	10^6 euros (at constant purchasers' prices)	(2.1)
$fbcf^L$, $fbcf^U$	Upper and lower bounds on GFCF.	10^6 euros (at constant purchasers' prices)	(2.1)
sc^L, sc^U	Upper and lower bounds on changes in inventories.	10^6 euros (at constant purchasers' prices)	(2.1)
$acov^L$, $acov^U$	Upper and lower bounds on ALDV.	10^6 euros (at constant purchasers' prices)	(2.1)
$expstcif^L$	Lower bounds of exports (excluding tourism) at CIF prices.	10^6 euros (at constant purchasers' prices)	(2.1)
cpe*	Upper interval bound on the tourism exports.	10^6 euros (at constant prices).	(2.2)
β_0	Autonomous household consumption.	10^6 euros (at constant purchasers' prices).	(2.3)
β_1	Marginal propensity to consume (interval coefficient).	10^6 euros (at constant purchasers' prices)/ 10^6 euros (at constant prices).	(2.3)
cpr*	Upper interval bound on the resident's household consumption.	10^6 euros (at constant purchasers' prices).	(2.3)
yd*	Upper interval bound on the resident's disposable income.	10^6 euros (at constant prices).	(2.3)
cptfr*	Upper interval bound on the resident's household consumption on the territory.	10^6 euros (at constant purchasers' prices).	(2.4)

Coefficient	Description	Unit	Expression
cpm*	Upper interval bound on the tourism imports.	10^6 euros (at constant prices).	(2.4)
α	Weight of the tourism imports on the resident's consumption.	%	(2.5)
a_{ciffob}	CIF/FOB adjustment.	10^6 euros /10^6 euros	(2.6), (2.11)
expstfob*	Upper interval bound on exports (excluding tourism) at FOB prices.	10^6 euros (at constant purchasers' prices).	(2.6)
$impstcif^L$	Lower bound on imports (excluding tourism) at CIF prices.	10^6 euros (at constant purchasers' prices).	(2.6)
$\hat{\mathbf{p}}_{exp}$	Diagonal matrix with convenient dimensions which allows converting export values from toe to euros.	Value one for non-energetic goods and services; average unitary prices for each toe in 10^6 euros (at constant basic prices) for energetic goods or services.	(2.7)
$\mathbf{a}_{expts}$	Vector with the weight of net taxes on exports of goods and services on total exports (excluding tourism).	10^6 euros (at constant prices)/ 10^6 euros (at constant purchasers' CIF prices).	(2.7)
$\mathbf{e}_1$, $\mathbf{e}_2$, …, $\mathbf{e}_{21}$	Vector with ones with convenient dimensions.	n.a.	(2.8), (2.10), (2.15), (2.25), (2.54), (2.84)
expfob*	Upper interval bound of total exports at FOB prices.	10^6 euros (at constant purchasers' prices).	(2.9)
$\mathbf{p}_{impc}$	Vector which allows converting competitive import values from toe to euros.	Value one for non-energetic goods and services; average unitary prices for each toe in 10^6 euros (at constant CIF basic prices) for energetic goods or services.	(2.10)
$\mathbf{p}_{impnc}$	Vector which allows converting non-competitive import values from toe to euros.	Average unitary prices for each toe in 10^6 euros (at constant CIF basic prices) for energetic goods or services	(2.10)
A_m^{nc}	Matrix of non-competitive import coefficients of energy.	toe/10^6 euros (at constant prices).	(2.10), (2.84)
$\mathbf{a}_{sc}^{nc}$	Vector with the weight of changes in inventories of non-competitive imports of energy on the total changes in inventories.	toe/10^6 euros (at constant purchasers' prices).	(2.10), (2.84)
A_m	Matrix of non-competitive imports of non-energetic goods or services coefficients.	10^6 euros (at constant CIF basic prices)/ 10^6 euros (at constant basic prices).	(2.10)
$\mathbf{am}_{cptf}$	Vector with the weights of non-competitive imports of non-energetic goods or services aimed at household consumption on the total household consumption on the territory.	10^6 euros (at constant CIF basic prices)/ 10^6 euros (at constant purchasers' prices).	(2.10)
$\mathbf{am}_{csf}$	Vector with the weights of non-competitive imports of non-energetic goods or services aimed at NPISH consumption on the total NPISH consumption.	10^6 euros (at constant CIF basic prices)/ 10^6 euros (at constant purchasers' prices).	(2.10)
$\mathbf{am}_{g}$	Vector with the weights of non-competitive imports of non-energetic goods or services aimed at public consumption on the total public consumption.	10^6 euros (at constant CIF basic prices)/ 10^6 euros (at constant purchasers' prices).	(2.10)
$\mathbf{am}_{fbcf}$	Vector with the weights of non-competitive imports of non-energetic goods or services aimed at GFCF on the total GFCF.	10^6 euros (at constant CIF basic prices)/ 10^6 euros (at constant purchasers' prices).	(2.10)
$\mathbf{am}_{sc}$	Vector with the weights of non-competitive imports of non-energetic goods or services aimed at changes in inventories on the total changes in inventories.	10^6 euros (at constant CIF basic prices)/ 10^6 euros (at constant purchasers' prices).	(2.10)
$\mathbf{am}_{acov}$	Vector with the weights of non-competitive imports of non-energetic goods or services aimed at ALDV on the total ALDV.	10^6 euros (at constant CIF basic prices)/ 10^6 euros (at constant purchasers' prices).	(2.10)
mstfob*	Upper interval bound of total imports (excluding tourism) at FOB prices.	10^6 euros (at constant FOB purchasers' prices)	(2.11)
mstfob*	Upper interval bound of total imports at FOB prices.	10^6 euros (at constant FOB purchasers' prices)	(2.12)
$\mathbf{a}_{rem}$	Vector with the weights of wages on the total output of each branch.	10^6 euros (at constant prices)/ 10^6 euros (at constant basic prices).	(2.13), (2.19)
$\mathbf{a}_{ot}$	Vector with the weights of taxes on the total output of each branch.	10^6 euros (at constant prices)/ 10^6 euros (at constant basic prices).	(2.13), (2.21)

Coefficient	Description	Unit	Expression
$\mathbf{a}_{os}$	Vector with the weights of subsidies on the total output of each branch.	10^6 euros (at constant prices)/ 10^6 euros (at constant basic prices).	(2.13), (2.21)
$\mathbf{a}_{ebermb}$	Vector with the weight of gross operating surplus and gross mixed incomes on the total output of each branch.	10^6 euros (at constant prices)/ 10^6 euros (at constant basic prices).	(2.13)
$\mathbf{l}$	Vector with the ratio between the number of employees in each branch (at full-time equivalent person) and the total output of each branch.	10^3 persons (at full-time equivalent person)/ 10^6 euros (at constant basic prices).	(2.14)
A_{ts}	Matrix with the weights of net taxes on goods and services on the total output of each branch.	10^6 euros (at constant prices)/ 10^6 euros (at constant basic prices).	(2.15)
$\mathbf{a}_{cptfts}$	Vector with the weights of net taxes on goods and services aimed at household consumption on total household consumption on the territory.	10^6 euros (at constant prices)/ 10^6 euros (at constant purchasers' prices).	(2.15)
$\mathbf{a}_{csfts}$	Vector with the weights of net taxes on goods and services aimed at NPISH consumption on the total NPISH consumption.	10^6 euros (at constant prices)/ 10^6 euros (at constant purchasers' prices).	(2.15)
$\mathbf{a}_{gts}$	Vector with the weights of net taxes on goods and services aimed at public consumption on the total public consumption.	10^6 euros (at constant prices)/ 10^6 euros (at constant purchasers' prices).	(2.15)
$\mathbf{a}_{fbcfts}$	Vector with the weights of net taxes on goods and services aimed at GFCF on total GFCF.	10^6 euros (at constant prices)/ 10^6 euros (at constant purchasers' prices).	(2.15)
$\mathbf{a}_{scts}$	Vector with the weights of net taxes on goods and services aimed at changes in inventories on total changes in inventories.	10^6 euros (at constant prices)/ 10^6 euros (at constant purchasers' prices).	(2.15)
$\mathbf{a}_{acovts}$	Vector with the weights of net taxes on goods and services aimed at ALDV on total ALDV.	10^6 euros (at constant prices)/ 10^6 euros (at constant purchasers' prices).	(2.15)
$\mathbf{a}_{exts}$	Vector with the weights of net taxes on goods and services aimed at exports on total exports.	10^6 euros (at constant prices)/ 10^6 euros (at constant CIF purchasers' prices).	(2.15)
A_{ts}^{nc}	Matrix with the weights of net taxes on non-competitive imports of energy on the total output of each branch.	10^6 euros (at constant prices)/ 10^6 euros (at constant basic prices).	(2.15)
ts^L	Lower bound on total net taxes on goods and services.	10^6 euros (at constant prices).	(2.15)
pib^L	Lower bound on GDP.	10^6 euros (at constant market prices).	(2.16), (2.17)
pib^*	Upper interval bound on GDP.	10^6 euros (at constant market prices).	(2.16), (2.17)
$pibcorr^*$	Upper interval bound on GDP.	10^6 euros (at current market prices).	(2.18)
$gcorr^L$, $gcorr^U$	Lower and upper bounds on public consumption.	10^6 euros (at current prices).	(2.18)
$fbcfcorr^L$, $fbcfcorr^U$	Lower and upper bounds on GFCF.	10^6 euros (at current prices).	(2.18)
$remcorr^*$	Upper interval bound on wages and salaries.	10^6 euros (at current prices).	(2.19)
pspibcorr	Corporations savings as a percentage of GDP (interval coefficient).	%	(2.20)
tigts	Weight of net indirect taxes received by the public sector on the total amount of net indirect taxes at current prices (interval coefficient).	%	(2.20), (2.23)
rtdydcorr	Weight of direct taxes on the disposable income of households and NPISH (interval coefficient).	%	(2.20), (2.23)
tdscpibcorr	Weight of direct taxes on the income of corporations on the GDP at current prices (interval coefficient).	%	(2.20), (2.23)
tcss	Weight of social security contributions received by the public sector on total wages and salaries (interval coefficient).	%	(2.20), (2.23)
repgpibcorr	Weight of corporations and property incomes of public sector on GDP at current prices (interval coefficient).	%	(2.20), (2.23)
$ydcorr^*$	Upper interval bound on disposable income.	10^6 euros (at current prices).	(2.20)

Coefficient	Description	Unit	Expression
rp*	Upper interval bound on balance of primary incomes with the rest of the world.	10^6 euros (at current prices).	(2.20)
tisub*	Upper interval bound on net indirect taxes.	10^6 euros (at current prices).	(2.20)
tisubg*	Upper interval bound on net indirect taxes received by the public administration.	10^6 euros (at current prices).	(2.20)
tre*	Upper interval bound on private transfers with the rest of the world.	10^6 euros (at current prices).	(2.20)
td*	Upper interval bound on direct taxes on disposable income of households and NPISH.	10^6 euros (at current prices).	(2.20)
tdsc*	Upper interval bound on direct taxes on income of corporations.	10^6 euros (at current prices).	(2.20)
css*	Upper interval bound on social security contributions.	10^6 euros (at current prices).	(2.20)
repg*	Upper interval bound on corporations and property incomes of the public sector.	10^6 euros (at current prices).	(2.20)
trig*	Upper interval bound on the balance of internal transfers from the public administrations to households.	10^6 euros (at current prices).	(2.20)
div*	Upper interval bound on public debt.	10^6 euros (at current prices).	(2.22)
div_{-1}*	Lower interval bound on the public debt of the previous period.	10^6 euros (at current prices).	(2.22)
sgg*	Lower interval bound of the public balance.	10^6 euros (at current prices).	(2.22)
dat*	Lower interval bound on the adjustment of the public debt.	10^6 euros (at current prices).	(2.22)
tkpibcorr	Weight of capital taxes received by the public sector on GDP at current prices (interval coefficients).	%	(2.23)
treg*	Upper interval bound on the balance of public transfers with the rest of the world.	10^6 euros (at current prices).	(2.23)
jurg*	Upper interval bound on the interests of public debt.	10^6 euros (at current prices).	(2.23)
tk*	Upper interval bound on capital taxes.	10^6 euros (at current prices).	(2.23)
trkg*	Upper interval bound on public capital transfers.	10^6 euros (at current prices).	(2.23)
gfbcf*	Upper interval bound on the public investment on GFCF.	10^6 euros (at current prices).	(2.23)
$\widehat{\mathbf{fctj}}_E$	Diagonal matrix with conversion factors from toe to terajoules - TJ - for each type of energy.	TJ/toe	(2.24), (2.26), (2.27), (2.28), (2.29), (2.30), (2.32), (2.33)
$\widehat{\mathbf{fec}}_E$	Diagonal matrix, whose main elements are the carbon (C) emission factors for each type of energy (interval coefficient).	Tonnes (t) of C by TJ (tC/TJ).	(2.24)
$\widehat{\mathbf{fco}}_E$	Diagonal matrix, whose main elements are the fractions of carbon oxidized for each type of energy.	%	(2.24)
A_E	Matrix with the coefficients of energy use by each branch. It is composed by the coefficients of energy use of A and A_m^{nc}, as well as by the coefficients of biomass use. It has interval coefficients.	toe/ 10^6 euros (at constant basic prices).	(2.24)
$\mathbf{a}_{cptfE}$	Vector with the coefficients of energy use by the households. This vector is composed by the coefficients of energy use of $\mathbf{a}_{cptf}$, as well as by the coefficients of biomass use. The elements refering to the non-competitive energy imports are null. It has interval coefficients.	toe/ 10^6 euros (at constant purchasers' prices).	(2.24), (2.33)
$\mathbf{a}_{csfE}$	Vector with the coefficients of energy use by the NPISH. This vector is composed by the energy use coefficients of $\mathbf{a}_{csf}$. The elements refering to the non-competitive energy imports and to the use of biomass are null.	toe/ 10^6 euros (at constant purchasers' prices).	(2.24), (2.33)

Coefficient	Description	Unit	Expression
$\mathbf{a}_{gE}$	Vector with the coefficients of energy use by the public sector. This vector is composed by the energy use coefficients of $\mathbf{a}_g$. The elements refering to the non-competitive energy imports and to the use of biomass are null.	toe/ 10^6 euros (at constant purchasers’ prices).	(2.24), (2.33)
N_E	Matrix with the coefficients of energy use with non-energetic purpose for each branch.	toe/ 10^6 euros (at constant basic prices) or toe, whether it is an energetic or non-energetic branch, respectively.	(2.24)
$\mathbf{a}_{ncptfE}$	Vector with the coefficients of energy use by the households with non-energetic purpose.	toe/ 10^6 euros (at constant purchasers’ prices).	(2.24)
$\mathbf{a}_{ncsfE}$	Vector with the coefficients of energy use by the NPISH with non-energetic purpose.	toe/ 10^6 euros (at constant purchasers’ prices).	(2.24)
$\mathbf{a}_{ngE}$	Vector with the coefficients of energy use by the public sector with non-energetic purpose.	toe/ 10^6 euros (at constant purchasers’ prices).	(2.24)
$\frac{44}{12}$	Ratio between the molecular weights of CO_2 and C.	n.a.	(2.24), (2.63)
10^{-3}	Factor which allows converting values into Gg.	Gg/t	(2.24); (2.48), (2.49), (2.50), (2.56), (2.63)
$\mathbf{fecelect}_w$	Vector with the emission factors for pollutant w (excluding CO_2) from energy combustion in electricity power generation, for each type of energy (it has interval coefficients). Non-energetic oil has null emission factors.	g/TJ	(2.26)
A_{Eelect}	Submatrix of A_E with the coefficients of energy consumption for each type of electricity generation. This submatrix has interval coefficients.	toe/toe	(2.26)
10^{-9}	Factor which allows converting values into Gg.	Gg/g	(2.26), (2.27), (2.28), (2.29), (2.30), (2.32), (2.33), (2.35), (2.36), (2.37), (2.38), (2.39), (2.40), (2.41), (2.43), (2.45), (2.46), (2.51), (2.52)
$\mathbf{feccog}_w$	Vector with the emission factors for pollutant w (excluding CO_2) from energy combustion in co-generation, for each type of energy (it has interval coefficients). Non-energetic oil has null emission factors.	g/TJ	(2.27)
$\mathbf{A}_{E.cog}$	Column of A_E with the coefficients of energy consumption in co-generation (it has interval coefficients).	toe/toe	(2.27)
$\mathbf{fecref}_w$	Vector with the emission factors for pollutant w (excluding CO_2) from energy combustion in refineries, for each type of energy (it has interval coefficients).	g/TJ	(2.28)
$\mathbf{A}_{E.ref}$	Column of A_E with the coefficients of energy consumption in the refineries (it has interval coefficients).	toe/toe	(2.28)
$\mathbf{N}_{E.ref}$	Column of N_E with the coefficients of energy consumption with non-energectic purpose in the refineries.	toe/toe	(2.28)
$\mathbf{fecind}_w$	Vector with the emission factors for pollutant w (excluding CO_2) from energy combustion in manufacturing industry and construction for each type of energy (it has interval coefficients).	g/TJ	(2.29)
A_{Eind}	Submatrix of A_E with coefficients of energy consumption for each industrial branch. It has interval coefficients.	toe/10^6 euros (at constant basic prices).	(2.29)
N_{Eind}	Submatrix of N_E with coefficients of energy consumption with non-energetic purpose for each industrial branch.	toe/10^6 euros (at constant basic prices).	(2.29)

Coefficient	Description	Unit	Expression
$\mathbf{fectr}_{wt}$	Vector with the emission factors for pollutant w (excluding CO_2) from energy combustion in the transport branches (t = 60 = road and rail, 61 = maritime, 62 = air), for each type of energy. Non-energetic oil has null emission factors. This vector has interval coefficients.	g/TJ	(2.30)
$\mathbf{A}_{E.t}$	Column of A_E with the coefficients of energy consumption in the transport branches (it has interval coefficients).	toe/10^6 euros (at constant basic prices).	(2.30)
$fectr_{wct}$	SO_2 (w = 6) emission factor from energy combustion of type c in the transport branches. Non-energetic oil has null emission factors. The value obtained is an element of $\mathbf{fectr}_{wt}$ (it has interval coefficients).	g/TJ	(2.31)
2	Ratio between the molecular weights of SO_2 and the sulphur content.	n.a.	(2.31)
s	Sulphur content in the fuel.	%	(2.31)
q	Net calorific value of the fuel.	TJ/Gg	(2.31)
10^9	Factor which allows converting Gg into g.	g/Gg	(2.31)
r	Sulphur retention in ash.	%	(2.31)
tred	Abatement efficiency.	%	(2.31)
$\mathbf{fecos}_{wy}$	Vector with the emission factors for pollutant w (excluding CO_2) from energy combustion in branch y, for each type of energy. Non-energetic oil has null emission factors. It has interval coefficients.	g/TJ	(2.32)
$\mathbf{A}_{E.y}$	Column of A_E with the coefficients of energy consumption in branch y (it has interval coefficients).	toe/10^6 euros (at constant basic prices).	(2.32)
$\mathbf{feccp}_{w}$	Vector with the emission factors for pollutant w (excluding CO_2) from energy combustion in final consumption, for each type of energy. Non-energetic oil has null emission factors. It has interval coefficients.	g/TJ	(2.33)
a_{pbref}	Element of A_E corresponding to the coefficient of crude oil consumption in the refining sector.	toe/toe	(2.35)
fct_{pb}	Factor which allows converting values from toe into t for crude oil.	t/toe	(2.35)
$feftpb_{w}$	Fugitive emission factor of pollutant w from crude oil transportation into refineries.	g/t	(2.35)
$fefpp_{w}$	Fugitive emission factor of pollutant w from the processing of oil products during refining activities.	g/toe	(2.36)
$fct_{gasolina}$	Factor which allows converting values from toe into t for gasoline.	t/toe	(2.37), (2.38)
$fefdist_{w}$	Fugitive emission factor of pollutant w regarding sales of gasoline from the refinery to the service stations.	g/t	(2.37)
$fefabast_{w}$	Fugitive emission factor of pollutant w from the sales of gasoline in the service stations.	g/t	(2.38)
$\mathbf{A}_{Egn.}$	Row vector of A_E with the coefficients of natural gas consumption for each branch.	toe/10^6 euros (at constant basic prices).	(2.39)
a_{cptfgn}	Element of $\mathbf{a}_{cptfE}$ with the coefficient of natural gas consumption per unit of household consumption on the territory.	toe/10^6 euros (at constant purchasers' prices).	(2.39)
a_{csfgn}	Element of $\mathbf{a}_{csfE}$ with the coefficient of natural gas consumption per unit of NPISH consumption.	toe/10^6 euros (at constant purchasers' prices).	(2.39)
a_{ggn}	Element of $\mathbf{a}_{gE}$ with the coefficient of natural gas consumption per unit of public consumption.	toe/10^6 euros (at constant purchasers' prices).	(2.39)
$fctj_{gn}$	Factor which allows converting values from toe into TJ for natural gas.	TJ/toe	(2.39)

Coefficient	Description	Unit	Expression
$fefgn_w$	Fugitive emission factor of pollutant w from natural gas transmission.	g/TJ	(2.39)
$fevent_w$	Fugitive emission factor of pollutant w from venting and flaring of oil products.	g/toe	(2.40)
$fegeot_w$	Fugitive emission factor of pollutant w from geothermal energy.	g/TJ	(2.41)
$fctj_{\mathbf{geot}}$	Factor which allows converting values from toe into TJ for geothermal energy.	TJ/toe	(2.41)
$fepr_{jw}$	Emission factor of pollutant w from industrial processes of branch j.	g/10^6 euros (at constant basic prices).	(2.43)
$\mathbf{A}_{Esolv.}$	Row vector of A_E with the coefficients of solvent consumption for each branch.	toe/10^6 euros (at constant basic prices).	(2.45)
$a_{cptfsolv}$	Element of $\mathbf{a}_{cptfE}$ with the solvent consumption per unit of household consumption on the territory.	toe/10^6 euros (at constant purchasers' prices).	(2.45)
$a_{csfsolv}$	Element of $\mathbf{a}_{csfE}$ with the solvent consumption per unit of NPISH consumption.	toe/10^6 euros (at constant purchasers' prices).	(2.45)
a_{gsolv}	Element of $\mathbf{a}_{gE}$ with the solvent consumption per unit of public consumption.	toe/10^6 euros (at constant purchasers' prices).	(2.45)
fct_{solv}	Factor which allows converting values from toe into t for solvents.	t/tep	(2.45)
$fefsolv_w$	Fugitive emission factor for pollutant w from the use of solvents.	g/t	(2.45)
$fefout_{wj}$	Fugitive emission factor for pollutant w from the use of other products.	g/10^6 euros (at constant basic prices).	(2.46)
$aest_r$	Coefficients of nitrogen excretion per animal type, r, in branch 1.	t/$10^3$of heads	(2.48)
$apec_r$	Ratio between the number of heads of animal type, r, and the total output of branch 1.	$10^3$of heads /10^6 euros (at constant basic prices).	(2.48), (2.49), (2.50)
$\mathbf{agte}_{gr}$	Vector with the assignment of the coefficients of nitrogen excretion per animal type, r, to the corresponding manure management system.	%	(2.48)
$\mathbf{fegte}_{wg}$	Vector with the emission factors of pollutant w, for each type of manure management system, g, for nitrogen excretion handling, in branch 1.	t/t	(2.48)
$fegte_{wr}$	Emission coefficients of pollutant w from producing animal type r in branch 1.	t/$10^3$of heads.	(2.49)
$fefent_{wr}$	Emission coefficients of pollutant w from enteric fermentation per each animal type, r, in branch 1.	t/$10^3$of heads.	(2.50)
ara_a	Coefficients of waste generation from the crop production of type a.	kg/ha – hectare	(2.51)
$fseca_a$	Fraction of dry matter per waste from crop production of type a.	%	(2.51)
apa_a	Ratio between the occupation of each crop production of type a and the output of branch 1.	ha/10^6 euros (at constant basic prices).	(2.51)
$aqra_a$	Fraction of waste burned for each crop production of type a.	%	(2.51)
$feqra_{aw}$	Emission factor of pollutant w (excluding CO_2) from waste burnt, for each crop production of type a.	g/kg	(2.51)
$fefn_{dw}$	Emission factor of pollutant w (excluding CO_2) from the application of nitrogen fertilizers according to the type of handling, d.	g/kg N	(2.52)
afn_d	Application pattern of nitrogen fertilizers according to the type of handling, d, regarding the total cultivated area.	kg N/ha	(2.52)
arsudom	Total amount of MSW generated per unit of household and NPISH consumption on the territory.	t/10^6 euros (at constant purchasers' prices).	(2.54)
arsucomserv	Total amount of MSW generated per unit of output of the commerce and services sectors.	t/ 10^6 euros (at constant basic prices).	(2.54)

Coefficient	Description	Unit	Expression
arsu90	Total amount of MSW handled and treated per unit of output of sanitation, public hygiene and similar services branch.	t/ 10^6 euros (at constant basic prices).	(2.54)
frsuaterro	Fraction of waste going to SWDS.	%	(2.55)
aresiduo_u	Fraction of waste of type u.	%	(2.55)
k_u	Methane generation rate for each type of waste u.	%	(2.56)
mfcrsu_u	Methane correction factor for each type of waste u.	%	(2.56)
docrsu_u	Degradable organic carbon for each type of waste u.	tC/t MSW	(2.56)
docfrsu_u	Fraction of degradable organic carbon dissimilated for each type of waste u.	%	(2.56)
f_w	Fraction of pollutant w in biogas.	%	(2.56)
$\frac{16}{12}$	Ratio between the molecular weights of CH_4 and C.	n.a.	(2.56)
n	Year of waste deposition in SWDS.	year	(2.56)
2	Multiplication factor which assumes that approximately 50% of the landfill gas is CO_2 and 50% is CH_4.	n.a.	(2.57), (2.60)
densch4	Density of CH_4, which allows converting the values from kg into m^3.	kg/m^3	(2.57), (2.60)
10^6	Factor which allows converting Gg into kg.	kg/Gg	(2.57), (2.60)
cconm	Concentration of non organic methane compounds (NMOC) in biogas.	ppmv	(2.57), (2.60)
10^{-6}	Factor for correcting the concentration of NMOC into units of ppmv. Factor which allows converting kg into Gg.	10^6 of parts/parts Gg/kg	(2.57), (2.58), (2.60), (2.61), (2.62), (2.66), (2.67), (2.68), (2.69)
86.18	Molecular weight of NMOC as hexane.	gmol	(2.57), (2.60)
pop	Operating pressure of the system	1 atm	(2.57), (2.60)
(8.205) (10^{-5})	Factor which allows converting NMOC emissions into kg/year.	m^3 atm/gmol K	(2.57), (2.60)
1000	Factor which allows converting kg into g.	g/kg	(2.57), (2.60)
273	Factor which allows converting Celsius degrees (^0C) into K degrees.	n.a.	(2.57), (2.60)
top	Temperature of the gas.	^0C	(2.57), (2.60)
covnm	Fraction of NMVOC.	%	(2.57), (2.60)
frsucomp	Fraction of waste assigned to anaerobic digestion.	%	(2.58)
fersucom_w	Emission factor of pollutant w from anaerobic digestion of organic waste (interval coefficient).	kg/t	(2.58)
redemrsu_w	Abatement efficiency for pollutant w.	%	(2.58)
feriborg_w	Emission factor of pollutant w from industrial waste deposition in SWDS.	kg/t	(2.59)
ari_j	Total amount of industrial waste per unit of output of branch j.	t/ 10^6 euros (at constant basic prices).	(2.59), (2.63)
fripri	Fraction of hazardous wastes on the total amount of industrial wastes.	%	(2.59), (2.63)
fribaterro	Fraction of industrial wastes deposited in SWDS.	%	(2.59)
friborgaterro	Fraction of organic industrial wastes deposited in SWDS.	%	(2.59)
fribincinsve	Fraction of industrial waste which is incinerated (with no energetic purpose).	%	(2.61)
feribincin_w	Emission factor of pollutant w from industrial waste incineration.	kg/t	(2.61)
arhininc_{85}	Amount of hospital waste incinerated per unit of output of branch 85 (health and social care).	t/ 10^6 euros (at constant basic prices).	(2.62), (2.63)
ferhincin_w	Emission factor of pollutant w from the hospital waste incineration.	kg/t	(2.62)
frsuincin (fribincin)	Fraction of MSW (industrial waste) which is incinerated.	%	(2.63)
ccrsurib	Carbon content of MSW and industrial wastes.	%	(2.63)

Coefficient	Description	Unit	Expression
fcfrsubrib	Fraction of fossil carbon in MSW and industrial wastes.	%	(2.63)
ccrh	Carbon content of hospital wastes.	%	(2.63)
fcfrh	Fraction of fossil carbon in hospital wastes.	%	(2.63)
efqueima	Efficiency of combustion.	%	(2.63)
bod	Per capita biochemical oxygen demand	kg/10^3 of persons year	(2.65)
$feagd1_w$	Emission factor of pollutant w from domestic waste water handling.	kg/kg bod	(2.66)
ds	Fraction of waste water converted into sludge.	%	(2.66)
$recagdt_w$	Abatement efficiency for pollutant w.	%	(2.66)
$fesd_w$	Emission factor of pollutant w from sludge handling.	kg/kg bod	(2.66)
$recds_w$	Abatement efficiency for pollutant w.	%	(2.66)
$feagd2_w$	Emission factor of pollutant w from nitrogen in domestic waste water.	kg/kg N	(2.67)
cprot	Per capita protein.	kg/10^3 inhabitants	(2.67)
fnpr	Fraction of Nitrogen in the protein.	%	(2.67)
fsepticas	Fraction of the population served with swage system.	%	(2.67)
$feagd3_w$	Emission factor of pollutant w from waste water handling, regarding the volume of waste water handled.	kg/m^3	(2.68)
cagd	Volume of water supply per capita.	$m^3/10^3$ inhabitants	(2.68)
fsaneamento	Sanitation rate.	%	(2.68)
$feagind_w$	Emission factor of pollutant w from industrial waste water handling.	kg/10^3 inhabitants	(2.69)
$etco^U$	Upper bound on CO emissions.	Gg	(2.70)
$etnox^U$	Upper bound on NO_x emissions.	Gg	(2.71)
$etn2o^U$	Upper bound on N_2O emissions.	Gg	(2.72)
$etch4^U$	Upper bound on CH_4 emissions.	Gg	(2.73)
$etcovnm^U$	Upper bound on NMVOC emissions.	Gg	(2.74)
$etso2^U$	Upper bound on SO_2 emissions.	Gg	(2.75)
$etnh3^U$	Upper bound on NH_3 emissions.	Gg	(2.76)
$etco2^U$	Upper bound on CO_2 emissions.	Gg	(2.77)
310	Factor which allows converting N_2O emissions into CO_2 equivalent.	Gg CO_2 /Gg N_2O	(2.78)
21	Factor which allows converting CH_4 emissions into CO_2 equivalent.	Gg CO_2/Gg CH_4	(2.78)
pag^U	Upper bound on GWP.	Gg of CO_2 equivalent	(2.78)
21.74	Factor which allows converting NO_x emissions into acid equivalent.	Acid equivalent/kg NO_x	(2.79)
31.25	Factor which allows converting SO_2 emissions into acid equivalent.	Acid equivalent /kg SO_2	(2.79)
58.82	Factor which allows converting NH_3 emissions into acid equivalent.	Acid equivalent /kg NH_3	(2.79)
eac^U	Upper bound on AEP	Gg of acid equivalent.	(2.79)
1.22	Factor which allows converting NO_x emissions into NMVOC equivalent.	Gg NMVOC/Gg NO_x	(2.80)
0.11	Factor which allows converting CO emissions into NMVOC equivalent.	Gg NMVOC /Gg CO	(2.80)
0.014	Factor which allows converting CH_4 emissions into NMVOC equivalent.	Gg NMVOC /Gg CH_4	(2.80)
$pfot^U$	Upper bound on TOP.	Gg of NMVOC equivalent.	(2.80)