Energy-Environment-Economy Interactions:
An Input-Output Approach Applied to the Portuguese Case

Luis M. G. Cruz *

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Abstract

Several of the earth's crucial environmental problems derive from the energy demand to sustain human needs and economic growth. Indeed, all goods and services produced in an economy are directly or indirectly associated with energy use and, as current energy production and use patterns rely heavily on the combustion of fossil fuels, also to carbon dioxide (CO_2) emissions (which are the principal cause of the greenhouse effect and of the 'resulting' climate change problem).

In an input-output approach, the economic structure is defined in terms of sectors, and this provides a modelling framework for asking specific questions about the relationship between economic structure and economic action. Moreover, extensions of the traditional input-output model can be performed, making 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. Thus, such an approach provides a consistent and systematic tool to evaluate impacts of measures regarding the achievement of both pollution control and sustainable development.

This paper presents an empirical input-output application of the energy-economy-environment interactions for Portugal, especially concerning the energy intensities and CO_2 emissions derived from fossil fuels use. More precisely, this paper presents a description of the appropriate modifications to the basic input-output model, followed by an outline of the data used. Finally, some results on (direct and indirect) energy requirements and CO_2 emissions are reported, the study's main conclusions are presented, and the limitations and needs for future research discussed.

Keywords: Input-output analysis; energy policy; energy intensities; CO_2 emissions; Portugal

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1. Introduction

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. Thus, 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-environment-economy interactions for Portugal, and therefore to support policy-makers' decision processes directed towards the achievement of these policy objectives.

This study will begin by presenting a brief outline of the basic input-output model, and then there will be succinctly discussed the core aspects of its extensions for the consideration of environmental and energy issues. Then, there will be presented the data sets used for the Portuguese case. Next, energy and CO_2 intensity coefficients by industry will be estimated, as well as the energy requirements and the level of CO_2 emissions derived from fossil fuel use attributable to given sets of final demand. Finally, the study's main conclusions will be presented and the limitations and needs for future research discussed.

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* School of Politics, Internat. Relations and the Environment, Keele University (UK); E-mail: l.m.g.cruz@keele.ac.uk
Faculty of Economics of the University of Coimbra (Portugal); E-mail: lmgcruz@sonata.fe.uc.pt

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) for human economic 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 sectors 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]:

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

[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:

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

This expression is the fundamental matrix representation of input-output analysis, and the inverse matrix $(\mathbf{I}\text{-}\mathbf{A})^{-1}$ is known as the 'Leontief inverse matrix', also referred to as the 'multiplier matrix'. If their elements are denoted by α_{ij}, representing the total amount of commodity *i* required both directly and indirectly to deliver one unit of final demand of commodity *j*, then the generic equation derived from the expression (4) is:

$$X_i = \sum_j \alpha_{ij} Y_j \qquad (5).$$

This expression makes clear the dependence of each of the outputs on the values of each of the final demands (Miller and Blair, 1985: 15).

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):

$$\mathbf{x} = \mathbf{y} + \mathbf{A}\mathbf{y} + \mathbf{A}^2\mathbf{y} + \ldots + \mathbf{A}^n\mathbf{y} + \ldots \qquad (6).$$

So, as Proops et al. (1996: 230) 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'.
- $\mathbf{A}^2\mathbf{y} = \mathbf{A}(\mathbf{A}\mathbf{y})$ is the production necessary to allow the production of **Ay**. This is the 'second-round indirect effect'.
- $\mathbf{A}^n\mathbf{y} = \mathbf{A}(\mathbf{A}^{n-1}\mathbf{y})$ is needed to produce the goods $\mathbf{A}^{n-1}\mathbf{y}$. This is the 'nth-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-environment-economy 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].

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'[7].

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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).
[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] The 'production demand' can also be designated as 'indirect consumption demand' for fuels, as the production demand for fuels can be ultimately attributable to final consumers. Indeed, final consumers purchase non-primary energy goods and services to industry sectors that have entailed primary fuels (and therefore CO_2 emissions) in their production, and that therefore constitute their indirect consumption of those fuels.

2. The distinction between various forms of primary (fossil) fuels[8], 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.:

$$\mathbf{f} = \mathbf{C}(\mathbf{I}-\mathbf{A})^{-1}\mathbf{y} + \mathbf{PHy} \qquad (7),$$

where: **C** is a (3xn) matrix, whose generic element (c_{fi}) represents the (physical) quantity of fuel f used by sector i per unit of total output[9] (here designated as 'energy intensities corresponding to direct production demand'); **P** is a (3xn) 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 (here designated as 'energy intensities corresponding to direct consumption demand'), and **H** is a (nxn) 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[10].

Furthermore, we can decompose equation (7), to show the progressive adjustments of energy requirements to final demand, as:

$$\mathbf{f} = \mathbf{PHy} + \mathbf{Cy} + \mathbf{CAy} + \mathbf{CA}^2\mathbf{y} + \ldots + \mathbf{CA}^{t-1}\mathbf{y} + \ldots \qquad (8),$$

where (**PHy**) represents the direct consumption demand for fossil fuels, while (**Cy**) represents the direct requirements and the sum of all the others $[(\mathbf{CA}+\mathbf{CA}^2+\ldots)\mathbf{y}]$ represents the total indirect requirements for fossil fuels of production demand[11].

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[8] 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, since the carbon in these fuels has already been accounted for in the supply of primary fuels from which they are derived (IPCC, 1996).

[9] 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.

[10] The final demand for fossil fuels corresponding to investment ('gross fixed capital formation' plus 'changes in stocks') 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 (nxn) scaling matrix, **H**, and therefore using a modified final demand vector (**Hy**).

[11] Therefore, the elements of matrix $[\mathbf{C}(\mathbf{I}-\mathbf{A})^{-1}]$ represent what will be here designated as the 'energy intensities corresponding to total production demand', and accordingly, the elements of $[\mathbf{C}(\mathbf{A}+\mathbf{A}^2+\ldots)]$ represent the 'energy intensities corresponding to indirect production demand'.

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 [$c_{dem} = \mathbf{e'PHy}$][12], i.e.:

$$c = \mathbf{e'C(I\text{-}A)^{-1}y} + \mathbf{e'PHy} \Leftrightarrow c = [\mathbf{e'C(I\text{-}A)^{-1}} + \mathbf{e'PH}]\ \mathbf{y} \qquad (9),^{13}$$

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

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

$$c = [\mathbf{e'PHy} + \mathbf{e'Cy}] + [\mathbf{e'CAy} + \mathbf{e'CA^2y} + \ldots + \mathbf{e'CA^{t-1}y} + \ldots] \qquad (10).$$

Thus, by combining energy and environmental (physical) data and (monetary) input-output tables, one gets a consistent and systematic tool to evaluate impacts of measures regarding one of these three 'dimensions' on the other two, therefore providing useful insights for economic planning that explicitly considers energy and environmental policy issues.

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

Equations (7) and (9) 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, $\mathbf{y}$). This can be particularly useful for policy analysis purposes, as this ultimately imputes all fossil fuel use and corresponding CO_2 emissions to households' purchases.

Moreover, as will be shown, according to the 'components' of the (total) final demand considered, it will be possible to distinguish energy requirements and CO_2 emissions attributable to the domestic consumption of goods and services produced in a country, 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 will then be 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 and the CO_2 emissions produced by the country's economy.

Usually, final demand has four main components: 'household consumption', 'government consumption', 'investment' ('changes in stocks' plus 'gross fixed capital formation'), and 'exports'.

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[12] 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.

[13] If we use $\hat{\mathbf{e}}$ (where $\hat{\mathbf{e}}$ is a (3x3) matrix, with the vector $\mathbf{e}$ on the diagonal) instead of $\mathbf{e}$', 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 $\mathbf{e}$', as is the case here, then the scalar of pollution obtained represents pollution intensities for the total fuels burnt.

The first three categories constitute the domestic final demand (given by the *n*-vector $\mathbf{y}_{\mathbf{dom}}$), while the last one represents foreign demand, for goods and services produced in the country under consideration (given by the *n*-vector $\mathbf{y}_{\mathbf{exp}}$). Therefore, one can represent the total final demand for goods and services produced in a country[14] (given by the *n*-vector **y**) as:

$$\mathbf{y} = \mathbf{y}_{\mathbf{dom}} + \mathbf{y}_{\mathbf{exp}} \qquad (11).$$

Accordingly, one can apply this decomposition to the equations representing total primary energy requirements by an economy, as well as the corresponding total CO_2 emissions (i.e., to equations (7) and (9), respectively). This gives:

$$\mathbf{f} = \mathbf{C}(\mathbf{I}\text{-}\mathbf{A})^{-1}\mathbf{y}_{\mathbf{dom}} + \mathbf{PZy}_{\mathbf{dom}} + \mathbf{C}(\mathbf{I}\text{-}\mathbf{A})^{-1}\mathbf{y}_{\mathbf{exp}} \qquad (12),$$

and,

$$c = \mathbf{e'C}(\mathbf{I}\text{-}\mathbf{A})^{-1}\mathbf{y}_{\mathbf{dom}} + \mathbf{e'PZy}_{\mathbf{dom}} + \mathbf{e'C}(\mathbf{I}\text{-}\mathbf{A})^{-1}\mathbf{y}_{\mathbf{exp}} \qquad (13).$$

The **Z** matrix 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 domestic final demand, for the three fossil fuel sectors[15].

Equation (13) can be interpreted as follows. The term ($\mathbf{e'C}(\mathbf{I}\text{-}\mathbf{A})^{-1}\mathbf{y}_{\mathbf{dom}}$) corresponds to the CO_2 emissions attributable to fossil fuel use for producing goods and services for domestic final demand. The term ($\mathbf{e'PZy}_{\mathbf{dom}}$) corresponds to the CO_2 emissions attributable directly to (domestic) households. Finally, the term ($\mathbf{e'C}(\mathbf{I}\text{-}\mathbf{A})^{-1}\mathbf{y}_{\mathbf{exp}}$) represents the CO_2 emissions attributable to the (domestic) production of goods and services for export[16].

However, if one intends to determine only the CO_2 emissions for which one country is ‘responsible’, the country’s emissions attributable to exports should not be considered, and the CO_2 emissions taking place in foreign countries, but resulting from the satisfaction of the country’s imports, should be added on (Gay and Proops, 1993: 130).

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[14] 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.

[15] The reader will note that the terms ($\mathbf{PHy}_{\mathbf{exp}}$) and ($\mathbf{e'PHy}_{\mathbf{exp}}$) (in equations (12) and (13), respectively) have been suppressed, as this would have no sensible interpretation. Moreover, the reader will also note that terms of the type ($\mathbf{PHy}_{\mathbf{dom}}$) and ($\mathbf{e'PHy}_{\mathbf{dom}}$) do not ‘come out’, but instead there appear the terms ($\mathbf{PZy}_{\mathbf{dom}}$) and ($\mathbf{e'PZy}_{\mathbf{dom}}$), respectively. This change, from matrix **H** to matrix **Z**, can be understood through the analysis of their own definitions. Indeed, as explained concerning final demand energy requirements (equation (7)), the final demand vector (**y**) was ‘modified’ to ‘exclude’ the investment and export components, by premultiplying it by the (*n*x*n*) scaling matrix **H**, and therefore using a modified final demand vector (**Hy**). Therefore, as what is now under consideration is the domestic final demand vector ($\mathbf{y}_{\mathbf{dom}}$) (that does not include exports), only the investment component needs to be excluded. This can be done by premultiplying the domestic final demand vector ($\mathbf{y}_{\mathbf{imp}}$) by a suitable (*n*x*n*) scaling matrix, **Z**, and therefore using a modified final demand vector ($\mathbf{Zy}_{\mathbf{dom}}$).

[16] Of course, the interpretation of equation (12) is similar, but concerning energy requirements instead of CO_2 emissions.

2. 3. 1. Primary energy requirements and CO_2 emissions corresponding to domestic consumption

As results from equations (12) and (13), the primary energy requirements and the CO_2 emissions corresponding to domestic consumption (given by the 3-vector $\mathbf{f_{dom}}$, and by the scalar c_{dom}, respectively), can be written as:

$$\mathbf{f_{dom}} = \mathbf{C(I\text{-}A)}^{-1}\mathbf{y_{dom}} + \mathbf{PZy_{dom}} \quad (14),$$

and,

$$c_{dom} = \mathbf{e'C(I\text{-}A)}^{-1}\mathbf{y_{dom}} + \mathbf{e'PZy_{dom}} \quad (15).$$

2. 3. 2. Primary energy and CO_2 'embodied' in exports

The appraisal of the energy 'embodied' in exports is obvious. Indeed, the goods and services that are exported are produced using exactly the same techniques as the ones that are consumed domestically, so the energy intensities corresponding to (direct and indirect) production demand will be the same. But, on the other hand, as what is under consideration are exports of non-primary energy goods and services, there is no sensible interpretation to primary energy intensities (and therefore requirements) attributable directly to the foreign final demand for fuels, which is why the term **P** is not considered. (Proops et al., 1993: 132).

Therefore, and as derives from equation (12), it is considered that the total (primary) energy 'embodied' in a country's exports will be given by the 3-vector $\mathbf{f_{exp}}$, i.e.:

$$\mathbf{f_{exp}} = \mathbf{C(I\text{-}A)}^{-1}\mathbf{y_{exp}} \quad (16).$$

Accordingly, the total production of CO_2 emissions attributable to a country's exports[17] (given by the scalar c_{exp}) will be given by:

$$c_{exp} = \mathbf{e'C(I\text{-}A)}^{-1}\mathbf{y_{exp}} \quad (17).$$

2. 3. 3. Primary energy and CO_2 'embodied' in imports

Regarding an accurate calculation of CO_2 emissions because of imports, the task is not so straightforward as for exports, since new energy intensity coefficients should be estimated based on input-output tables of the relevant countries from which the imports come. Evidently, this would be a major task, if not operationally impossible. However, as Machado (2000: 5) remarks, if the aim is to assess the energy 'saved' by a country, by importing non-primary energy goods, then the appropriate energy intensity coefficients to be used in assessing the energy embodied in imports are the same estimated for domestic industrial production.

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[17] I.e., the CO_2 emissions produced by the country's economy to meet the demand for goods and services by foreign consumers and industries.

Therefore, the total energy 'embodied' in a country's imports (given by the 3-vector $\mathbf{f_{imp}}$) will be given by:

$$\mathbf{f_{imp}} = \mathbf{C(I\text{-}A)^{-1}B(I\text{-}A)^{-1}y_{dom}} + \mathbf{C(I\text{-}A)^{-1}y_{imp}} \quad (18),$$

where $\mathbf{B}$ is the imports coefficient matrix, and $\mathbf{y_{imp}}$ represents the country's (final demand) imports vector[18].

Thus, following Proops et al. (1993: 138)[19], the level of CO_2 emissions that occurs in foreign countries in order to meet the domestic and the imported final demand of a country is given by:

$$c_{imp} = \mathbf{e'C(I\text{-}A)^{-1}B(I\text{-}A)^{-1}y_{dom}} + \mathbf{e'C(I\text{-}A)^{-1}y_{imp}} \quad (19)$$ [20].

2. 3. 4. The country's 'responsibility' for CO_2 emissions *versus* CO_2 emissions produced by the country's economy

Finally, combining the results achieved in the previous sub-sections, it is also possible to determine:

- the country's 'responsibility' for CO_2 emissions (given by the scalar c_{resp}), i.e. the CO_2 emissions attributable to consumption by a country's economy, whether arising from domestic or from foreign goods and services; as well as
- the CO_2 emissions produced by the country's economy (given by the scalar c_{emis}), 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.

Therefore, the country's 'responsibility' for CO_2 emissions, which can be derived from equations (15) and (19), is given by:

$$c_{resp} = \mathbf{e'C(I\text{-}A)^{-1}y_{dom}} + \mathbf{e'PZy_{dom}} + \mathbf{e'C(I\text{-}A)^{-1}B(I\text{-}A)^{-1}y_{dom}} + \mathbf{e'C(I\text{-}A)^{-1}y_{imp}} \quad (21).$$

Likewise, the CO_2 emissions produced by the country's economy, which can be derived from equations (15) and (17), are given by:

$$c_{emis} = \mathbf{e'C(I\text{-}A)^{-1}y_{dom}} + \mathbf{e'PZy_{dom}} + \mathbf{e'C(I\text{-}A)^{-1}y_{exp}} \quad (22)$$ [21].

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[18] Concerning the (intermediate demand) imports coefficient matrix ($\mathbf{B}$), it is achieved by dividing the imports used to satisfy the intermediate demand of the country's sectors by the domestic total inputs (=total outputs) by industry. Concerning the imported direct final demand, as interest is directed towards only those fuels which are burnt, only its domestic final consumption is considered. Therefore, the final demand vector ($\mathbf{y_{imp}}$) considered in the study includes only the imported final demand components: 'final consumption of households' plus 'collective consumption'.

[19] A detailed analysis of the calculation of CO_2 attributable to imports can be found in Proops et al. (1993: Section 8.4.3).

[20] The first term corresponds to foreign CO_2 emissions attributable to one country's imports that will be used as intermediate consumption, i.e., attributable to imported products that will be introduced in the county's production processes in order to satisfy domestic final demand (which is given by vector $\mathbf{y_{dom}}$). The second term corresponds to foreign CO_2 emissions that occur to meet the country's imported final demand (imports for direct final consumption, which is given by vector $\mathbf{y_{imp}}$).

[21] This representation of the total CO_2 emissions produced by an economy is no more than the rewriting of the expression used in equation (13). Alternatively, one can represent CO_2 emissions produced by the country's economy considering its dependence on total final demand, which is no more than the expression used in equation (9).

3. The Portuguese case

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[22]

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) 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, 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[23].

It is also important to mention that in order to be able to explore alternative scenarios for electricity generation, it was decided to disaggregate the electricity sector into three sub-sectors[24]: '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 sub-sectors (6A and 6B) sell all of their output to the distribution sector (6C);
- the fuel inputs to electricity are attributed entirely to fossil fuel generation[25], 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[26].

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

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[22] 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 (in preparation).
[23] Of course, the absence of more up-to-date data availability 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, so for many aspects, the table(s) will be relevant over a reasonable period of time (Miller and Blair, 1985: 269).
[24] 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.
[25] 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).
[26] This means that the two electricity-generating sectors have zero final demand.

(=total outputs) by industry at basic prices, as usual. It was also from this table that were derived the matrices **H** and **Z**, as well as the various vectors according to the different components of final demand considered, i.e.: $\mathbf{y}$, $\mathbf{y_{dom}}$, $\mathbf{y_{exp}}$, and $\mathbf{y_{imp}}$.

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

Moreover, 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 one of the 38 sectors and by final consumers in 1992[27]. Then, dividing these values by the corresponding 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 contents 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 3.881498544 tonnes of CO_2, and that each toe of oil burnt generates 3.0396168 tonnes of CO_2. 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.

[27] 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.

3. 2. The input-output assessment of Portuguese primary energy requirements

In this section there will first be determined the primary energy intensities per unit of total output and per unit of final demand, in terms of toe/million Portuguese Escudos (PTE), and then the corresponding energy requirements will be estimated.

3. 2. 1. Primary energy intensities

Table 1 contains the basic data on fuel use (for convenience of presentation, the elements of the matrices are presented in transpose form).

The highest energy intensity for coal is found in ‘mining and manufacture of coal by-products’, while for oil it is found in ‘extraction of crude petroleum, and manufacture of refined petroleum products’, which clearly results from the importance of consumption of coal and oil directly by final consumers. The second highest energy intensity for both of the fuels appears in ‘fossil fuel electricity generation’, mainly because of direct production demand. The ‘electricity distribution’ sector also presents relatively high energy intensities for both fuels. As expected, the transport sectors (‘land transport and transport via pipeline services’ and ‘water and air transport services’) are also high ranking for oil intensity use, while important figures for coal intensity use are found in ‘extraction and manufacture of ferrous and non-ferrous ores and metals’ and ‘extraction and manufacture of non-metallic products’. On the other hand, the smallest energy intensity coefficients were generally registered in the services sectors.

Comparing direct and indirect energy intensities corresponding to production demand, it can be seen that concerning the use of coal there are very few sectors presenting values for direct energy intensity. Concerning the use of oil, there are figures for direct intensities for almost all the sectors, although they are almost negligible for the services sectors. Therefore, it is clear that, generally speaking, the indirect production energy intensities are typically larger than the direct ones.

3. 2. 2. Primary energy requirements corresponding to domestic consumption

Following equation (14), multiplying the primary energy intensities presented above by the domestic final demand vector, one achieves the primary energy requirements of the economy to satisfy domestic consumption, which are shown in Table 2.

It was estimated that the consumption by the Portuguese of domestic production in 1992 required the use of 2,246,810 toe of coal and 10,473,628 toe of oil. Of this, ‘electricity distribution’, ‘construction’, ‘wholesale and retail trade’, and ‘hotel and restaurant services’, are the sectors that clearly require more coal. Indeed, ‘electricity distribution’ alone is ultimately responsible for 30%, and together with the other three sectors for more than two- thirds, of the total requirements of coal.

Moreover, it is also important to emphasize that the coal requirements of all these sectors correspond entirely to indirect production demand. This result is clear evidence of the ‘value-added’ that the input-output technique may bring to policy analysis, as an approach that takes economic

Table 1
Primary Energy Intensities

unit: toe / million PTE	Corresponding to Direct Production demand		+ Corresponding to Indirect Production demand		= Corresponding to Total Production demand		+ Corresponding to Direct Consumption Demand		= Corresponding to Final Demand			
	C		$C(A+A^2+...)$		$C(I-A)^{-1}$		P		**Total Primary Energy Intensity**		*Tt. Primary Energy Intensities' "Ranking"*	
	(1) coal	(2) oil	(3) coal	(4) oil	(5) coal	(6) oil	(7) coal	(8) oil	(9) coal	(10) oil	*coal*	*oil*
01 Agriculture, hunting and related service activit.	0.00	0.37	0.11	0.48	0.11	0.85	0.00	0.00	0.11	0.85	20	14
02 Forestry, logging and related service activities	0.00	0.23	0.02	0.09	0.02	0.32	0.00	0.00	0.02	0.32	36	26
03 Fishing and related service activities	0.00	1.05	0.03	0.28	0.03	1.34	0.00	0.00	0.03	1.34	34	9
04 Mining and manufacture of coal by-products	8.87	0.18	0.31	0.57	9.18	0.76	102.42	0.00	111.60	0.76	1	15
05 Extr. crude petroleum ..., and manuf. refined petroleum products	0.00	2.52	0.08	0.51	0.08	3.03	0.00	52.26	0.08	55.29	24	1
6A Fossil fuel electricity generation	9.13	12.60	0.07	0.24	9.20	12.85	0.00	0.00	9.20	12.85	2	2
6B Hydroelectricity	0.00	0.00	0.01	0.04	0.01	0.04	0.00	0.00	0.01	0.04	38	38
6C Electricity Distribution	0.00	0.00	4.16	5.82	4.16	5.82	0.00	0.00	4.16	5.82	3	5
07 Gas production and distribution	0.00	4.63	0.49	2.53	0.49	7.15	0.00	0.00	0.49	7.15	7	4
08 Water supply	0.00	0.00	0.73	1.04	0.73	1.04	0.00	0.00	0.73	1.04	6	12
09 Extraction and manuf. of ferrous and non-ferrous ores and metals	1.10	0.32	0.84	1.01	1.93	1.33	0.00	0.00	1.93	1.33	4	10
10 Extraction and manuf. of non-metallic minerals	0.96	0.78	0.47	0.95	1.43	1.73	0.00	0.00	1.43	1.73	5	8
11 Manuf. of chemicals and chemical products	0.02	1.95	0.18	0.61	0.20	2.55	0.00	0.00	0.20	2.55	13	6
12 Manufacture of fabricated metal products	0.00	0.06	0.32	0.58	0.32	0.64	0.00	0.00	0.32	0.64	9	20
13 Manuf. of electrical and non-electrical machinery and equipment	0.00	0.02	0.11	0.27	0.11	0.29	0.00	0.00	0.11	0.29	19	27
14 Manufacture of transport equipment	0.00	0.05	0.10	0.24	0.10	0.29	0.00	0.00	0.10	0.29	23	28
15 Manufacture of food products and beverages	0.00	0.12	0.11	0.51	0.11	0.63	0.00	0.00	0.11	0.63	21	21
16 Manufacture of tobacco and tobacco products	0.00	0.06	0.02	0.07	0.02	0.13	0.00	0.00	0.02	0.13	37	36
17 Manufacture of textiles and clothing	0.00	0.12	0.19	0.54	0.19	0.67	0.00	0.00	0.19	0.67	14	19
18 Manufacture of leather and footwear	0.00	0.07	0.06	0.29	0.06	0.35	0.00	0.00	0.06	0.35	29	25
19 Other manufacturing products (includ. wood, cork and furniture)	0.00	0.22	0.14	0.47	0.14	0.69	0.00	0.00	0.14	0.69	15	18
20 Manufacture of pulp, paper, paper products and printing products	0.00	0.39	0.24	0.71	0.24	1.10	0.00	0.00	0.24	1.10	10	11
21 Manufacture of rubber and plastic products	0.00	0.06	0.21	0.65	0.21	0.71	0.00	0.00	0.21	0.71	12	17
22 Construction	0.00	0.22	0.32	0.50	0.32	0.72	0.00	0.00	0.32	0.72	8	16
23 Recycling, recovery and repair services	0.00	0.06	0.02	0.08	0.02	0.15	0.00	0.00	0.02	0.15	35	34
24 Wholesale and retail trade	0.00	0.05	0.12	0.48	0.12	0.53	0.00	0.00	0.12	0.53	17	23
25 Hotel and restaurant services	0.00	0.04	0.22	0.56	0.22	0.60	0.00	0.00	0.22	0.60	11	22
26 Land transport and transport via pipeline serv.	0.00	6.99	0.14	0.64	0.14	7.63	0.00	0.00	0.14	7.63	16	3
27 Water and air transport services	0.00	1.62	0.06	0.42	0.06	2.03	0.00	0.00	0.06	2.03	27	7
28 Supporting and auxiliary transport services	0.00	0.05	0.10	0.89	0.10	0.95	0.00	0.00	0.10	0.95	22	13
29 Post and telecommunication services	0.00	0.01	0.05	0.26	0.05	0.28	0.00	0.00	0.05	0.28	31	29
30 Financial intermediation services (except insurance and ...)	0.00	0.00	0.05	0.11	0.05	0.11	0.00	0.00	0.05	0.11	30	37
31 Insurance and pension funding services	0.00	0.02	0.12	0.35	0.12	0.37	0.00	0.00	0.12	0.37	18	24
32 Real estate services and other renting services	0.00	0.00	0.07	0.23	0.07	0.24	0.00	0.00	0.07	0.24	25	32
33 Education and R & D services	0.00	0.01	0.04	0.13	0.04	0.14	0.00	0.00	0.04	0.14	33	35
34 Health and veterinary market services	0.00	0.00	0.05	0.20	0.05	0.21	0.00	0.00	0.05	0.21	32	33
35 Other services (market and non-market)	0.00	0.02	0.06	0.22	0.06	0.24	0.00	0.00	0.06	0.24	28	31
36 Public administration non-market services	0.00	0.03	0.06	0.24	0.06	0.27	0.00	0.00	0.06	0.27	26	30

Table 2
Primary Energy Requirements
corresponding to domestic consumption

(y_{dom} = "Final consumption of households"+"Collective consumption"+"Gross fixed capital formation"+ "Change in stocks")

unit: toe	Energy Requirements by Direct Production demand +		Energy Requirements by Indirect Production demand =		Energy Requirements by Total Production demand +		Energy Requirements by Direct Consumption Demand =		Energy Requirements by Final Demand					
	Cy_{dom}		$C(A+A^2+...)y_{dom}$		$C(I-A)^{-1}y_{dom}$		PZy_{dom}		**Total Primary Energy Requirements**		*Tt. Primary Energy Requirements' "Ranking"*		*Relative distrib. of T.Pr. Energy Req. by Industry*	
	(1) coal	(2) oil	(3) coal	(4) oil	(5) coal	(6) oil	(7) coal	(8) oil	(9) coal	(10) oil	*coal*	*oil*	*coal*	*oil*
01 Agriculture, hunting and related service activit.	0	112 987	34 388	147 728	34 388	260 716	0	0	34 388	260 716	11	10	1.5%	2.5%
02 Forestry, logging and related service activities	0	3 974	376	1 526	376	5 500	0	0	376	5 500	36	35	0.0%	0.1%
03 Fishing and related service activities	0	53 299	1 500	14 252	1 500	67 552	0	0	1 500	67 552	34	21	0.1%	0.6%
04 Mining and manufacture of coal by-products	665	14	23	43	688	57	7 682	0	8 370	57	23	36	0.4%	0.0%
05 Extr. crude petroleum ..., and manuf. refined petroleum prod.	0	102 505	3 379	20 641	3 379	123 146	0	2 450 418	3 379	2 573 564	31	1	0.2%	24.6%
6A Fossil fuel electricity generation	0	0	0	0	0	0	0	0	0	0	37	37	0.0%	0.0%
6B Hydroelectricity	0	0	0	0	0	0	0	0	0	0	37	37	0.0%	0.0%
6C Electricity Distribution	0	0	674 662	942 802	674 662	942 802	0	0	674 662	942 802	1	4	30.0%	9.0%
07 Gas production and distribution	0	46 729	4 953	25 517	4 953	72 246	0	0	4 953	72 246	29	19	0.2%	0.7%
08 Water supply	0	0	19 681	27 967	19 681	27 967	0	0	19 681	27 967	18	29	0.9%	0.3%
09 Extraction and manuf. ferrous and non-ferrous ores and metals	10 337	3 052	7 871	9 509	18 208	12 561	0	0	18 208	12 561	19	32	0.8%	0.1%
10 Extraction and manuf. of non-metallic minerals	20 842	16 834	10 141	20 612	30 983	37 446	0	0	30 983	37 446	12	26	1.4%	0.4%
11 Manuf. of chemicals and chemical products	2 378	271 427	25 524	84 454	27 902	355 881	0	0	27 902	355 881	15	8	1.2%	3.4%
12 Manufacture of fabricated metal products	0	8 158	41 108	75 643	41 108	83 801	0	0	41 108	83 801	9	16	1.8%	0.8%
13 Manuf. of electrical and non-electrical machinery and equip.	0	5 133	27 322	65 060	27 322	70 194	0	0	27 322	70 194	16	20	1.2%	0.7%
14 Manufacture of transport equipment	0	7 404	15 285	36 363	15 285	43 766	0	0	15 285	43 766	22	23	0.7%	0.4%
15 Manufacture of food products and beverages	6	127 073	117 277	537 917	117 283	664 990	0	0	117 283	664 990	5	6	5.2%	6.3%
16 Manufacture of tobacco and tobacco products	0	9 160	2 760	10 688	2 760	19 848	0	0	2 760	19 848	32	31	0.1%	0.2%
17 Manufacture of textiles and clothing	0	37 632	59 187	165 980	59 187	203 612	0	0	59 187	203 612	7	11	2.6%	1.9%
18 Manufacture of leather and footwear	0	7 249	6 549	31 838	6 549	39 087	0	0	6 549	39 087	25	25	0.3%	0.4%
19 Other manufacturing products (includ. wood, cork and furnit.)	300	23 837	15 156	50 809	15 456	74 646	0	0	15 456	74 646	21	17	0.7%	0.7%
20 Manuf. of pulp, paper, paper products and printing products	0	25 833	16 023	46 897	16 023	72 729	0	0	16 023	72 729	20	18	0.7%	0.7%
21 Manufacture of rubber and plastic products	0	1 673	6 116	18 596	6 116	20 268	0	0	6 116	20 268	26	30	0.3%	0.2%
22 Construction	0	327 393	471 665	747 625	471 665	1 075 018	0	0	471 665	1 075 018	2	3	21.0%	10.3%
23 Recycling, recovery and repair services	0	15 317	5 247	19 817	5 247	35 134	0	0	5 247	35 134	28	27	0.2%	0.3%
24 Wholesale and retail trade	0	88 131	209 197	822 410	209 197	910 541	0	0	209 197	910 541	3	5	9.3%	8.7%
25 Hotel and restaurant services	0	27 957	162 470	405 473	162 470	433 429	0	0	162 470	433 429	4	7	7.2%	4.1%
26 Land transport and transport via pipeline serv.	8	1 240 995	25 210	113 960	25 218	1 354 955	0	0	25 218	1 354 955	17	2	1.1%	12.9%
27 Water and air transport services	0	32 316	1 259	8 380	1 259	40 696	0	0	1 259	40 696	35	24	0.1%	0.4%
28 Supporting and auxiliary transport services	0	3 903	7 317	63 409	7 317	67 312	0	0	7 317	67 312	24	22	0.3%	0.6%
29 Post and telecommunication services	0	1 111	5 353	26 991	5 353	28 103	0	0	5 353	28 103	27	28	0.2%	0.3%
30 Financial intermediation services (except insurance and ...)	0	27	3 665	7 743	3 665	7 770	0	0	3 665	7 770	30	33	0.2%	0.1%
31 Insurance and pension funding services	0	356	2 319	6 884	2 319	7 240	0	0	2 319	7 240	33	34	0.1%	0.1%
32 Real estate services and other renting services	0	3 790	55 573	182 813	55 573	186 602	0	0	55 573	186 602	8	12	2.5%	1.8%
33 Education and R & D services	0	5 690	29 933	114 391	29 933	120 081	0	0	29 933	120 081	13	14	1.3%	1.1%
34 Health and veterinary market services	0	2 498	29 549	115 073	29 549	117 571	0	0	29 549	117 571	14	15	1.3%	1.1%
35 Other services (market and non-market)	0	12 969	35 825	132 010	35 825	144 980	0	0	35 825	144 980	10	13	1.6%	1.4%
36 Public administration non-market services	0	33 118	70 728	261 842	70 728	294 960	0	0	70 728	294 960	6	9	3.1%	2.8%
Total	34 536	2 659 545	2 204 592	5 363 665	2 239 128	8 023 210	7 682	2 450 418	2 246 810	10 473 628			100.0%	100.0%

interrelations into account, as on a first 'thought' one might have completely excluded these sectors from the 'list' of those for whose production the use of coal is required.

On the other hand, 'extraction of crude petroleum, and manufacture of refined petroleum products' (24.6%), 'land transport and transport via pipeline services' (12.9%), 'construction' (10.3%), 'electricity distribution' (9%), 'wholesale and retail trade' (8.7%) and 'manufacture of food products and beverages' (6.3%) are the sectors which are responsible for more than two-thirds of oil needs. Here, contrary to what happens for coal, the 'responsibility' for the oil requirements does not have a 'pattern'. Indeed, if for the first sector the main 'guilt' is attributable to direct final consumption (by final consumers, e.g. when households use primary fuels in their private cars), for the second it is mainly attributable to the sector's direct production demand (as fuels are inputs directly required for the production of transport services). Moreover, for the third is mainly attributable to the sector's indirect production demand, but with an important 'contribution' of the direct production demand, while for the fourth the 'guilt' is totally attributable to the sector's indirect production demand (as it is assumed that 'electricity distribution' does not directly require oil, but the production of this sector requires inputs from other sectors whose production directly or indirectly requires primary fuels).

Relating these results with those from Table 1, one can notice that the sectors that are more highly energy intensive are not necessarily the ones whose total production requires more energy. This is explained by what might be called the 'scale effect' of the final demand (corresponding to the fact that the total energy requirements of any sector are given by the product of the intensity per unit of final demand and the level of final demand)[28].

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

In this section there will first be calculated the CO_2 intensities corresponding to the primary energy intensities presented in the previous section, in terms of tonnes of CO_2/million PTE. Subsequently, there will be reported the total CO_2 emissions for a given structure of Portuguese final consumption, both in aggregate and disaggregated to 38 sectors.

3. 3. 1. The CO_2 Intensities

As derives from equation (10), 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 (i.e. the 'CO_2 intensities corresponding to direct production demand'); the elements of [$\mathbf{e'C(I\text{-}A)}^{-1}$]

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[28] Indeed, the 'construction' and the services sectors, for example, which were generally seen to have relatively low energy-intensities, require important amounts of fuels; this happens because these sectors account for important shares of the values of the transactions made in the Portuguese economy. Conversely, for example sectors such as 'gas production and distribution', 'extraction and manufacture of ferrous and non-ferrous ores and metals' and 'extraction and manufacture of non-metallic minerals' are quite fuel-intensive, but they do not account for significant amounts of fuels because their final demand is not very considerable (this indicates that most of the energy required in making their products will be recorded as indirect energy requirements for other sector(s)).

represent tonnes of CO_2 emitted directly and indirectly by each sector, per million PTE of final demand for the output of that sector (i.e. 'CO2 intensities corresponding to total production demand'); and the difference between them (i.e. [$\mathbf{e'C}(\mathbf{A}+\mathbf{A}^2+\ldots)$]), represents tonnes of CO_2 emitted throughout the rest of the economy for each sector, per million PTE of final demand for the output of that sector (i.e. the 'CO_2 intensities corresponding to indirect production demand'). Moreover, the elements of the vector ($\mathbf{e'P}$), containing only two non-zero elements (one for each type of fuel), represents tonnes of CO_2 emitted per million PTE of demand by consumers for fuels (i.e. the 'CO_2 intensities corresponding to direct consumption demand'). 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 (generally designated as the 'total CO_2 intensities'). The corresponding figures are presented (again, for convenience of presentation, in transpose form) in Table 3, below.

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%, 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 mainly because of indirect production demand.

3. 3. 2. The production of CO_2 emissions attributable to domestic consumption

As results from equation (15), multiplying the CO_2 intensities determined above by the domestic final demand figures, one achieves the corresponding tonnes of CO_2 emitted by each sector. The results obtained are reported in Table 4.

According to the estimation made through the model, the production of CO_2 emissions by the consumption of domestic production by the Portuguese was of 40,556,803 tonnes.

The top five sectors 'responsible' for those CO_2 emissions are 'extraction of crude petroleum, and manufacture of refined petroleum products' (19.3%), 'electricity distribution' (13.5%), 'construction' (12.6%), 'land transport and transport via pipeline services' (10.4%), and 'wholesale and retail trade' (8.8%). This means that these sectors account for almost two-thirds of total CO_2 emissions attributable to the consumption by the Portuguese of goods and services domestically produced. The smallest contributions to CO_2 emissions were registered in 'forestry, logging and related service activities', 'insurance and pension funding services', 'mining and manufacturing of coal by-products', and 'financial intermediation services'.

Similarly to what was seen in relation to energy requirements, one can notice a clear 'scale effect', and it is also noticeable that the great majority of industries are 'responsible' for much more

Table 3
CO_2 Intensities

unit: tonnes of CO_2 / million PTE

	Corresponding to Direct Production Demand	+	Corresponding to Indirect Production Demand	=	Corresponding to Total Production Demand +	Corresponding to Direct Consumption Demand	=	Corresponding to Final Demand	
	e'C		**e'C (A+A^2+...)**		**e'C (I-A)$^{-1}$**	**e'P**		**Total CO_2 Intensity**	*Total CO_2 Intensities' "Ranking"*
	(1)	*(1)/(5)*	(2) = (3)-(1)	*(2)/(5)*	(3)	(4)	*(4)/(5)*	(5) = (3)+(4)	
01 Agriculture, hunting and related service activit.	1.12	37.1%	1.89	62.9%	3.01	0.00	0.0%	3.01	17
02 Forestry, logging and related service activities	0.71	66.5%	0.36	33.5%	1.07	0.00	0.0%	1.07	28
03 Fishing and related service activities	3.20	76.7%	0.97	23.3%	4.17	0.00	0.0%	4.17	13
04 Mining and manufacture of coal by-products	34.99	8.0%	2.94	0.7%	37.93	397.56	91.3%	435.49	1
05 Extr. crude petroleum ..., and manuf. refined petroleum products	7.67	4.6%	1.87	1.1%	9.54	158.85	94.3%	168.39	2
6A Fossil fuel electricity generation	73.74	98.7%	1.00	1.3%	74.75	0.00	0.0%	74.75	3
6B Hydroelectricity	0.00	0.0%	0.17	100.0%	0.17	0.00	0.0%	0.17	38
6C Electricity Distribution	0.00	0.0%	33.83	100.0%	33.83	0.00	0.0%	33.83	4
07 Gas production and distribution	14.06	59.5%	9.58	40.5%	23.64	0.00	0.0%	23.64	6
08 Water supply	0.00	0.0%	6.01	100.0%	6.01	0.00	0.0%	6.01	11
09 Extraction and manuf. of ferrous and non-ferrous ores and metals	5.24	45.4%	6.31	54.6%	11.55	0.00	0.0%	11.55	7
10 Extraction and manuf. of non-metallic minerals	6.09	56.4%	4.71	43.6%	10.80	0.00	0.0%	10.80	8
11 Manuf. of chemicals and chemical products	5.98	70.1%	2.55	29.9%	8.53	0.00	0.0%	8.53	9
12 Manufacture of fabricated metal products	0.19	6.0%	2.99	94.0%	3.18	0.00	0.0%	3.18	16
13 Manuf. of electrical and non-electrical machinery and equipment	0.06	4.9%	1.26	95.1%	1.32	0.00	0.0%	1.32	25
14 Manufacture of transport equipment	0.15	11.7%	1.11	88.3%	1.26	0.00	0.0%	1.26	27
15 Manufacture of food products and beverages	0.36	15.6%	1.97	84.4%	2.34	0.00	0.0%	2.34	22
16 Manufacture of tobacco and tobacco products	0.19	39.2%	0.29	60.8%	0.48	0.00	0.0%	0.48	37
17 Manufacture of textiles and clothing	0.37	13.5%	2.40	86.5%	2.78	0.00	0.0%	2.78	19
18 Manufacture of leather and footwear	0.20	15.3%	1.10	84.7%	1.30	0.00	0.0%	1.30	26
19 Other manufacturing products (includ. wood, cork and furniture)	0.68	25.7%	1.97	74.3%	2.65	0.00	0.0%	2.65	21
20 Manufacture of pulp, paper, paper products and printing products	1.18	27.7%	3.09	72.3%	4.27	0.00	0.0%	4.27	12
21 Manufacture of rubber and plastic products	0.18	6.0%	2.80	94.0%	2.98	0.00	0.0%	2.98	18
22 Construction	0.67	19.5%	2.76	80.5%	3.42	0.00	0.0%	3.42	14
23 Recycling, recovery and repair services	0.20	36.6%	0.34	63.4%	0.53	0.00	0.0%	0.53	36
24 Wholesale and retail trade	0.16	7.5%	1.93	92.5%	2.09	0.00	0.0%	2.09	23
25 Hotel and restaurant services	0.12	4.4%	2.56	95.6%	2.67	0.00	0.0%	2.67	20
26 Land transport and transport via pipeline serv.	21.24	89.5%	2.50	10.5%	23.74	0.00	0.0%	23.74	5
27 Water and air transport services	4.91	76.4%	1.52	23.6%	6.43	0.00	0.0%	6.43	10
28 Supporting and auxiliary transport services	0.17	5.1%	3.11	94.9%	3.27	0.00	0.0%	3.27	15
29 Post and telecommunication services	0.03	3.2%	1.01	96.8%	1.04	0.00	0.0%	1.04	30
30 Financial intermediation services (except insurance and ...)	0.00	0.2%	0.56	99.8%	0.56	0.00	0.0%	0.56	35
31 Insurance and pension funding services	0.06	3.5%	1.54	96.5%	1.59	0.00	0.0%	1.59	24
32 Real estate services and other renting services	0.01	1.5%	0.99	98.5%	1.00	0.00	0.0%	1.00	31
33 Education and R & D services	0.02	3.6%	0.55	96.4%	0.57	0.00	0.0%	0.57	34
34 Health and veterinary market services	0.01	1.6%	0.82	98.4%	0.83	0.00	0.0%	0.83	33
35 Other services (market and non-market)	0.07	6.8%	0.91	93.2%	0.98	0.00	0.0%	0.98	32
36 Public administration non-market services	0.09	8.6%	0.97	91.4%	1.06	0.00	0.0%	1.06	29

Table 4
CO_2 Emissions
corresponding to domestic consumption

(y_{dom} = "Final consumption of households"+"Collective consumption"+"Gross fixed capital formation"+ "Change in stocks")

unit: tonnes of CO_2

	Attributable to Direct Production Demand	+	Attributable to Indirect Production Demand	=	Attributable to Total Production Demand	+ Attributable to Direct Consumption Demand	=	Attributable to Final Demand		
	$e'Cy_{dom}$		**$e'C\ (A+A^2+\ldots)y_{dom}$**		**$e'C\ (I-A)^{-1}y_{dom}$**	**$e'PZy_{dom}$**		**Total CO_2 emissions**	*Total CO_2 Emissions' "Ranking"*	*Relative Distribut. of Tt. CO_2 Emissions by Industry*
	(1)	*(1)/(5)*	(2) = (3)-(1)	*(2)/(5)*	(3)	(4)	*(4)/(5)*	(5) = (3)+(4)		
01 Agriculture, hunting and related service activit.	343 439	37.1%	582 513	62.9%	925 951	0	0.0%	925 951	10	2.3%
02 Forestry, logging and related service activities	12 079	66.5%	6 098	33.5%	18 177	0	0.0%	18 177	36	0.0%
03 Fishing and related service activities	162 010	76.7%	49 146	23.3%	211 156	0	0.0%	211 156	23	0.5%
04 Mining and manufacture of coal by-products	2 625	8.0%	220	0.7%	2 845	29 817	91.3%	32 661	34	0.1%
05 Extr. crude petroleum ..., and manuf. refined petroleum products	311 575	4.0%	75 859	1.0%	387 434	7 448 331	95.1%	7 835 765	1	19.3%
6A Fossil fuel electricity generation	0	0.0%	0	0.0%	0	0	0.0%	0	37	0.0%
6B Hydroelectricity	0	0.0%	0	0.0%	0	0	0.0%	0	37	0.0%
6C Electricity Distribution	0	0.0%	5 484 456	100.0%	5 484 456	0	0.0%	5 484 456	2	13.5%
07 Gas production and distribution	142 038	59.5%	96 789	40.5%	238 827	0	0.0%	238 827	20	0.6%
08 Water supply	0	0.0%	161 401	100.0%	161 401	0	0.0%	161 401	25	0.4%
09 Extraction and manuf. of ferrous and non-ferrous ores and metals	49 400	0.0%	59 457	0.0%	108 857	0	0.0%	108 857	29	0.3%
10 Extraction and manuf. of non-metallic minerals	132 068	56.4%	102 014	43.6%	234 081	0	0.0%	234 081	21	0.6%
11 Manuf. of chemicals and chemical products	834 265	70.1%	355 780	29.9%	1 190 044	0	0.0%	1 190 044	8	2.9%
12 Manufacture of fabricated metal products	24 798	6.0%	389 485	94.0%	414 283	0	0.0%	414 283	16	1.0%
13 Manuf. of electrical and non-electrical machinery and equipment	15 603	4.9%	303 809	95.1%	319 412	0	0.0%	319 412	17	0.8%
14 Manufacture of transport equipment	22 504	11.7%	169 858	88.3%	192 362	0	0.0%	192 362	24	0.5%
15 Manufacture of food products and beverages	386 276	15.6%	2 090 272	84.4%	2 476 548	0	0.0%	2 476 548	6	6.1%
16 Manufacture of tobacco and tobacco products	27 841	39.2%	43 201	60.8%	71 043	0	0.0%	71 043	32	0.2%
17 Manufacture of textiles and clothing	114 387	13.5%	734 251	86.5%	848 638	0	0.0%	848 638	11	2.1%
18 Manufacture of leather and footwear	22 035	15.3%	122 192	84.7%	144 227	0	0.0%	144 227	26	0.4%
19 Other manufacturing products (includ. wood, cork and furniture)	73 621	25.7%	213 265	74.3%	286 886	0	0.0%	286 886	18	0.7%
20 Manufacture of pulp, paper, paper products and printing products	78 521	27.7%	204 740	72.3%	283 261	0	0.0%	283 261	19	0.7%
21 Manufacture of rubber and plastic products	5 084	6.0%	80 264	94.0%	85 348	0	0.0%	85 348	31	0.2%
22 Construction	995 149	19.5%	4 103 263	80.5%	5 098 412	0	0.0%	5 098 412	3	12.6%
23 Recycling, recovery and repair services	46 558	36.6%	80 601	63.4%	127 160	0	0.0%	127 160	28	0.3%
24 Wholesale and retail trade	267 886	7.5%	3 311 810	92.5%	3 579 695	0	0.0%	3 579 695	5	8.8%
25 Hotel and restaurant services	84 978	4.4%	1 863 109	95.6%	1 948 087	0	0.0%	1 948 087	7	4.8%
26 Land transport and transport via pipeline serv.	3 772 179	89.5%	444 248	10.5%	4 216 427	0	0.0%	4 216 427	4	10.4%
27 Water and air transport services	98 228	76.4%	30 360	23.6%	128 588	0	0.0%	128 588	27	0.3%
28 Supporting and auxiliary transport services	11 863	5.1%	221 139	94.9%	233 003	0	0.0%	233 003	22	0.6%
29 Post and telecommunication services	3 377	3.2%	102 823	96.8%	106 200	0	0.0%	106 200	30	0.3%
30 Financial intermediation services (except insurance and ...)	84	0.2%	37 760	99.8%	37 844	0	0.0%	37 844	33	0.1%
31 Insurance and pension funding services	1 082	3.5%	29 926	96.5%	31 008	0	0.0%	31 008	35	0.1%
32 Real estate services and other renting services	11 519	1.5%	771 388	98.5%	782 907	0	0.0%	782 907	12	1.9%
33 Education and R & D services	17 295	3.6%	463 889	96.4%	481 185	0	0.0%	481 185	14	1.2%
34 Health and veterinary market services	7 592	1.6%	464 473	98.4%	472 065	0	0.0%	472 065	15	1.2%
35 Other services (market and non-market)	39 422	6.8%	540 317	93.2%	579 739	0	0.0%	579 739	13	1.4%
36 Public administration non-market services	100 667	8.6%	1 070 430	91.4%	1 171 097	0	0.0%	1 171 097	9	2.9%
Total	8 218 049	20.3%	24 860 606	61.3%	33 078 655	7 478 148	18.4%	40 556 803		100.0%

CO_2 production indirectly than directly. Unsurprisingly, the exceptions, i.e. the sectors that have a significant (direct) production element are: ‘forestry, logging and related service activities’, ‘fishing and related service activities’, ‘gas production and distribution’, ‘extraction and manufacture of non-metallic minerals’, ‘manufacture of chemicals and chemical products’, ‘land transport and transport via pipeline services’ and ‘water and air transport services’.

It is also important to highlight that 18.4% of the CO_2 emissions produced in 1992 occur when coal and oil are burnt by (Portuguese) final consumers, mainly associated with fuel use in private cars, and at a much smaller scale with the use of cooking and heating equipment.

3. 4. Analysis of energy and CO_2 ‘embodied’ in Portuguese international trade

The study performed above concentrates on the appraisal of the emissions of CO_2 attributable to the (final and intermediate) consumption by the Portuguese of goods and services produced in Portugal. However, the reality is that Portugal is an open economy, and greenhouse gas emissions and climate change are global phenomena, with transboundary effects. Therefore, it is important to analyse what happens to energy use and CO_2 emissions in relation to Portuguese imports and exports of non-primary energy goods and services.

As described above, taking some simplifying assumptions, it is possible to estimate the energy and CO_2 ‘embodied’ in the Portuguese international trade.

It can be said that in 1992 there were 702,765 toe of coal and 2,674,429 toe of oil ‘embodied’ in Portuguese exports. The sectors that contributed most to these energy requirements were: ‘manufacture of textiles and clothing’ (18.3%), ‘manufacture of chemicals and chemical products’ (10.9%), ‘land transport and transport via pipeline services’ (10.4%) and ‘water and air transport services’ (9.7%) for oil; and ‘extraction and manufacture of non-metallic minerals’ (24.5%), ‘manufacture of textiles and clothing’ (20.2%) and ‘extraction and manufacture of ferrous and non-ferrous ores and metals’ (14.6%) for coal. While for the generality of these sectors the energy-intensity is relatively high, it is important to mention that ‘manufacture of textiles and clothing’ is a sector situated in the middle of the energy-intensities’ ranking; but its importance in terms of energy ‘embodied’ in exports (the greatest aggregating oil and coal) is not at all surprising, mainly because of the ‘scale effect’, as it is a traditionally very important sector in Portuguese exports.

Moreover, it was estimated that 853,400 toe of coal and 2,713,638 toe of oil were ‘embodied’ in Portuguese imports, which can be interpreted as the quantities of energy that were ‘saved’ by Portugal because it imported the corresponding goods and services instead of producing them in Portugal. In terms of ranking, it is worthwhile to mention that: ‘construction’ (26.2%), ‘electricity distribution’ (8.8%), and ‘manufacture of food products and beverages’ (8.5%), were the top three regarding coal; and the top three sectors for oil were ‘manufacture of food products and beverages’ (16.4%), ‘construction’ (13.4%), and ‘wholesale and retail trade’ (8.1%).

Thus, it can be said that in 1992 Portugal faced a negative (but relatively small) ‘primary energy trade balance’ (for both coal and oil).

Concerning CO_2 emissions, the main results obtained are obviously in accordance to the ones found for energy requirements. Indeed, for example the sectors which contributed most to CO_2 emissions attributable to Portuguese exports were ‘manufacture of textiles and clothing’ (18.7%), ‘extraction and manufacture of non-metallic minerals’ (12%), ‘manufacture of chemicals and chemical products’ (9%), ‘land transport and transport via pipeline services’ (8%) and ‘water and air transport services’ (7.6%). The estimated CO_2 emissions attributable to Portuguese exports were of 10,857,023 tonnes.

The top three sectors in terms of ‘responsibility’ for foreign CO_2 emissions in order to satisfy Portuguese final demand were ‘construction’ (17.1%), ‘manufacture of food products and beverages’ (14.1%), and ‘wholesale and retail trade’ (7.8%), not because of their CO_2-intensity, but mainly for the reason that their final demand by the Portuguese was high. It is also important to note that 82.4% of the 11,560,888 tonnes of CO_2 emitted in foreign countries in order to satisfy Portuguese final demand are attributed to imported goods and services that were used in further production, and therefore that only 17.6% are attributed to imported goods and services that were directly used by final consumers.

Therefore, in 1992, the difference between the emissions that occurred in foreign countries to satisfy Portuguese final demand and the emissions that occurred in Portugal to satisfy foreign final demand was of 703,865 tonnes, which means Portugal faced a negative ‘CO_2 emissions trade balance’.

As for the ‘primary energy trade balance’, the sectors which most contributed for this negative ‘CO_2 emissions trade balance’ were ‘construction’, ‘manufacture of food products and beverages’ and ‘wholesale and retail trade’, while the sectors that most counteracted its effect were ‘manufacture of textiles and clothing’, ‘extraction and manufacture of non-metallic minerals’ and the (land and air) transport sectors.

To sum up, one can say that total Portuguese imports ‘embodied’ more energy and CO_2 than total Portuguese exports.

3. 5. Portuguese ‘responsibility’ for CO_2 emissions *versus* CO_2 emissions produced by the Portuguese economy

Finally, combining the results achieved in the two previous sections, as shown in Table 5, it is also possible to determine:

Table 5 **Portuguese 'responsibility' for CO_2 emissions *versus* CO_2 emissions produced by the Portuguese economy** (y_{dom} = "Final Consumption of households"+"Collective consumption"+"Gross fixed capital formation"+"Change in stocks") (y_{exp} = "Exports of goods and services") (y_{imp} = "Imports of goods and services") *unit: tonnes of CO_2*	Attributable to domestic consumption **$e'C(I-A)^{-1} y_{dom}+e'PZy_{dom}$** (1)	+ *(1)/(3)*	Attributable to Portuguese imports **$e'C(I-A)^{-1} B(I-A)^{-1}y_{dom} + e'C (I-A)^{-1}y_{imp}$** (2)	= *(2)/(3)*	Portuguese 'responsibility' for CO_2 emissions $c_{resp} = c_{dom} + c_{imp}$ (3)=(1)+(2)	*Portug. 'respons.' for CO_2 Emis.' "Rank."*	*Rel. Distr. of Portug. 'respons.' for CO_2 Emis. by Industry*	Attributable to domestic consumption **$e'C(I-A)^{-1} y_{dom}+e'PZy_{dom}$** (4)	+ *(4)/(6)*	Attributable to Portuguese exports **$e'C (I-A)^{-1}y_{exp}$** (5)	= *(5)/(6)*	CO_2 emissions produced by the Portuguese Economy $c_{emis} = c_{dom} + c_{exp}$ (6)=(4)+(5)	*CO_2 emis. by the Port. economy's "Rank."*	*Rel. Distr. of CO_2 Emis. by the Port. economy by Industry*
01 Agriculture, hunting and related service activit.	925 951	72.0%	360 072	28.0%	1 286 023	10	2.5%	925 951	87.2%	136 229	12.8%	1 062 181	12	2.1%
02 Forestry, logging and related service activities	18 177	85.2%	3 161	14.8%	21 338	36	0.0%	18 177	69.2%	8 087	30.8%	26 264	36	0.1%
03 Fishing and related service activities	211 156	55.6%	168 777	44.4%	379 933	22	0.7%	211 156	84.8%	37 851	15.2%	249 006	26	0.5%
04 Mining and manufacture of coal by-products	32 661	97.0%	1 008	3.0%	33 669	35	0.1%	32 661	73.2%	11 948	26.8%	44 609	33	0.1%
05 Extr. crude petroleum ..., and manuf. refined petroleum products	7 835 765	94.3%	477 697	5.7%	8 313 462	1	16.0%	7 835 765	92.2%	662 915	7.8%	8 498 681	1	16.5%
6A Fossil fuel electricity generation	0	0.0%	0	0.0%	0	37	0.0%	0	0.0%	0	0.0%	0	37	0.0%
6B Hydroelectricity	0	0.0%	0	0.0%	0	37	0.0%	0	0.0%	0	0.0%	0	37	0.0%
6C Electricity Distribution	5 484 456	92.0%	479 428	8.0%	5 963 884	3	11.4%	5 484 456	95.6%	251 027	4.4%	5 735 484	2	11.2%
07 Gas production and distribution	238 827	85.3%	41 278	14.7%	280 105	24	0.5%	238 827	100.0%	71	0.0%	238 898	27	0.5%
08 Water supply	161 401	84.6%	29 410	15.4%	190 811	28	0.4%	161 401	99.8%	367	0.2%	161 768	29	0.3%
09 Extraction and manuf. of ferrous and non-ferrous ores and metals	108 857	0.0%	33 585	0.0%	142 443	31	0.3%	108 857	15.1%	613 766	84.9%	722 624	19	1.4%
10 Extraction and manuf. of non-metallic minerals	234 081	86.6%	36 177	13.4%	270 259	25	0.5%	234 081	15.3%	1 299 465	84.7%	1 533 546	10	3.0%
11 Manuf. of chemicals and chemical products	1 190 044	69.1%	533 124	30.9%	1 723 168	8	3.3%	1 190 044	55.0%	972 149	45.0%	2 162 193	8	4.2%
12 Manufacture of fabricated metal products	414 283	43.0%	549 557	57.0%	963 840	13	1.8%	414 283	57.1%	311 092	42.9%	725 375	18	1.4%
13 Manuf. of electrical and non-electrical machinery and equipment	319 412	48.9%	333 631	51.1%	653 043	16	1.3%	319 412	43.8%	410 302	56.2%	729 714	17	1.4%
14 Manufacture of transport equipment	192 362	33.1%	389 407	66.9%	581 770	18	1.1%	192 362	38.8%	302 987	61.2%	495 349	21	1.0%
15 Manufacture of food products and beverages	2 476 548	60.3%	1 633 330	39.7%	4 109 877	6	7.9%	2 476 548	89.5%	291 888	10.5%	2 768 436	7	5.4%
16 Manufacture of tobacco and tobacco products	71 043	44.2%	89 848	55.8%	160 890	30	0.3%	71 043	99.7%	179	0.3%	71 222	32	0.1%
17 Manufacture of textiles and clothing	848 638	69.2%	377 094	30.8%	1 225 732	11	2.4%	848 638	29.4%	2 035 153	70.6%	2 883 792	6	5.6%
18 Manufacture of leather and footwear	144 227	33.4%	287 456	66.6%	431 683	21	0.8%	144 227	33.3%	289 309	66.7%	433 535	24	0.8%
19 Other manufacturing products (includ. wood, cork and furniture)	286 886	63.5%	164 934	36.5%	451 820	20	0.9%	286 886	36.3%	503 689	63.7%	790 575	16	1.5%
20 Manufacture of pulp, paper, paper products and printing products	283 261	47.5%	313 410	52.5%	596 672	17	1.1%	283 261	34.8%	529 878	65.2%	813 139	15	1.6%
21 Manufacture of rubber and plastic products	85 348	32.0%	181 099	68.0%	266 448	26	0.5%	85 348	45.1%	103 808	54.9%	189 157	28	0.4%
22 Construction	5 098 412	72.1%	1 971 836	27.9%	7 070 248	2	13.6%	5 098 412	100.0%	0	0.0%	5 098 412	3	9.9%
23 Recycling, recovery and repair services	127 160	57.7%	93 318	42.3%	220 478	27	0.4%	127 160	95.9%	5 401	4.1%	132 561	31	0.3%
24 Wholesale and retail trade	3 579 695	79.9%	899 150	20.1%	4 478 846	4	8.6%	3 579 695	99.6%	15 143	0.4%	3 594 838	5	7.0%
25 Hotel and restaurant services	1 948 087	77.6%	563 372	22.4%	2 511 459	7	4.8%	1 948 087	97.9%	40 941	2.1%	1 989 028	9	3.9%
26 Land transport and transport via pipeline serv.	4 216 427	97.4%	110 570	2.6%	4 326 997	5	8.3%	4 216 427	83.0%	864 071	17.0%	5 080 497	4	9.9%
27 Water and air transport services	128 588	77.0%	38 341	23.0%	166 929	29	0.3%	128 588	13.5%	822 423	86.5%	951 011	14	1.8%
28 Supporting and auxiliary transport services	233 003	78.2%	64 904	21.8%	297 907	23	0.6%	233 003	68.1%	109 134	31.9%	342 137	25	0.7%
29 Post and telecommunication services	106 200	84.3%	19 811	15.7%	126 011	32	0.2%	106 200	77.6%	30 663	22.4%	136 863	30	0.3%
30 Financial intermediation services (except insurance and ...)	37 844	75.7%	12 145	24.3%	49 989	33	0.1%	37 844	100.0%	0	0.0%	37 844	35	0.1%
31 Insurance and pension funding services	31 008	63.2%	18 088	36.8%	49 095	34	0.1%	31 008	77.2%	9 174	22.8%	40 182	34	0.1%
32 Real estate services and other renting services	782 907	76.4%	242 408	23.6%	1 025 314	12	2.0%	782 907	80.8%	185 763	19.2%	968 670	13	1.9%
33 Education and R & D services	481 185	84.2%	90 351	15.8%	571 536	19	1.1%	481 185	100.0%	0	0.0%	481 185	22	0.9%
34 Health and veterinary market services	472 065	60.2%	311 758	39.8%	783 824	15	1.5%	472 065	100.0%	0	0.0%	472 065	23	0.9%
35 Other services (market and non-market)	579 739	67.2%	282 492	32.8%	862 232	14	1.7%	579 739	99.6%	2 150	0.4%	581 890	20	1.1%
36 Public administration non-market services	1 171 097	76.5%	358 859	23.5%	1 529 956	9	2.9%	1 171 097	100.0%	0	0.0%	1 171 097	11	2.3%
Total	40 556 803	77.8%	11 560 888	22.2%	52 117 691		100.0%	40 556 803	78.9%	10 857 023	21.1%	51 413 826		100.0%

• the Portuguese ‘responsibility’ for CO_2 emissions (c_{resp} – as results from equation (21)), and

• the CO_2 emissions produced by the Portuguese economy (c_{emis} – as results from equation (22)).

In 1992, 51,413,826 tonnes of CO_2 were emitted on Portuguese territory, derived from the use of fossil fuels[29]. This figure corresponds to the CO_2 emissions that were produced by the Portuguese economy in 1992, in order to satisfy the (domestic and foreign) final demand for goods and services domestically produced. Of these, 78.9% occurred in order to satisfy the final demand by Portuguese consumers, while the remaining 21.1% resulted from the satisfaction of the foreign final demand (exports).

The sectors that contributed the most to this amount of CO_2 emissions were ‘extraction of crude petroleum, and manufacture of refined petroleum products’ (16.5%), ‘electricity distribution’ (11.2%), ‘construction’ (9.9%), ‘land transport and transport via pipeline services’ (9.9%), ‘wholesale and retail trade’ (7%), and ‘manufacture of textiles and clothing’ (5.6%). 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 transports are ‘responsible’ for around one-quarter of all the emissions that occurred in Portugal in 1992.

Concerning the CO_2 emissions whose ‘responsibility’ is attributed to the consumption of the Portuguese economy, whether of goods and services domestically produced or imported, the amount estimated was of 52,117,691 tonnes. Furthermore, one can say that only 77.8% of these CO_2 emissions for which the Portuguese economy is ‘responsible’ were released in Portuguese territory, while the remaining 22.2% were released in foreign countries. The top five sectors in terms of contribution to these emissions were ‘extraction of crude petroleum, and manufacture of refined petroleum products’ (16%), ‘construction’ (13.6%), ‘electricity distribution’ (11.4%), ‘wholesale and retail trade’ (8.6%), and ‘land transport and transport via pipeline services’ (8.3%)[30].

Thus, in 1992, the CO_2 emissions that are attributable to production in the Portuguese economy were (slightly) lower than the ones that are Portuguese ‘responsibility’.

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[29] This figure is slightly higher than alternative estimates made by the Directorate-General for Environment (body of the Portuguese Ministry of Environment and Land Use Planning), following the ‘IPCC Guidelines’, and published by EEA (2001), which reports that the total production of CO_2 derived from fuel combustion, in 1992, was of 45,289,956 tonnes of CO_2. However, it is important to underline that the methodologies used were not the same. Besides, 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.

[30] These are precisely the same top five sectors mentioned above for the emissions of CO_2 produced by the Portuguese economy in 1992; but for example the sixth position in the ranking is here occupied by ‘manufacture of food products and beverages’, instead of ‘manufacture of textiles and clothing’, as would be expected according to the traditional composition of Portuguese exports and imports.

4. Final comments

In this study, an extensive input-output analysis was used to investigate energy flows and CO_2 emissions in the Portuguese economy, for 1992.

The approach used allowed the distinction between the 'direct consumption demand' (by final consumers), and the (direct and indirect) 'production demand' (by industries) for primary energy fuels. One of the key results found was the significant importance of the indirect production demand for fuels in the production of CO_2. Indeed, it was seen that more than half (61.3%) of the domestic CO_2 emissions are attributable to indirect demand for fossil fuels, while 18.4% of the emissions are directly attributable to household demand for fossil fuels, and the remaining 20.3% to direct demand by industries.

These results "indicate how crucial it is to use an approach which takes economic interrelations into account when analysing CO_2 production" (Gay and Proops, 1993: 123), and therefore show that the analysis here performed has clear policy relevance.

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. Therefore, it came as no surprise that transports were 'responsible' for almost one-third of all the emissions that occurred in 1992 in order to satisfy domestic demand, as well as that around one-eighth of domestic CO_2 emissions are attributable to electricity generation (using fossil fuels).

Hence, it looks almost 'natural' that important reductions in CO_2 emissions in Portugal can be achieved by focusing policies on transport (such as, e.g., promoting the use of public transport, as well as the use of more efficient vehicles) and concerning the production of electricity (such as, e.g., the replacing of coal and oil use in electricity generation by natural gas, which is less CO_2-intensive, and by promoting the increase of the share of renewables in electricity generation).

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 industries are 'responsible' for much more CO_2 production indirectly than directly.

The study here performed also revealed that the sectors that are more highly energy (or CO_2) intensive are not necessarily the ones whose production requires more energy (or which produce more CO_2 emissions), which is explained by what might be called as the 'scale effect' of the final demand.

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, with adequate information campaigns it is possible to show to final consumers that they have much more 'responsibility' for CO_2 emissions than they usually assume, and subsequently 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 economic, energy and environmental interactions in an input-output framework, is that it allows the analysis of how energy, and therefore CO_2 emission, 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.

Additionally, and according to the 'components' of the final demand considered, the analysis performed also allowed the estimation of primary energy and CO_2 emissions 'embodied' in Portuguese international trade, as well as the Portuguese 'responsibility' for CO_2 emissions and the CO_2 emissions produced by the Portuguese economy. One of the key results was that total Portuguese exports 'embodied' less energy and CO_2 than total Portuguese imports. Accordingly, it was also assessed that the CO_2 emissions that are attributable to production in the Portuguese economy were lower than the ones that were said to be of Portuguese 'responsibility'.

This type of analysis is of great importance in the context of the Kyoto Protocol, as it draws attention to the possibility that some countries may be tempted to reduce their greenhouse gas emissions 'artificially', mostly by stopping producing certain (energy and CO_2 intensive) goods to import them from other countries[31] (Machado, 2000: 1).

Finally, it is also 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 need to condense information, so that it can be comprehended and thus allow policy conclusions to be drawn. Nevertheless, it is also worthwhile to note that the full potential of the data set was not exploited; indeed, many areas of further work remain, and there are several extensions to the model that should be explored in later stages of the research; i.e.:

- Analysis of the consequences of switching entirely to non-fossil-fuel electricity generation.
- Examination of the effect of switching to a mix of fuel inputs with lower CO_2 emissions (inter-fuel substitution).
- Study of the impacts of changes in the technologies used for specific purposes (energy efficiency).

[31] Indeed, since Portugal is 'responsible' for more CO_2 emissions than it emits, when trade patterns are taken into account, it is possible to say that this might have been the case for Portugal in 1992, although in a very small extent.

• Examination of the effect of alterations in the structure of inter-industry relations, as well as in the structure and in the level of the final demand.

• Incorporation of the non-fuel sources of CO_2.

• To perform the analysis for more recent years and to investigate the reasons behind the changes which might have occurred (through structural decomposition analysis), as soon as the information becomes available, particularly concerning National Accounts.

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