Estimation of the Production of CO_2 Emissions by the Portuguese Economy in an Input-Output Framework

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ABSTRACT

Trade-offs among three objectives – energy security, environmental protection, and economic growth – have been dominant concerns in Portuguese energy policy making for the last two decades. Particularly relevant in this context is the case of anthropogenic carbon dioxide (CO_2) emissions, which are a key factor of the greenhouse effect and of the 'resulting' global climate change.

The main aim of this paper is to contribute to the raising of the level of general awareness of the complex interactions between energy, economic and environmental issues, by summarizing and synthesising information in a way that can help policy makers to make better-informed decisions. This will be done using an extended input-output empirical application, from which is assessed the production of CO_2 emissions (derived from fossil fuels use) in Portugal.

Furthermore, an important feature of the input-output technique is that it supports scenario-based approaches, providing a basis for the determination of the effects of alternative economic actions (or policy measures), whether they are to be *ex ante* tested or *ex post* evaluated.

Therefore, there will also be performed a scenario analysis of the potential development of some components which influence the supply and the demand of energy in Portugal, and consequently the level of CO_2 emissions. This performance is directed towards the production of useful insights for practical economic planning that explicitly consider energy and environmental policy issues, particularly in the context of the accomplishment (or not) of the Portuguese commitments to a maximum increase of 40 per cent in CO_2 emissions from 1990 to 2008-2012 (under the Kyoto Protocol).

Keywords: Input-output analysis; Energy policy; CO_2 emissions; Scenarios analysis; Kyoto Protocol; Portugal

1. Introduction

The main aim of this paper is to present and discuss the use of a particular kind of analytical tool – input-output analysis – to model energy-economy-environment interactions for Portugal, and therefore to support policy-makers' decision processes directed towards the achievement of these policy objectives. Moreover, the study will be particularly focused on the analysis of the accomplishment (or not) of the Kyoto Protocol target for the Portuguese CO_2 emissions.

For this, the paper is organised as follows. In Section 2, there will be presented a brief outline of the basic input-output model, and then succinctly discussed the core aspects of its extensions for the consideration of environmental and energy issues. In Section 3, there will be presented the data sets used for the Portuguese case, and then an extended input-output empirical application, from which is assessed the production of CO_2 emissions (derived from fossil fuels use) by the Portuguese economy. In Section 4, there will be a scenarios analysis of the potential development of some components that influence the supply and the demand of energy in Portugal, and consequently the level of CO_2 emissions. The relevance of the key policy findings concerning each part of the empirical application will be presented at the end of Sections 3 and 4, respectively.

2. The input-output framework

In an input-output approach the economic structure is defined in terms of sectors. It can be said that the relative simplicity of such a systematic connection of a set of economic variables provides a modelling framework suitable for calculating economic impacts (over all of the economy) of several human activities.

2. 1. The basic input-output model[1]

The basic principle of input–output analysis states that each sector's production process can be represented by a vector of structural coefficients that describe the relationship between the inputs it absorbs and the outputs it produces[2].

As the total output (production) of a sector i (X_i) can be delivered for intermediate or for final demand, an output equation may be defined by:

$$X_i = \sum_j x_{ij} + Y_i \quad (1),$$

where the element x_{ij} represents the 'value' of input from sector i to sector j (where i represents the number of the row and j the number of the column), and Y_i represents the total final demand for sector i (which includes production for consumption (of households and governments), investment purposes (fixed capital formation, changes in stocks) or exports).

Considering constant returns to scale, the output (or supply) equation of one generic sector becomes:

$$X_i = \sum_j a_{ij} X_j + Y_i \quad (2),$$

where the coefficients a_{ij}, defined as the delivery from sector i to j per unit of sector's j output, are known as the 'technical' or 'technological coefficients'.

To represent the nation's productive system, we will have a system of n (linear) simultaneous equations, each one describing the distributions of one sector's product through the economy. As the algebraic manipulation of such a system is very complex, it is useful to use its representation in matrix (condensed) form[3]:

$$\mathbf{Ax} + \mathbf{y} = \mathbf{x} \quad (3),$$

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[1] The basic concepts of input-output analysis were discussed in detail by Wassily Leontief in the 1960s (Leontief, 1966), and more recently by Miller and Blair (1985), and Proops et al. (1993).

[2] General assumptions of the basic input-output model are: homogeneity (i.e. each sector or industry produces a single product) and linear production functions (which implies proportionality of inputs with outputs in each sector and excludes both the possibility of economies or diseconomies of scale, and of substitution between production factors).

[3] Notational conventions: upper case bold letters are used to denote matrices, and lower case italic letters with subscript indices to denote its elements; lower case bold letters are used to denote vectors, and upper case italic letters with subscript indices to denote its elements; and lower case italic letters are used to denote scalars.

where **A** is the matrix of the technological coefficients, **y** is the vector of final demand, and **x** is the vector of corresponding total outputs.

Using the basic concepts of matrix algebra, with **I** as the unit matrix, expression (3) can be reorganized, to give:

$$\mathbf{x} = (\mathbf{I}-\mathbf{A})^{-1}\mathbf{y} \qquad (4).$$

This expression is the fundamental matrix representation of input-output analysis, and the inverse matrix $(\mathbf{I}-\mathbf{A})^{-1}$ is known as the 'Leontief inverse matrix' (or also as the 'multiplier matrix').

By decomposing equation (4) (which can be seen as the result of an iterative process that shows the progressive adjustments of output to final demand and input requirements), one can separate out the direct from the indirect requirements for production in the economy, which are necessary to satisfy a certain vector of final demand commodities (Gay and Proops, 1993: 115-116):

$$\mathbf{x} = \mathbf{y} + \mathbf{A}\mathbf{y} + \mathbf{A}^2\mathbf{y} + \ldots + \mathbf{A}^t\mathbf{y} + \ldots \qquad (5).$$

So, as Proops et al. (1993: 112) point out, we can decompose the total demand for the *n* goods produced in the economy as follows:

- **y** is required for final demand. This is the direct effect.
- **Ay** is the production necessary to allow the production of a final demand vector, **y**. This is the 'first-round indirect effect'.
- $\mathbf{A}^t\mathbf{y} = \mathbf{A}(\mathbf{A}^{t-1}\mathbf{y})$ is needed to produce the goods $\mathbf{A}^{t-1}\mathbf{y}$. This is the '$t^{th}$-round indirect effect'.

Clearly, the total indirect effects (or intermediate demand) are the sum of the first-round, second-round, etc. (Gay and Proops, 1993: 115-116).

2. 2. Extensions of the basic model to account for energy-economy-environment interactions

Having established the basic input-output framework, it is time to move on to discuss some extensions of this technique, in order to make particularly explicit the link between the level of economic activity in a country, its corresponding impact on the environment, and/or the corresponding energy interactions.

Extensions of the application of input-output models to the examination of interactions between economic activity and environmental issues date back to the late 1960s and early 1970s[4]. These studies can be considered as benchmarks of an approach that would be further developed by some energy analysts during the 1970s and the 1980s, extending the use of input-output analysis to consider energy-economy interactions[5].

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[4] Detailed surveys of environmental input-output models, with many references, including theoretical extensions and applications are provided, for example, by: Hawdon and Pearson (1995), Miller and Blair (1985, Chapter 7), Richardson (1972: Chapter 11), Victor (1972: Chapter 2).

[5] Detailed surveys of energy input-output analysis are presented, for example, by: Miller and Blair (1985, Chapter 6), and Casler and Wilbur (1984).

But, over time, the modelling approaches have become more and more complex, to allow, for example, the consideration of global environmental issues such as the greenhouse effect and the 'resulting' climate change problem. This has led to the development of numerous theoretical models and empirical studies that combine both perspectives, making it hard to distinguish between environment and energy models, and therefore it become usual to talk about 'energy-economy-environment' models (Faucheaux and Levarlet, 1999: 1123).

Thus, it is not surprising that also the input-output models have been extended to deal with both environmental and energy issues. Therefore, in this section, it is intended to illustrate some of the potentialities of the energy-economy-environment models, applying the input-output technique to the structural analysis of energy requirements and CO_2 emissions by economies, relating this pollution with the use of fuels. This will be done using an approach very similar to the one used by Gay and Proops (1993) and Proops et al. (1993)[6].

To start, it is important to note that we need to introduce two kinds of distinctions into the analysis:

1. The division of the fossil fuel use, and the corresponding pollution emissions, into what concerns energy directly demanded by household consumers (for lighting, cooking, heating/cooling, transport, etc.), and energy (directly and indirectly) demanded by industrial and agricultural producers of goods to 'power' the production process (Proops, 1988: 202). The former will be designated as 'direct consumption demand' and the latter as (direct plus indirect) 'production demand'.
2. The distinction between various forms of primary (fossil) fuels[7], namely solid (coal), liquid (oil) and gaseous (natural gas), since they have different pollution emissions per unit mass, and per unit of energy delivered.

Accordingly, it is considered in this model that the total (primary) energy requirements by an economy (given by the 3-vector **f**) can be considered as the sum of the production energy requirements (given by the 3-vector [$\mathbf{f_{ind}}=\mathbf{C}(\mathbf{I}-\mathbf{A})^{-1}\mathbf{y}$]), and final demand energy requirements (given by the 3-vector [$\mathbf{f_{dem}}=\mathbf{PHy}$]), i.e.:

$$\mathbf{f} = \mathbf{C}(\mathbf{I}-\mathbf{A})^{-1}\mathbf{y} + \mathbf{PHy} \qquad (6)$$[8],

[6] The basic concepts and explanations of the method to apply here have been discussed in detail by Proops et al. (1993: Chapter 8). Therefore, the main equations and explanation of its contents will just be restated briefly.

[7] Applying an input-output approach to fuel use, as it is the case, "only primary fuels need be consider directly", since the use of secondary fuels is "dealt with automatically within the interindustry demand structure" (Gay and Proops, 1993: 116). This means that the manufacture of secondary fuels (such as, e.g. electricity or gasoline) should be ignored in the main calculation of CO_2 emissions so that double counting is avoided (IPCC, 1996).

[8] This expression is also the result of some considerations, namely: *n* activity sectors; three types of fossil fuels: natural gas, coal and oil; and the assumption that the use of fossil fuels by any sector is proportional to the total output from that sector.

where: **C** is a (3x*n*) matrix, whose generic element (c_{fi}) represents the (physical) quantity of fuel *f* used by sector *i* per unit of total output (i.e. the 'energy intensities corresponding to direct production demand'); **P** is a (3x*n*) matrix, which has only three non-zero elements, one for each fuel type, expressing the (physical) quantity of fossil fuel use per unit of final demand (i.e. the 'energy intensities corresponding to direct consumption demand'); and **H** is a (*n*x*n*) diagonal matrix, with only three non-zero elements, which are the ratios of the sum of 'final consumption of households' and 'collective consumption', to total final demand, for the three fossil fuel sectors[9].

Correspondingly, it is considered in this study that the total CO_2 emissions by an economy (given by the scalar *c*) can be considered as the sum of the production CO_2 emissions [$c_{ind} = \mathbf{e'C(I\text{-}A)^{-1}y}$] and final demand CO_2 emissions [$c_{dem} = \mathbf{e'PHy}$][10], that is:

$$c = \mathbf{e'C(I\text{-}A)^{-1}y} + \mathbf{e'PHy} \Leftrightarrow c = [\mathbf{e'C(I\text{-}A)^{-1}} + \mathbf{e'PH}]\ \mathbf{y} \qquad (7)^{11},$$

where **e'** is the transpose of a 3-vector, **e**, whose generic element (e_f) represents the amount of CO_2 emission per unit of fuel *f*.

Furthermore, we can decompose the total CO_2 emissions as the result of an iterative process that shows CO_2 emissions progressive adjustments to final demand and fossil fuel requirements:

$$c = [\mathbf{e'PHy} + \mathbf{e'Cy}] + [\mathbf{e'CAy} + \mathbf{e'CA^2y} + \ldots + \mathbf{e'CA^{t-1}y} + \ldots] \qquad (8).$$

where (**e'PHy**) represents the CO_2 emissions attributable to direct consumption demand for fossil fuels, while (**e'Cy**) represents the CO_2 emissions attributable to direct, and the sum of all the others [$\mathbf{e'(CA+CA^2+\ldots)y}$] to indirect production demand.

2. 3. The 'attribution' of the energy requirements and CO_2 emissions

Equations (6) and (7) make clear that both the energy requirements and the total CO_2 emissions produced by an economy can be attributed to total final demand for goods and services (represented by the final demand vector, **y**). This can be particularly useful for policy analysis purposes, as this ultimately imputes all fossil fuel use and CO_2 emissions to households' purchases.

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[9] The final demand for fossil fuels corresponding to investment is not used (burnt), and consequently do not correspond to CO_2 emissions. Furthermore, the final demand for fossil fuels corresponding to exports, as these fuels leave the country concerned, are used elsewhere and therefore does not corresponds to domestic CO_2 emissions. Thus, as interest is directed towards only those fuels which were burnt (Proops et al., 1993: 154), there is need to consider only the final consumption ('final consumption of households' plus 'collective consumption'). Accordingly, we can 'modify' the final demand vector (**y**) to 'exclude' the investment and export components, by premultiplying it by a suitable (*n*x*n*) scaling matrix, **H**, and therefore using a modified final demand vector (**Hy**).

[10] For reasons of completeness, other minor sources of CO_2 emissions – other then fossil-fuel burning – should have been included in the analysis. Proops et al. (1993) do this in their analysis. However, in this specific study, and because of a lack of detailed information for Portugal, the production of CO_2 emissions from non-fuel sources will not be covered, which can be considered as a shortcoming of this work.

[11] If we use **ê** (where **ê** is a (3x3) matrix, with the vector **e** on the diagonal) instead of **e'**, the fuel sources fundamentally responsible for CO_2 emissions are explicitly identified, since a vector of pollution intensities for each of the fuels combusted in the economy is estimated. If we use **e'**, as is the case here, then the scalar of pollution obtained represents pollution intensities for the total fuels burnt.

Moreover, according to the 'components' of the final demand considered, it is possible to distinguish energy requirements and CO_2 emissions attributable to domestic consumption, from that attributable to exports, as well as to estimate the levels of energy and CO_2 emissions 'embodied' in the country's imports. It is then possible to estimate primary energy and CO_2 emissions 'embodied' in a country's international trade, as well as the country's 'responsibility' for CO_2 emissions (i.e. the CO_2 emissions attributable to consumption by a country's economy, whether arising from domestic or from foreign goods and services), and the CO_2 emissions produced by the country's economy (i.e. the CO_2 emissions attributable to the production made in the country's economy, whether demanded by national or by foreign final consumers and industries)[12].

Such an exhaustive analysis of the energy requirements and CO_2 emissions attributable to the different 'components' of the final demand was performed elsewhere for the Portuguese case (Cruz, 2002a). Here, as the interest is on the analysis of the accomplishment of the Portuguese CO_2 emissions target established under the Kyoto Protocol, we shall concentrate on the appraisal of the CO_2 emissions attributable to the production made in the Portuguese economy (and therefore released on Portuguese territory). Indeed, the Kyoto Protocol, as well as other international agreements, focus on activity solely in the national boundary[13].

2. 4. The assessment of the impacts on the level of employment

The modelling framework presented above, by combining energy and environmental (physical) data and (monetary) input-output tables, is suitable for the analysis of economic, energy, and/or environmental effects of specific 'developments', whether resulting from the 'natural' progress of the economies, whether shaped by specific policy measures.

But particularly within a perspective of sustainable development, there should also be included in the analysis the study of social or socio-economic aspects (impacts on society), such as, for example, income distribution, poverty issues, social integration/exclusion, and/or employment.

Therefore, it is appropriate to extend further the analysis to include the social dimension, which will here be measured through the level of employment in an economy. Of course, it is easily arguable that this 'indicator' is not the most appropriate one, or at least not the only one. But behind this 'selection' were two main stimuli: on the one hand, practical implementation concerns in terms of the empirical analysis which will be performed (mainly availability of suitable data)[14]; and, on

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[12] Also, it is important to recall that what is considered in the input-output table is the domestic output by sector (i.e., imports are excluded); therefore, the energy requirements and 'consequent' CO_2 emissions correspond to goods and services produced in the country.

[13] This is so because, among other factors, as the Protocol is legally binding, no government can be held responsible for the actions that occur in another country.

[14] Of course, particularly the use of the SAM or SAMEA statistical data's framework would have allowed the use of much more appropriate indicators (with particular emphasis for income distribution issues).

the other hand, the fact that the reduction of unemployment (to as low as is practicably possible without harming other aspects of the economy, society and environment) should be a core aim for sustainable development.

Thus, this social (or perhaps more correctly, this socio-economic) variable will be added to the analysis, within the input-output empirical framework, a task that can be done in a quite straightforward manner[15]. Indeed, the total employment of one country's economy (represented by scalar l) can be written as:

$$l = \mathbf{j'}(\mathbf{I}\text{-}\mathbf{A})^{-1}\mathbf{y} \qquad (9),$$

where **j'** is the transpose of a n-vector **j**, whose generic element (j_i) represents the employment's requirements per unit of total output in sector i (i.e. the inverse of labour productivity).

Therefore, the implications of specific 'actions' on the level of employment, as well as some constraints that this 'subject' imposes on other dimensions, may also be assessed in the scenarios analysis that will be performed in Section 4 of this paper.

3. Estimation of CO_2 emissions by the Portuguese economy

In this section, there will be presented an input-output empirical application of the energy-economy-environment interactions for Portugal, especially concerning the energy intensities and CO_2 emissions derived from fossil fuels use, according to the modelling approach described above.

3. 1. Data preparation[16]

3. 1. 1. Portuguese national accounts and the input-output table

A number of adjustments needs to be made to the way figures are presented by the Portuguese system of economic accounts, published by the National Institute of Statistics (INE, 1999), to achieve a valuation of the supply and use flows as consistently and homogenously as possible, and obtain the input-output tables that are the basis for the empirical analysis to be performed in this work. However, the estimation of such tables was only possible for 1992[17],

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[15] Actually, employment considerations were included in input-output analysis, under the label of 'employment multipliers', even before the incorporation of energy and environment considerations. Indeed, the estimation of the effects of exogenous changes in the level of employment is one of the most frequent applications of input-output analysis. The assumptions underlying the incorporation of the analysis of employment in the input-output framework are that there exists a direct and linear relationship between employment and output in all sectors of the economy, and that labour is homogeneous (Bulmer-Thomas, 1982: 199).

[16] A detailed description of the adjustments made to the Portuguese national accounts, as well as the characteristics and the adjustments made in the Portuguese energy data used may be found in Cruz (2002b).

[17] Of course, the absence of more up-to-date data may constitute a restriction to providing useful information for practical policy decisions. However, the basic economic structure of the economy changes relatively slowly over time and therefore, for many aspects, the table(s) will be relevant over a reasonable period of time (Miller and Blair, 1985: 269). Nevertheless, the performance of the analysis for more recent years and the investigation of the reasons behind the changes which might have occurred (through structural decomposition analysis), should be explored as soon as the information becomes available, particularly concerning National Accounts.

because the ‘auxiliary’ data to perform the required treatments is only surveyed with a breakdown of all interindustry transactions (by industries and by products) and of final uses by product for the 1992 Portuguese national accounts.

It is also important to mention that in order to be able to explore alternative scenarios for electricity generation, the electricity sector was disaggregated into three ‘sub-sectors’[18]: 6A - Fossil Fuel Electricity Generation, 6B - Hydroelectricity, and 6C - Electricity Distribution. To perform this disaggregation, following Gay and Proops (1993), and Proops et al. (1993), it is assumed that:

- the two generating sectors (6A and 6B) sell all of their output to the distribution sector (6C)[19];
- the fuel inputs to electricity are attributed entirely to fossil fuel generation[20], and all other inputs are split between the two generating sectors in proportion to their total output; and
- all purchases of electricity by the remaining sectors and by final demand are supplied by electricity distribution.

This resulted in the use of a (38x38) industry-by-industry input-output table, for Portugal, in 1992. From this table was derived the matrix **A**, by dividing inter-industry flows by the total inputs (=total outputs) by industry at basic prices, as usual. It was also from this table that was derived matrix **H**, as well as the final demand vector **y** and the employment requirements vector **j**.

3. 1. 2. The physical quantities of primary fossil fuels used in the Portuguese economy

To perform the study there is also the need to consider the (physical) quantities of primary fossil fuels used by each industry per unit of total output, as well as the quantities of fossil fuels used per unit of final demand. However, such data was generally not directly available in the appropriate, or consistent, form. Therefore, there was the need to make some assumptions and estimations in order to correlate the different data sources, namely the input-output tables (provided by the INE) and the energy balance statistics (supplied by the Portuguese Directorate General of Energy – DGE).

According to the ‘Energy Balance’ statistics for 1992 (DGE, 1995), the Portuguese economy total consumption of coal and (crude) oil was of 2,949,576 and 13,148,058 tonnes of oil equivalent (toe), respectively. These values were considered as credible totals of domestic energy use (by type of fuel) and it was from these that were derived the physical quantities of coal and oil used by each of the 38 sectors and by final consumers in 1992[21]. Then, dividing these values by the corresponding

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[18] This was done because of the need to distinguish fossil-fuel electricity generation from other electricity generation, since electricity obtained, e.g., from hydro, wind, and solar sources, do not correspond to CO_2 emissions.
[19] This means that the two electricity-generating sectors have zero final demand.
[20] Which means that hydroelectricity generation and the distribution side of electricity are recorded as using no fossil fuel at all, which is clearly an underestimate (Gay and Proops, 1993: 123).
[21] It is important to note that the use of natural gas was introduced in Portugal only in 1997. Thus, as the analysis done in this study is for 1992, only two primary energy sources were considered. Consequently, matrices **C** and **P** are of dimension (2x38), and vector **e** is a 2-vector.

element of the total input (=total output) vector or by the final demand vector, it was possible to determine the primary energy intensities (or requirements) per unit of total output by sector (the 2x38 matrix **C**) and per unit of final demand (the 2x38 matrix **P**).

3. 1. 3. The carbon content of primary fuels

CO_2 emissions are produced when carbon-based fuels are burned. Therefore, after adjusting primary energy figures, it is possible to estimate CO_2 emissions from fuel combustion, by considering the carbon contents of each type of fuel. For this purpose, conversion factors from primary energy to CO_2 were applied. These conversion factors were calculated following the IPCC's default methodology to make countries' greenhouse gas emissions inventories (IPCC, 1996), and were arranged in a vector of CO_2 emission per unit (toe) of fuel burnt (the 2-vector **e**). Accordingly, it is assumed that each toe of coal burnt generates 3.88 tonnes of CO_2, and that each toe of oil burnt generates 3.04 tonnes of CO_2[22]. These figures clearly show that the amounts of CO_2 emitted directly depend on the fuel, with more CO_2 being emitted per unit of energy content for coal than for oil (and for natural gas).

3. 2. The input-output assessment of CO_2 emissions

In this section there will first be determined the CO_2 intensities per unit of total output and per unit of final demand, in terms of tonnes of CO_2 per million Portuguese Escudos (PTE). Subsequently, there will be reported the total CO_2 emissions for a given structure of final consumption, both in aggregate and disaggregated to 38 sectors.

3. 2. 1. The CO_2 intensities

As derived from equation (8), the elements of the row-vector ($\mathbf{e'C}$) represent the tonnes of CO_2 emitted directly by each sector, per million PTE of final demand for the output of that sector; and the elements of [$\mathbf{e'C}(\mathbf{A}+\mathbf{A}^2+\ldots)$] represent tonnes of CO_2 emitted throughout the rest of the economy (i.e. indirectly) by each sector, per million PTE of final demand for the output of that sector. Moreover, the elements of the vector ($\mathbf{e'P}$), containing only two non-zero elements (one for each type of fuel), represent tonnes of CO_2 emitted per million PTE of demand by consumers for fuels. Thus, the sum of CO_2 intensities corresponding to total production demand and to direct consumption demand, represents tonnes of CO_2 emitted per million PTE of final demand, for each sector. Table 1 contains the estimated corresponding figures.

[22] Likewise, it was also estimated that each toe of natural gas combusted generates 2.34 tonnes of CO_2. This result will only be used later, in the scenarios analysis, as in 1992 there was no use of natural gas in Portugal.

Table 1
CO_2 intensities
and
CO_2 emissions produced by the Portuguese economy

unit for CO_2 intensities: tonnes of CO_2 / million PTE
unit for CO_2 emissions: 10^3 tonnes of CO_2

	CO_2 intensities (corresponding to:)						**CO_2 emissions produced by the Portuguese economy** (attributable to:)									
	Direct Production Demand +	Indirect Production Demand =	Total Production Demand +	Direct Consumption Demand =	Final Demand		Direct Production Demand +		Indirect Production Demand =		Total Production Demand +	Direct Consumption Demand =		Final Demand		
	e'C	**e'C (A+A²+...)**	**e'C (I-A)⁻¹**	**e'P**	**Total CO_2 Intensity**	*Total CO_2 Intens. Rank.*	**e'Cy**	(6)/(10)	**e'C (A+A²+...)y**	(7)/(10)	**e'C (I-A)⁻¹y**	**e'PZy**	(9)/(10)	**Total CO_2 emissions**	*Total CO_2 Emis. Rank.*	*% Distrib of CO_2 Emis. by Ind.*
	(1)	(2) = (3)-(1)	(3)	(4)	(5) = (3)+(4)		(6)	%	(7) = (8)-(6)	%	(8)	(9)	%	(10) = (8)+(9)		
01 Agriculture, Hunting and Related Service Activities	1.12	1.89	3.01	0.00	3.01	17	394.0	37.1	668.2	62.9	1 062.2	0.0	0.0	1 062.2	12	2.1
02 Forestry, Logging and Related Service Activities	0.71	0.36	1.07	0.00	1.07	28	17.5	66.5	8.8	33.5	26.3	0.0	0.0	26.3	36	0.1
03 Fishing and Related Service Activities	3.20	0.97	4.17	0.00	4.17	13	191.1	76.7	58.0	23.3	249.0	0.0	0.0	249.0	26	0.5
04 Mining and Manufacture of Coal By-Products	34.99	2.94	37.93	397.56	435.49	1	13.6	30.6	1.1	2.6	14.8	29.8	66.8	44.6	33	0.1
05 Extr. Crude Petrol. ..., & Man. Refined Petroleum Prod.	7.67	1.87	9.54	158.85	168.39	2	844.7	9.9	205.7	2.4	1 050.3	7 448.3	87.6	8 498.7	1	16.5
6A Fossil Fuel Electricity Generation	73.74	1.00	74.75	0.00	74.75	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	37	0.0
6B Hydroelectricity	0.00	0.17	0.17	0.00	0.17	38	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	37	0.0
6C Electricity Distribution	0.00	33.83	33.83	0.00	33.83	4	0.0	0.0	5 735.5	100.0	5 735.5	0.0	0.0	5 735.5	2	11.2
07 Gas Production and Distribution	14.06	9.58	23.64	0.00	23.64	6	142.1	59.5	96.8	40.5	238.9	0.0	0.0	238.9	27	0.5
08 Water Supply	0.00	6.01	6.01	0.00	6.01	11	0.0	0.0	161.8	100.0	161.8	0.0	0.0	161.8	29	0.3
09 Extr. & Man. of Ferrous & Non-Ferrous Ores & Metals	5.24	6.31	11.55	0.00	11.55	7	327.9	0.0	394.7	0.0	722.6	0.0	0.0	722.6	19	1.4
10 Extraction and Manuf. of Non-Metallic Minerals	6.09	4.71	10.80	0.00	10.80	8	865.2	56.4	668.3	43.6	1 533.5	0.0	0.0	1 533.5	10	3.0
11 Manuf. of Chemicals and Chemical Products	5.98	2.55	8.53	0.00	8.53	9	1 515.8	70.1	646.4	29.9	2 162.2	0.0	0.0	2 162.2	8	4.2
12 Manufacture of Fabricated Metal Products	0.19	2.99	3.18	0.00	3.18	16	43.4	6.0	682.0	94.0	725.4	0.0	0.0	725.4	18	1.4
13 Man. of Electrical and Non-Electrical Machinery & Equipm.	0.06	1.26	1.32	0.00	1.32	25	35.6	4.9	694.1	95.1	729.7	0.0	0.0	729.7	17	1.4
14 Manufacture of Transport Equipment	0.15	1.11	1.26	0.00	1.26	27	57.9	11.7	437.4	88.3	495.3	0.0	0.0	495.3	21	1.0
15 Manufacture of Food Products and Beverages	0.36	1.97	2.34	0.00	2.34	22	431.8	15.6	2 336.6	84.4	2 768.4	0.0	0.0	2 768.4	7	5.4
16 Manufacture of Tobacco and Tobacco Products	0.19	0.29	0.48	0.00	0.48	37	27.9	39.2	43.3	60.8	71.2	0.0	0.0	71.2	32	0.1
17 Manufacture of Textiles and Clothing	0.37	2.40	2.78	0.00	2.78	19	388.7	13.5	2 495.1	86.5	2 883.8	0.0	0.0	2 883.8	6	5.6
18 Manufacture of Leather and Footwear	0.20	1.10	1.30	0.00	1.30	26	66.2	15.3	367.3	84.7	433.5	0.0	0.0	433.5	24	0.8
19 Other Manuf. Products (incl. Wood, Cork & Furniture)	0.68	1.97	2.65	0.00	2.65	21	202.9	25.7	587.7	74.3	790.6	0.0	0.0	790.6	16	1.5
20 Man. of Pulp, Paper, Paper Prod. & Printing Products	1.18	3.09	4.27	0.00	4.27	12	225.4	27.7	587.7	72.3	813.1	0.0	0.0	813.1	15	1.6
21 Manufacture of Rubber and Plastic Products	0.18	2.80	2.98	0.00	2.98	18	11.3	6.0	177.9	94.0	189.2	0.0	0.0	189.2	28	0.4
22 Construction	0.67	2.76	3.42	0.00	3.42	14	995.1	19.5	4 103.3	80.5	5 098.4	0.0	0.0	5 098.4	3	9.9
23 Recycling, Recovery and Repair services	0.20	0.34	0.53	0.00	0.53	36	48.5	36.6	84.0	63.4	132.6	0.0	0.0	132.6	31	0.3
24 Wholesale and Retail Trade	0.16	1.93	2.09	0.00	2.09	23	269.0	7.5	3 325.8	92.5	3 594.8	0.0	0.0	3 594.8	5	7.0
25 Hotel and Restaurant Services	0.12	2.56	2.67	0.00	2.67	20	86.8	4.4	1 902.3	95.6	1 989.0	0.0	0.0	1 989.0	9	3.9
26 Land Transport and Transport Via Pipeline Serv.	21.24	2.50	23.74	0.00	23.74	5	4 545.2	89.5	535.3	10.5	5 080.5	0.0	0.0	5 080.5	4	9.9
27 Water and Air Transport Services	4.91	1.52	6.43	0.00	6.43	10	726.5	76.4	224.5	23.6	951.0	0.0	0.0	951.0	14	1.8
28 Supporting and Auxiliary Transport Services	0.17	3.11	3.27	0.00	3.27	15	17.4	5.1	324.7	94.9	342.1	0.0	0.0	342.1	25	0.7
29 Post and Telecommunication Services	0.03	1.01	1.04	0.00	1.04	30	4.4	3.2	132.5	96.8	136.9	0.0	0.0	136.9	30	0.3
30 Financial Intermediation Services (except Insurance and ...)	0.00	0.56	0.56	0.00	0.56	35	0.1	0.2	37.8	99.8	37.8	0.0	0.0	37.8	35	0.1
31 Insurance and Pension Funding Services	0.06	1.54	1.59	0.00	1.59	24	1.4	3.5	38.8	96.5	40.2	0.0	0.0	40.2	34	0.1
32 Real Estate Services and Other Renting Services	0.01	0.99	1.00	0.00	1.00	31	14.3	1.5	954.4	98.5	968.7	0.0	0.0	968.7	13	1.9
33 Education and R & D Services	0.02	0.55	0.57	0.00	0.57	34	17.3	3.6	463.9	96.4	481.2	0.0	0.0	481.2	22	0.9
34 Health and Veterinary Market Services	0.01	0.82	0.83	0.00	0.83	33	7.6	1.6	464.5	98.4	472.1	0.0	0.0	472.1	23	0.9
35 Other Services (Market and Non-Market)	0.07	0.91	0.98	0.00	0.98	32	39.6	6.8	542.3	93.2	581.9	0.0	0.0	581.9	20	1.1
36 Public Administration Non-Market Services	0.09	0.97	1.06	0.00	1.06	29	100.7	8.6	1 070.4	91.4	1 171.1	0.0	0.0	1 171.1	11	2.3
							12 676.8	**24.7**	**31 258.9**	**60.8**	**43 935.7**	**7 478.1**	**14.5**	**51 413.8**		100

Concerning total CO_2 intensities, the energy sectors (except Hydroelectricity) are unsurprisingly the ones that appear in the upper ranking, followed also predictably by the Land Transport sector. The total CO_2 intensity of the two top sectors (Mining and Manufacture of Coal By-Products and Extraction of Crude Petroleum and Natural Gas; and Manufactured Refined Petroleum Products) is dominated (in 91.3 and 94.3 per cent, respectively) by the intensities corresponding to direct consumption demand. For all the other sectors, the CO_2 intensities correspond only to production demand (on the clear majority of them mainly to indirect production demand).

3. 2. 2. CO_2 emissions produced by the Portuguese economy

From equation (8), multiplying the CO_2 intensities presented above by the final demand vector, one achieves the corresponding tonnes of CO_2 emitted by each sector, which are shown also in Table 1.

In 1992, according to the estimation made through the model, 51,413.8 kilotonnes of CO_2 were emitted on Portuguese territory, derived from the use of fossil fuels, in order to satisfy the domestic and foreign final demand for goods and services domestically produced[23].

The top five sectors 'responsible' for those CO_2 emissions are Extraction of Crude Petroleum, and Manufacture of Refined Petroleum Products (16.5 per cent), Electricity Distribution (11.2 per cent), Construction (9.9 per cent), Land Transport and Transport Via Pipeline Services (9.9 per cent), and Wholesale and Retail Trade (7 per cent). This means that the former four sectors account for almost half of total CO_2 emissions attributable to production in the Portuguese economy. Moreover, as the CO_2 emissions by the Extraction of Crude Petroleum, and Manufacture of Refined Petroleum Products sector are mainly associated with the use of private cars, and as the production of CO_2 emissions by the Land Transport and Transport Via Pipeline Services is mainly connected with freight and passengers transport, one can say that (personal and public) transport (of passengers and goods) was 'responsible' for almost one-quarter of all the emissions that occurred in Portugal in 1992.

Relating these results with those concerning CO_2 intensities, one can notice that the sectors that are more highly CO_2 intensive are not necessarily the ones whose production generates more CO_2 emissions. This is explained by what might be called the 'scale effect' of the final demand (corresponding to the fact that the total CO_2 emissions of any sector are given by the product of the intensity per unit of final demand and the level of final demand).

[23] This figure is slightly higher than the 45,165.9 kilotonnes of CO_2 reported by EEA (2002), which were estimated also following the IPCC Guidelines (IPCC, 1996). It is important to remember that not only are some components of the data used in this work of poor quality, which implied the making of some assumptions, but also that only one coefficient was used for each fuel, which may have had some effect in this discrepancy.

Another key result is the significant importance of the indirect production demand for fuels in the production of CO_2 emissions. Indeed, more than half (60.8 per cent) of the CO_2 emissions are attributable to indirect demand, while 24.7 per cent of the emissions are attributable to direct demand for fossil fuels by industries; the remaining 14.5 per cent are directly attributable to household demand for fossil fuels.

3. 3. Policy relevance

The results obtained in this empirical application are clear evidence of the 'value-added' that the input-output technique may bring to policy analysis, as an approach which takes economic interrelations into account when analysing CO_2 production (Gay and Proops, 1993: 123).

Indeed, it appears that there is significant general awareness about the CO_2 emissions that occur from direct energy use in households and private cars, as well as about the CO_2 emitted directly in energy industries and by the transport sectors. But more significant is that it appears that there does not exist a general awareness about the major importance of industries' indirect production demand for fuels, and consequently of the fact that the great majority of direct consumption is 'responsible' for much more CO_2 production indirectly than directly.

Therefore, the analysis performed here may help policy-makers in dealing with the problem of CO_2 emissions as they are better informed about the root causes of some outcomes.

It may also help to make final consumers aware that the non-primary energy goods and services they purchase from industry sectors have entailed CO_2 emissions in their production. Indeed, through sensitisation campaigns and/or by labelling the final products (indicating there the direct as well as the indirect CO_2 emissions 'embodied' in such products), for example, it is possible to show to final consumers that they have much more 'responsibility' for CO_2 emissions than they usually assume. Then, it is possible to pass the 'message' to them that their individual action in terms of the goods and services they purchase (or not) may 'count' in the global struggle against climate change.

Thus, it is possible to claim that one of the key accomplishments of the use of this type of modelling, which integrates (socio-)economic, energy and environmental interactions in an input-output framework, is that it allows the analysis of how energy, and therefore CO_2 emissions, are related to industrial production, and ultimately to final demand, making it a tool particularly important for (*ex ante* and/or *ex post*) policy analysis purposes.

Further, both the model and the database are formulated in terms of detailed technical parameters, on a multisectoral basis, that can be directly evaluated by technical experts and readily changed in order to explore the consequences of alternative scenarios.

4. Scenarios analysis

This section will make use of scenarios analysis, based on the model presented in Section 2. The focus will be on the analysis of the accomplishment (or not) of the Portuguese commitment to a maximum increase of 40 per cent in CO_2 emissions from 1990 to 2008-2012 (established by the European Union 'burden-sharing' agreement on greenhouse gas emissions reduction, under the Kyoto Protocol targets). Accordingly, 1992 will be taken as the base year, and 2010 is the year chosen to be the time horizon[24].

The simulations that will be carried out do not have forecasting or prediction purposes. Instead, the aim is to be illustrative, in the sense that they will explore the structure of the Portuguese economy, in order to extract implications that may help in the derivation of useful insights for (socio-)economic, energy and/or environmental policy purposes.

For this, there will be first presented the Basic Scenario, where changes in the structure and level of final demand will be considered. Then, in Section 4.2, there will be added some hypotheses concerning technological changes, to account for some CO_2 emissions mitigation options for the Portuguese economy. Finally, in Section 4.3, there will be offered the key policy findings which were derived from the performance of such scenarios analysis.

4. 1. Changes in the structure and level of final demand (the Basic Scenario)

In this section, there will be offered the general description of the Basic Scenario for 2010. This scenario assumes changes in the structure and level of final demand (changes in vector **y**), but no technological changes[25], considering the 1992 data (presented in Section 3) as the base.

According to the figures published by INE (2002), in the 'Preliminary Annual National Accounts 1995-2001', the Portuguese average annual real growth rate of GDP for the period 1995-2001 was 3.5 per cent. The maintenance of this rate of growth until 2010 seems possible, and in the Portuguese case it can be 'normatively' considered as 'required', in the sense that such a rate of growth would allow Portuguese economic convergence with the other European Union's economies. Therefore, we shall assume as given an average annual growth rate of 3.5 per cent for

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[24] The base year in terms of the Kyoto Protocol is 1990, but for convenience of data availability, 1992 will be here considered as the base year, with the conviction that the differences are not very considerable, or at least that the conclusions of the analysis will not be significantly biased. Therefore, the information shown in Section 3 constitutes what may be designated as the 'baseline' that will assist in the running of the scenarios simulations. Moreover, the targets of the Kyoto Protocol were established from 1990 figures to the average of 2008-2012; this is usually referred to as the 2010 target for simplicity.

[25] Accordingly, we assume that both the Portuguese basic structure of inter-industry relations (elements of the matrix **A**), as well as the (primary) direct energy and CO_2 intensities (elements of matrices **C** and **P,** and vector **e**) do not change from 1992 to 2010.

GDP, from 1992 until 2010. Moreover, we shall assume here that the sum of all the sectors' final demands at basic prices ($Y=\sum_{i=1}^{n} Y_i$) will increase at exactly this rate[26].

Besides the change in the total level of final demand, there will also be considered different rates of final demand growth for the different sectors (i.e. we are considering that the proportion of each sector's final demand in relation to the total final demand will change relatively to 1992).

The 'Preliminary Annual National Accounts 1995-2001' (INE, 2002) also allowed the calculation of the average annual growth rates of total inputs (equal to total outputs) for specific groups of sectors, for the period 1995-2001, as follows:

- 'Agriculture, Forestry and Fishing' (Sectors 1, 2 and 3): - 0.9%
- 'Electricity' (Sectors 6A, 6B, 6C, and 7): 4.2%
- 'Construction' (Sector 22): 5.0%
- 'Trade and Hotels and Restaurants'(Sectors 23, 24 and 25): 3.2%
- 'Transports and Communications' (Sectors 26 to 29): 4.6%
- 'Financial Intermediation and Real Estate Activities' (Sectors 30, 31 and 32): 8.6%
- 'Other Services' (Sectors 33 to 36): 2.9%

As expected, these figures are in accordance with the general trend for a shift away from the 'primary sectors' of the economy, towards large and rapidly expanding 'tertiary sectors'. This expansion is particularly notable in financial intermediation services. Moreover, in recent years, with the increase in the Portuguese standard of living, there has been an increase in average per capita energy services, especially from increased demand for lighting, electrical appliances, and space conditioning. There has also been an important increase in the use of communication services, as well as in the number of (private and public) motor vehicles, and in the number of miles they are driven. Further, these trends are expected to continue for the coming years. Therefore, we shall assume that, from 1992 to 2010, the final demand for each sector will increase (decrease) at the corresponding average annual rates presented above.

Moreover, the rates of change of the final demand for the remaining sectors (i.e. the 'Industry' sectors) are determined in a way that allows compatibility between all of the previous assumptions concerning final demand changes. That is, in order to bring into equality the sum of all of the sector's estimated final demand, considering different rates of change for each sector, with the figure estimated for the total final demand of the economy in 2010 according to the given 3.5 per cent annual rate of growth. This requires the assumption of:

[26] This is equivalent to say that the assumed growth of GDP, and therefore of the total final demand, from 1992 to 2010 is 85.75 per cent.

• an annual average rate of growth of 1.7 per cent for the final demand of those remaining sectors[27] (i.e., in Sectors 4, 5, and 8 to 21).

Furthermore, we assume that the proportions corresponding to each component of the final demand for each sector (according to the structure of matrix **H**) remain constant in relation to the 1992 situation.

Moreover, concerning the employment 'dimension', it is pertinent to take into consideration expected sectoral gains of productivity. According to Proença and Dias (1999), annual growth rates of labour productivity of the order of 3.1 per cent in the Portuguese economy are feasible, and this was the annual average rate considered in their macroeconomic reference scenario for the period 2000-2006. Furthermore, according to data provided by INE (1999), it was possible to estimate the aggregate and the sectoral trends for the period 1989-1995. For example, the number of 'full time equivalent' (FTE) jobs required per unit of total output for the Portuguese economy decreased annually at an average rate of 3 per cent (which is equivalent to an improvement in productivity of 3.1 per cent). Therefore, we shall assume this aggregate rate for our period of analysis (1992-2010), as well as the corresponding annual average rates of reduction in each element of vector **j**.

Therefore, it is possible to estimate the employment, energy requirements, CO_2 emissions, and the matching levels of total output, which correspond to such a set of hypotheses, as shown in Table 2.

Table 2 – The Basic Scenario

Output, Employment, Energy requirements, and CO_2 emissions attributable to total final demand

(Assumed rate of growth for total final demand from 1992 to 2010 = 85.75% ⇔ 3.5% p.a.)	**2010**	**% Change** from 1992 to 2010
Total Output (at basic prices)	42,328 (billion PTE at 1992 prices)	84.6
Employment required in the economy	4,568 (10^3 FTE jobs)	1.6
Primary energy requirements	5,487.7 (10^3 toe of coal)	86.1
	22,915.1 (10^3 toe of oil)	74.3
Total CO_2 emissions	90,953.6 (10^3 tonnes of CO_2)	76.9

Concerning the estimated growth in the global level of output by the Portuguese economy by 2010, it is clear that it is similar to the assumed growth for the global level of final demand, as one would have expected. However, concerning each sector's output, it is worthwhile to note that their rates of growth are not exactly the same as those for final demand. Indeed, although it was

[27] This rate of growth, below the average annual growth rate for the economy, seems acceptable as it reflects the general trend for the increasing importance of services and commerce in the Portuguese economy, and at the same time it reflects the fact that industry sectors' output continues to increase but at a slower rate.

assumed that only the final demand for twelve sectors would growth more than the assumed growth rate for total final demand, it can be said that the estimations show that fourteen of the thirty-eight sectors will grow faster than total Portuguese product. Also worth mentioning is that, for example, there is estimated a rate of growth of 19.1, 48.1 and 9.9 per cent in the output of Sectors 1, 2 and 3, respectively, despite the fact that we have assumed a 15 per cent decrease in their final demand[28].

Concerning the estimated global level of employment required in the Portuguese economy to satisfy its final demand in 2010, one can notice that it increases 1.6 per cent (compared with the 4,495.6 thousands of FTE jobs that were required in 1992)[29].

The estimations also show that, as expected, the increased volume of economic activity implied by the assumptions taken, *ceteris paribus*, involves substantial increases in energy use and pollutant emissions. Indeed, under this Basic Scenario, satisfying the final demand in 2010 would require 76.4 per cent more (primary) energy than in 1992 (i.e. 86.1 per cent more toe of coal, and 74.3 per cent more toe of oil), with a corresponding increase of 76.9 per cent in CO_2 emissions.

But it is also noticeable that the assumed changes will lead to a slower growth of CO_2 emissions than the global growth of final demand (76.9 per cent against 84.6 per cent, respectively). Accordingly, it is possible to claim that the general trend for 'de-materialisation' (which is to some extent translated in the assumptions here made concerning the alterations in the structure and level of final demand) is somewhat favourable for CO_2 emissions.

Nevertheless, this is not enough. Indeed, these results show that with everything remaining the same until 2010, with the exception of final demand, Portugal will be very far from accomplishing their commitments to a maximum increase of 40 per cent in CO_2 emissions.

But besides final demand, other factors, policy driven or not, have changed from 1992 and will continue to change until 2010, and we shall also try to reflect some of these changes and their potential impacts in the scenario(s) that will be analysed in the next section.

4. 2. Technological changes

As seen in the previous section, it is imperative to change the 'state of affairs'. Just as the bulk of CO_2 emissions results from the use of fossil fuel energy, so the majority of the savings, or at least the major contribution to bring to an end the growth of CO_2 emissions, will have to result from action to reduce this. Accordingly, it can be argued that the most appropriate CO_2 emissions mitigation options for the Portuguese economy can be divided into three main categories, which

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[28] This is the result of the interconnections of all the sectors in the economy, which are well captured when making use of the input-output methodology. Indeed, despite the assumed decrease in the final demand for these sectors' output, their total output will increase. This is because the intermediate demand for the products of these sectors will increase more significantly, in order to satisfy the assumed increasing final demand for all the other sectors' products.

[29] Of course, this figure is the result of the sectoral assumptions concerning both the expected growth in final demand and in labour's productivity.

are: the increasing penetration of natural gas use; growing employment of renewable energy sources (particularly in electricity generation); and energy efficiency improvements.

4. 2. 1. Introduction and increasing penetration of natural gas use

The use of natural gas in Portugal was introduced in 1997, and from then to the present there has been a decided shift in the use of fuels, both by (energy and non-energy) industries and households, from coal and oil to natural gas. This shift has been particularly noticeable in the use of coal, which is expected to be almost completely abandoned in the medium term (not only in Portugal, but as a general 'trend' in all the European Union countries). Furthermore, according to DGE/ME (2002: 40) it is expected that natural gas will represent 22-23 per cent of primary energy consumption in 2010.

Accordingly, there will be assumed here a total replacement of coal use (which seems very plausible as the use of coal is mainly for electricity generation) and a 5 per cent replacement of oil use by natural gas, both by industries and final consumers.

The consideration of this switching to a mix of fuel inputs with lower CO_2 emissions in the whole economy demands a complex 'reconstruction' of the model, as the natural gas sector did not exist in 1992. Therefore, it will be necessary to 'build' new matrices (namely matrices **A***, **C*** and **P***), and new vectors (**e***, **x*** and **y***) to account for such a new energy sector[30].

4. 2. 2. Increase of non-fossil fuel electricity generation

There will also be considered a hypothetical change in the structure of electricity generation, to account for a significant increase in the use of renewable energy sources. More specifically, it will be assumed that the share of renewables in electricity generation will increase from 17 per cent in 1992 to 39 per cent in 2010, as this is the national target for the contribution of renewable energy sources to electricity production established in Directive 2001/77/EC (European Commission, 2001).

To account for this, the intermediate demand, as well as the total output, for the two electricity generation sectors[31] needs to be revised. As a result, a new vector **x****, as well as a new matrix **A**** and the respective Leontief Inverse matrix, are obtained.

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[30] Concerning the information required to construct the new (38x38) matrix **A***, where only the row and the column corresponding to the new Natural Gas sector are different from the matrix **A** estimated for 1992 (replacing the ones originally corresponding to the Coal sector), there was the need to obtain it through a benchmarking approach. After a comparative critical assessment, it was decided to extrapolate a 'possible' representation for a Natural Gas sector in Portugal according to the figures found for the Natural Gas sector in the Germany economy (in 1990). Grateful acknowledgement is due to E. Symons, S. Speck, and J. Proops, who provided the data concerning technical coefficients for Germany, which they used in the 2000 working paper "The effects of pollution and energy taxes across the European Income Distribution".

[31] However, it is important to note that we are not confounding electricity generation from renewables with hydroelectricity; it is only a simplifying assumption to incorporate all renewables contribution into Sector 6B, which means that the hydroelectricity technology will be considered as a *proxy* for electricity generation from renewables.

4. 2. 3. Energy efficiency improvements

Finally, there will also be considered a general energy efficiency improvement, both in the energy supply/production chain and in end-use systems.

The analysis of the (primary) energy efficiency situation in Portugal is necessarily limited, again due to the lack of available statistical information. In the absence of national data, autonomous energy efficiency improvements can be based on international figures, taken, for example, from studies analysing energy efficiency developments in different sectors, or even entire economies, as well as from assumptions made on the construction of scenarios on climate change issues. For example, Proops et al. (1993: Chapter 11), Manne and Richels (1998), IPCC (2000), and WRI (2001), present several scenarios and/or references, which typically assume annual improvements in energy efficiency between 0-2 per cent.

Therefore, there will be considered energy efficiency improvements which are felt to be desirable but also actually achievable, namely assuming an annual reduction of 0.5 per cent (i.e., 8.6 per cent reduction in the period 1992-2010) in each element of matrix **C**, as well as in the intensities of coal and oil use by final consumers (the two non-zero elements of matrix **P**)[32].

4. 2. 4. The 'Combined' Scenario

Thus, in this sub-section there will be performed an alternative scenario, continuing to assume the changes in the level and structure of the final demand presented in the Basic Scenario, together with a 'combination' of the structural changes in the technological relations succinctly described above, and which are intended to reflect those three CO_2 mitigation options[33]. The results produced are summarised in Table 3, presented below.

According to the results achieved, it can be claimed that, despite the poor situation so far[34], it is still possible to accomplish the Kyoto target for Portuguese CO_2 emissions, but also that such achievement does not oblige the sacrifice of economic progress and/or social responsibility. In fact, one of the most noteworthy findings that can be taken from this scenario is that, globally speaking, there need be no trade-offs between environmental and socio-economic improvements.

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[32] Although the rate of energy efficiency improvement varies between sectors, there will here be assumed an average rate for all the economy. It is also worth noting that, considering the average annual increase of 1.2 per cent in energy intensity from 1992 to 1999, to achieve an annual average decrease of 0.5 per cent between 1992 and 2010 implies that, from 2000 to 2010, the energy intensity will have to decrease at an average rate of 1.6 per cent per annum. Moreover, it is also important to note that we are not confounding energy efficiency with reductions in energy intensities of the products. Indeed, energy efficiency is only one of several factors that may contribute to reductions in the energy intensity.

[33] A detailed description of the practical adjustments made in order to incorporate such set of assumptions in the model, as well as the performance and analysis of separate scenarios for each of the three CO_2 mitigation options, may be found in Cruz (2002b).

[34] According to the estimations published by the European Energy Agency (EEA, 2002), the 40 per cent limit for the increase in Portuguese CO_2 emissions was already surpassed in the year 2000.

Indeed, the results estimated show that the developments considered in this scenario allow the restraining of the CO_2 emissions growth to 32.7 per cent by 2010. Moreover, these developments also allow a considerably superior rate of growth for total production (namely 85.8 per cent), as well as a 1.8 per cent rate of growth for total employment in the economy, from 1992 to 2010. But the most significant from this is that these rates of growth for total output and employment are not below the levels estimated in the Basic Scenario.

However, this does not means that to curb the current trend for a large expansion in Portuguese CO_2 emissions, and particularly to be below the 40 per cent limit by 2010, will be 'trouble-free'. On the contrary, it requires considerable efforts, as each one of these CO_2 emissions mitigation options, by itself (or even combining only two of the three), is not enough for Portugal to achieve its Kyoto commitments.

Actually, supposing that everything else happens as assumed above, except in what concerns, for example, energy efficiency, the results in terms of surpassing or not the Portuguese limit for CO_2 emissions growth vary importantly. Indeed, if the projected gains in energy efficiency do not happen at all, the estimated CO_2 emissions growth is 45.2 per cent by 2010. Also, if the 0.5 per cent annual average increase in energy efficiency occurs only in industrial fuel use (changes in matrix **C**), the CO_2 emissions are then estimated to increase by 34.3 per cent until 2010. If the efficiency gains only occur in direct final demand fuel use (changes in matrix **P**), the estimated rate for the growth of CO_2 emissions until 2010 is 43.6 per cent. Moreover, it is also noteworthy that if the assumed efficiency gains occur only in the (industrial and residential) use of oil, the CO_2 emissions will grow by 34.8 per cent; while if such improvement occurs only in the (industrial and residential) use of natural gas, the CO_2 emissions are estimated to increase by 43.1 per cent.

Undoubtedly, and as expected, 'current' more-efficient technologies (i.e. which make use of less fuel for a given level of output or final demand) produce lower CO_2 emissions than the average practice technologies that were in use in 1992 (and which were considered in the Basic Scenario)[35]. Moreover, energy-use effectiveness, in all sectors (including the 'residential') of the economy, can contribute not only to less adverse environmental impacts (e.g., in terms of CO_2 emissions), but also to improvements in terms of energy security (of supply), and to less dependence on imports (and corresponding improvements in terms of the balance of payments).

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[35] Indeed, the expected increase in energy demand resulting from increased standards of living, will be, to some extent (but not entirely), offset by expected gains in energy efficiency, as the new technologies are generally more efficient and cleaner than the ones they displace.

Table 3 - The 'Combined' Scenario
Output, Employment,
Energy Requirements, and CO_2 emissions
corresponding to total (domestic plus foreign) final demand

Main assumptions:
- rate of growth for total final demand from 1992 to 2010 = 3.5% p.a.
- different rates of final demand growth for the different sectors (see page 14)
- complete substitution of coal use, and 5% replacement of oil use, by natural gas
- increase to a 39% contribution of renewable energy sources to electricity product.
- energy efficiency improvement rate from 1992 to 2010 = 0.5% p.a.

	Total Output **2010**	% Change in Total Output (basic prices) 1992 to 2010	Employment required in the economy to satisfy the sector's final demand **2010**	% Change in Employment required in the economy 1992 to 2010	Energy Requirements by Final Demand **2010**		% Change in Energy Requirements by Final Demand 1992 to 2010		% of total CO_2 emiss. Attribut. to Direct Product. Demand	% of total CO_2 emiss. Attribut. to Indirect Product. Demand	% of total CO_2 emiss. Attribut. to Direct Consumption Demand	Total CO_2 Emissions Attributable to Final Demand **2010**	% Change in T. CO_2 Emissions Attributable to Final Demand 1992 to 2010	*CO_2 emiss. 'Rank.'* **2010**	*% Distr. of CO_2 Emiss. by Industry* **2010**
	$x^{2010} = (I-A)^{-1}y^{2010}$	$x^{2010}/x^{1992}-1$	$l^{2010} = j'(I-A)^{-1}y^{2010}$	$l^{2010}/l^{1992}-1$	$f^{2010} = [C(I-A)^{-1}+PH]\ y^{2010}$		$f^{2010}/f^{1992}-1$					$c^{2010} = [e'C(I-A)^{-1}+e'PH]\ y^{2010}$	$c^{2010}/c^{1992}-1$		
	billion PTE at 1992 prices	%	10^3 FTE jobs	%	10^3 toe of n. gas	10^3 toe of oil	% (n.gas)	% (oil)	**2010**	**2010**	**2010**	10^3 tonnes of CO_2	%		
01 Agriculture, Hunting and Related Service Activities	1 076	19.1	187.5	- 42.4	34.5	213.7	--	- 28.6	41.4	58.6	0.0	730.1	- 31.3	16	1.1
02 Forestry, Logging and Related Service Activities	164	48.1	1.5	- 51.3	0.6	5.9	--	- 25.9	69.2	30.8	0.0	19.4	- 26.3	36	0.0
03 Fishing and Related Service Activities	98	9.9	17.5	- 27.4	4.1	58.8	--	- 26.2	77.9	22.1	0.0	188.2	- 24.4	29	0.3
37 Natural Gas	167	--	0.1	--	161.4	4.5	--	--	0.0	3.8	96.2	391.0	--	27	0.6
05 Extr. Crude Petrol. ..., & Man. Refined Petroleum Prod.	509	87.2	3.8	- 13.6	28.3	3 122.9	--	12.2	10.8	2.2	87.0	9 558.6	12.5	2	14.0
6A Fossil Fuel Electricity Generation	331	36.8	0.0	--	0.0	0.0	--	--	0.0	0.0	0.0	0.0	--	37	0.0
6B Hydroelectricity	212	327.1	0.0	--	0.0	0.0	--	--	0.0	0.0	0.0	0.0	--	37	0.0
6C Electricity Distribution	995	86.2	9.9	- 25.3	1 058.5	1 333.1	--	35.2	0.0	100.0	0.0	6 526.1	13.8	4	9.6
07 Gas Production and Distribution	37	100.0	1.5	31.7	14.1	129.8	--	79.6	62.9	37.1	0.0	427.5	79.0	26	0.6
08 Water Supply	104	56.0	1.4	- 34.1	19.3	25.3	--	- 9.8	0.0	100.0	0.0	122.0	- 24.6	33	0.2
09 Extr. & Man. of Ferrous & Non-Ferrous Ores & Metals	249	61.2	24.7	63.8	122.7	85.0	--	2.0	50.2	49.8	0.0	545.1	- 24.6	23	0.8
10 Extraction and Manuf. of Non-Metallic Minerals	975	98.0	40.9	- 3.7	250.5	287.4	--	17.1	55.1	44.9	0.0	1 458.8	- 4.9	13	2.1
11 Manuf. of Chemicals and Chemical Products	993	53.5	34.5	- 3.4	86.9	748.3	--	15.7	74.5	25.5	0.0	2 477.6	14.6	9	3.6
12 Manufacture of Fabricated Metal Products	603	53.6	77.5	- 0.5	76.6	158.1	--	7.7	8.0	92.0	0.0	659.5	- 9.1	19	1.0
13 Man. of Electrical and Non-Electrical Machinery & Equipm.	1 000	44.1	66.7	- 36.2	67.7	175.9	--	9.7	6.3	93.7	0.0	692.9	- 5.0	18	1.0
14 Manufacture of Transport Equipment	648	39.5	36.7	- 39.5	43.2	123.2	--	9.3	14.9	85.1	0.0	475.4	- 4.0	24	0.7
15 Manufacture of Food Products and Beverages	2 469	38.8	403.4	- 5.0	168.3	849.3	--	14.2	17.7	82.3	0.0	2 974.9	7.5	7	4.4
16 Manufacture of Tobacco and Tobacco Products	200	35.4	3.9	- 28.1	3.7	22.5	--	13.1	44.2	55.8	0.0	77.1	8.3	35	0.1
17 Manufacture of Textiles and Clothing	1 924	38.0	368.4	12.0	222.2	741.6	--	7.2	17.1	82.9	0.0	2 773.5	- 3.8	8	4.1
18 Manufacture of Leather and Footwear	526	35.5	69.3	- 18.2	25.1	132.0	--	12.3	17.6	82.4	0.0	459.7	6.0	25	0.7
19 Other Manuf. Products (incl. Wood, Cork & Furniture)	753	58.1	96.5	2.3	52.4	230.4	--	12.0	30.0	70.0	0.0	822.8	4.1	15	1.2
20 Man. of Pulp, Paper, Paper Prod. & Printing Products	852	77.0	41.5	- 2.2	54.6	234.4	--	12.3	32.8	67.2	0.0	840.1	3.3	14	1.2
21 Manufacture of Rubber and Plastic Products	226	51.8	21.6	42.2	15.1	48.6	--	8.2	7.5	92.5	0.0	183.2	- 3.2	31	0.3
22 Construction	4 080	139.6	645.1	30.8	998.9	2 180.1	--	102.8	24.1	75.9	0.0	8 961.0	75.8	3	13.1
23 Recycling, Recovery and Repair services	780	83.5	29.0	- 41.3	9.6	54.4	--	48.6	41.1	58.9	0.0	188.0	41.8	30	0.3
24 Wholesale and Retail Trade	4 824	76.2	675.8	32.1	321.3	1 317.2	--	44.0	9.0	91.0	0.0	4 754.6	32.3	5	7.0
25 Hotel and Restaurant Services	1 578	78.9	290.4	0.0	229.2	601.3	--	35.9	5.8	94.2	0.0	2 363.2	18.8	10	3.5
26 Land Transport and Transport Via Pipeline Serv.	861	105.0	64.9	5.8	212.7	3 167.2	--	94.0	91.1	8.9	0.0	10 124.3	99.3	1	14.8
27 Water and Air Transport Services	467	114.6	36.6	50.5	45.0	583.4	--	93.8	78.5	21.5	0.0	1 878.5	97.5	11	2.8
28 Supporting and Auxiliary Transport Services	577	100.9	22.5	10.9	26.1	186.3	--	88.5	5.6	94.4	0.0	627.3	83.3	20	0.9
29 Post and Telecommunication Services	676	111.0	9.1	- 54.0	14.1	66.6	--	84.0	3.8	96.2	0.0	235.5	72.0	28	0.3
30 Financial Intermediation Services (except Insurance and ...)	1 790	122.3	22.6	178.9	12.3	25.5	--	227.7	0.3	99.7	0.0	106.1	180.4	34	0.2
31 Insurance and Pension Funding Services	179	197.3	17.2	72.5	10.7	32.6	--	247.0	4.5	95.5	0.0	124.0	208.7	32	0.2
32 Real Estate Services and Other Renting Services	5 999	230.4	513.2	190.0	254.3	816.6	--	253.7	1.8	98.2	0.0	3 076.5	217.6	6	4.5
33 Education and R & D Services	1 434	67.6	133.3	- 52.2	42.6	161.9	--	34.8	4.4	95.6	0.0	591.8	23.0	21	0.9
34 Health and Veterinary Market Services	973	66.9	76.4	- 50.2	42.0	158.4	--	34.7	2.0	98.0	0.0	579.5	22.8	22	0.8
35 Other Services (Market and Non-Market)	1 305	87.3	267.9	- 12.9	51.2	197.3	--	35.6	8.3	91.7	0.0	719.4	23.6	17	1.1
36 Public Administration Non-Market Services	1 967	68.8	261.8	- 32.1	104.1	412.2	--	39.7	10.2	89.8	0.0	1 496.1	27.8	12	2.2
Total	**42 601**	**85.8**	**4 574.3**	**1.8**	**4 884.3**	**18 691.4**	**--**	**42.2**	**29.9**	**57.4**	**12.7**	**68 229.5**	**32.7**		100

Another key insight is that gradual fuel substitution for electricity generation, from fossil fuel to renewable fuels, offers multiple benefits. Indeed, the transition to renewables (which are endogenous sources) allows considerable reductions in CO_2 emissions, but can be also very important in other aspects, particularly given the almost complete Portuguese external dependence for fossil fuels.

Moreover, a total replacement of coal use, and a 5 per cent replacement of oil use by natural gas (not considering improvements in energy efficiency, nor the increasing share of renewables in electricity generation), will lead to an increase in CO_2 emissions from 1992 to 2010 of 'only' 59 per cent, against the 76.9 per cent increase estimated in the Basic Scenario (where natural gas use was not considered at all). However, it is important to highlight that the greater environmental 'improvement' resulting from the increasing penetration of natural gas use occurs through the replacement of coal use (which is the fossil fuel whose combustion produces more CO_2 emissions), and that the exploitation of such potential was already fully considered in the scenario. Indeed, further penetration of natural gas use can only be achieved by promoting extra oil use replacement, a shift that is (economically and technically) more difficult to achieve and that will have lower marginal benefits in terms of CO_2 emissions because of the smaller difference in the carbon contents of these two fuels (than between natural gas and coal).

The results also show that 29.9 per cent of the emissions estimated to be released in 2010 are 'due' to direct production demand, while 12.7 per cent are due to direct consumption demand for oil and natural gas; this means that the great majority (57.4 per cent) are attributable to indirect production demand for fuels. As already discussed in Section 3, these results have important policy relevance as they show that the great majority of industries are 'responsible' for much more CO_2 emissions indirectly than directly.

It is also worth noting that, according to the estimations made in the 'Combined' Scenario, by 2010 the sectors that will be contributing the most to CO_2 emissions are: Land Transport and Transport Via Pipeline Services (14.8 per cent), Extraction of Crude Petroleum and Natural Gas, and Manufacture of Refined Petroleum Products (14.0 per cent), Construction (13.1 per cent), Electricity Distribution (9.6 per cent), and Wholesale and Retail Trade (7 per cent).

This means that the former two sectors (which were in fourth and first position in the 1992 'ranking', respectively), will account for 28.8 per cent of total CO_2 emissions attributable to production in the Portuguese economy (against 26.4 per cent in 1992). Therefore, one can say that, similarly to what was seen concerning 1992, by 2010 (personal and public) transport (of passengers and goods) will account for around one-quarter of the CO_2 emissions that will be released on Portuguese territory[36].

Moreover, it is also useful to note that the position of the CO_2 emissions attributable to the final demand for the Electricity Distribution sector will fall from second (in 1992) to fourth (in 2010), as one would expect, given the consideration of the increasing contribution of both renewable energy sources and natural gas technologies in electricity generation.

Finally, it is important to remind that, in this study, it is assumed that the supposed changes in the use of energy, materials, and other inputs, are achieved through current-account substitutions of some inputs for others. This means that we are neglecting the effects of changes that imply investment in new types of capital goods. In reality, for example, the shift to natural gas or to renewables requires investment (i.e. increases in final demand). This may lead to increases in the total output and in CO_2 emissions in the medium term, unless this change in final demand is a displacement from consumption. Accordingly, some care should be put in the results of the analysis made in this section, as we might have underestimated the levels of output, employment, energy requirements and CO_2 emissions. Thus, in future research, there will be extended the analysis in order to account for the impacts of the investment in new type of capital goods.

4. 3. Policy relevance

From the analysis made, it is possible to conclude that one of the most important options or opportunities for reducing (or at least bringing to an end the growth of) CO_2 emissions in Portugal is in the reinforcement (or real application) of existing, and introduction of new, energy efficiency and conservation measures. It was also seen that the accomplishment of the 39 per cent target for the contribution of renewable energy sources to electricity production established in Directive 2001/77/EC, as well as the increasing penetration of natural gas technologies, are critical to restraining CO_2 emissions in Portugal.

Another key insight than can be taken from the analysis performed in this paper is that those three main 'categories' of CO_2 emissions mitigation options for the Portuguese economy (individually or together) allow the reduction of CO_2 emissions without reducing economic growth and employment.

When the target for a limit of 40 per cent increase was established for the Portuguese CO_2 emissions (under the European Union 'burden-sharing' agreement to accomplish each countries' Kyoto Protocol targets), it seemed that it would be relatively easy to accomplish. And the 68,229.5 kilotonnes of anthropogenic CO_2 emissions here estimated to be released on Portuguese Territory in

[36] Therefore, the analysis of the potential effects of a shift from individual to mass transit modes of transportation (i.e., of a reduction in private/personal car use, replacing it by public transports), for example, should be explored in future research.

the year 2010 (32.7 per cent more than in 1992), in order to satisfy the total final demand for goods and services domestically produced, can be considered as attainable.

However, the simulations here performed also show that this is not an easy task at all. The results suggest that there is no 'margin' for deviation, either from the rates of improvement in energy efficiency, or from the rates of penetration of renewable energy sources and natural gas technologies, which were here assumed, if the Kyoto target is to be accomplished[37].

Overall, one can say that the changes that will have to be effected in Portugal to reverse the trend in terms of CO_2 emissions, require a considerable break with past and current production and consumption practices. Of course, this means that such changes will be hard to implement, not only socially and politically, but also economically[38].

Furthermore, it is vital to recognize that we are running out of time to really 'start' taking actions that can truly contribute to curb the current trend for CO_2 emissions increase, as the 40 per cent limit for increase in CO_2 emissions was already surpassed in the year 2000 (see EEA, 2002). The need for action is urgent.

Therefore, what will be more important in making a decisive change from the *status quo*, is the 'will' – which can be translated as resources, involvement and courage (to make hard choices) – mainly of the policy makers, but also of each single producer and consumer. But the only real choice is whether to make it easier on ourselves and start adapting our economy now (through cleaner and lower energy consumption), or leave it till later when it will be more painful, disruptive and expensive.

Finally, it is relevant to mention that the information generated by the analysis undertaken was vast. However, only some of it is shown in the tables presented. This was a deliberate approach, as there is the need to condense information, so that it can be comprehended and thus allow policy conclusions to be drawn. The same criterion led to the consideration of a small number of scenarios, otherwise it might have led to 'scenario fatigue'.

On balance, it is possible to claim that the kind of scenarios analysis here performed, based on an expanded (energy-economy-environment) input-output model, is a useful tool for the analysis of possible actions taken, or to be taken, in order to achieve sustainable development, balancing economic progress with environmental care and social responsibility.

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[37] Besides, it is also important to remember that we performed the analysis taking 1992 figures as the base, while the Kyoto targets were established taking 1990 as the base year; thus, the 40 per cent limit for the growth of CO_2 emissions by 2010 seems to be even more difficult to accomplish.

[38] Some lifestyles will have to change and some particular interests will be threatened (at least in the short term). Moreover, some of the advances that are required demand important technological developments, as well as some innovative plans (for example in the design of public transport systems), which are generally very expensive to develop, and for which there is no evident institutional and financial support. A considerable increase in the use of renewable energy sources also involves significant financial investment.

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