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Economic activity and atmospheric pollution in Spain: an input-output approach

by

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When I started to study Economics one teacher said that Economics was as a pair of glasses that makes you to see the world from a different perspective than a lawyer or a doctor. Now, I may say that input-output has been to me a new pair of glasses to see Economics. This dissertation is the final product of my PhD work at the Department of Economic Theory at the Faculty of Economics and Business of the University of Barcelona. There are many people that have been supportive, helpful or simply a pleasant colleague during my PhD period, and I am very grateful for that.

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To Franky.

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1. Introduction

> "Economic phenomena are characterized by a multiplicity of causal relationships. For example, there is a variety of inputs which may be used in the production of a particular good, and each good in turn may be used in a variety of ways. [...] This leads to a system of economic interrelationships between economic processes. However, it does not mean that the economic sphere is isolated from other spheres; precisely because of the many-sidedness of economic relationships the interactions with the non-economic sphere will be particularly close." (Leontief, 1928, p. 182)

1.1. Motivation and approach

1.1.1. Motivation

The United Nations Conference on Environment and Development held in Rio de Janeiro in 1992 provided the fundamental principles and the programme of action for achieving sustainable development[1]; these statements were strongly reaffirmed ten years afterwards in 2002 at the World Summit on Sustainable Development in Johannesburg. The Agenda 21, as it is known the programme of action, identified unsustainable patterns of production and consumption as the major causes of the continued deterioration of the global environment and it stated that it would be necessary to change the way societies produce and consume to achieve a global sustainable development.

Economic activities in its various stages have different effects on the environment. These effects are not usually reflected in market transactions and they are considered externalities of the economic system. Nevertheless, these 'environmental externalities' exist precisely because the economic system is not isolated and there are physical linkages between the environment and the economy.

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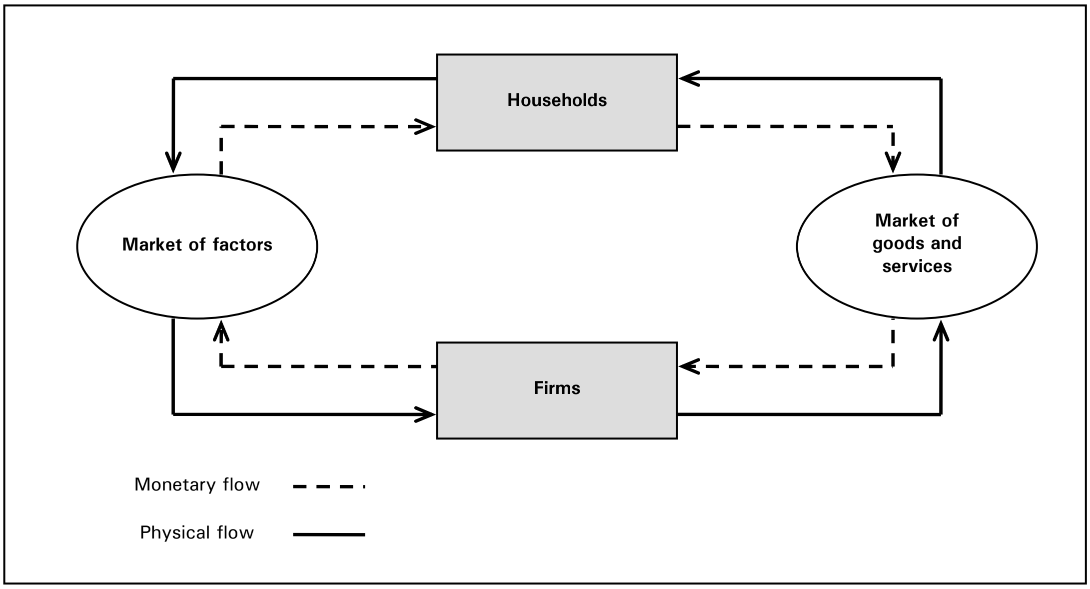
[1] The concept of 'sustainable development' was defined by the Commission on Environment and Development as "the development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs". This concept takes economic, environmental, and social considerations equally into account (see http://www.un.org/esa/sustdev/).

These linkages, however, have seldom been considered in the past probably because the impacts of the economic activity were comparatively less harm than now (Ayres and Kneese, 1969). But nowadays the situation is different and the deterioration of the global environment has become a central issue not only in politic and social spheres but also in the academia.

Generally, economists have considered the economy as a close system in which producers and consumers decisions are coordinated by prices determined in the market. Although with a high level of simplification of the reality, the circular flow of income reflects this idea (Figure 1.1). In its simplest version, firms (producers) provide households (consumers) with goods and services in exchange for consumer expenditure and, on the other hand, households provide firms with factors of production in exchange for a payment. Thus, this model describes not only the monetary flow between households and firms but also the associated physical flow.

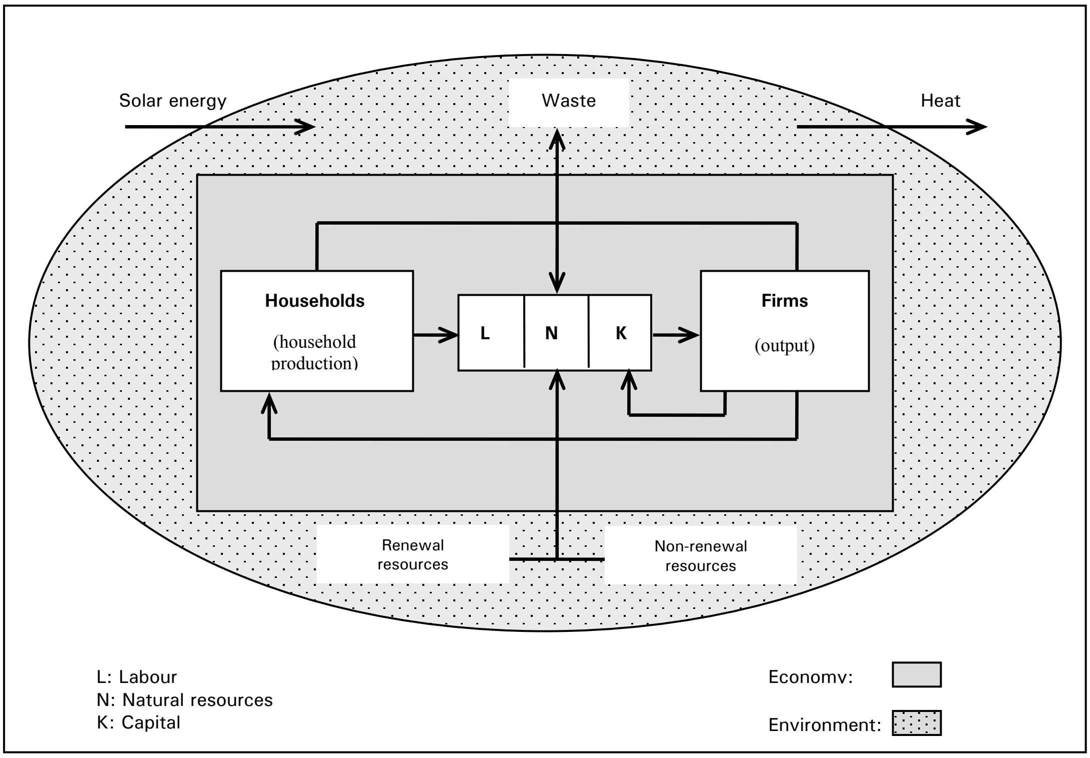
Figure 1.1: Circular flow of income of a two-sector economy



Source: own elaboration.

This simple model can be enlarged by introducing the financial, the government, or the foreign sector; however, our interest is to extend it to reflect the linkages between the economy and the environment (Figure 1.2). For doing so, first, we need to place the economic system within a broader context; that is, the economy is part of the ecosystem or environment. In the ecosystem the solar energy enters and it allows for different biogeochemical cycles that are basic for the continuity of natural life. It is in this context where the economic activity is connected with the environment. On one hand, firms use not only labour and capital but also natural resources to produce goods and services. These natural resources can be either renewable or non-renewable depending whether they can be reproduced by any ‘natural’ process within the ecosystem or not. On the other hand, in the process of production and consumption some waste is generated and then giving back in the environment. Part of this waste can be recycled within the economic system and re-used again as a factor or production; however, in industrial economies the most part of this waste is placed in the environment being one of the major causes of the deterioration of the environment.

Figure 1.2: Physical flows between the economy and the environment



Source: own elaboration from Daly (1999) and Roca (2005)

Moreover, through economic growth the economic subsystem (grey box) may expand its physical dimension and it may assimilate into itself a larger and larger proportion of the ecosystem (dotted grey area). That is, the economy usually needs more space whether it be living space for expanding population or space taken over to provide raw materials and sinks for waste (Daly, 1999, p. 635). However, the economic growth may also be compatible with environmental improvement to some extent since, for instance, new and less pollutant technologies can be introduced. This fact shows that relationships between economic growth and environmental pressures are undoubtedly complex. Indeed, the effects of economic growth on the environment have been receiving increasing attention in recent years. Specifically, since the early 1990's the debate on the environmental effects of economic growth has been strongly influenced by the so-called Environmental Kuznets Curve (EKC) hypothesis. This hypothesis states that an inverted U relationship can be found between environmental pressures and per-capita income; that is, environmental quality deteriorates in early stage of economic growth, but once a critical level of per-capita income has been reached the environmental quality improves as per-capita income increases (Grossman and Krueger, 1991; Shafik and Bandyopadhyay, 1992)[2]. However, following de Bruyn and Opschoor's (1997) differentiation it could be distinguished an absolute (or strong) and a relative (or weak) delinking between economic growth and environmental pressures. In the first case, there would be an absolute reduction in environmental pressures; whereas in the second case, there would only be a reduction in environmental pressures per unit of income, which would not be enough for environmental improvement.

The EKC hypothesis is founded on the fact that per-capita income growth may involve changes in production process and/or final demand towards less pollutant production and consumption patterns. According to the EKC literature there are three main factors provoked by the own process of economic growth that may explain this environmental improvement: technology-scale-composition effects, individual preferences, and international trade. Considering other factors remain constant, i.e. *ceteris paribus*, the first factor claims the fact that economic growth affects the quality of environment in three different channels. On one hand, increasing output may require more inputs but also more natural resources and more waste that contribute to degrade environmental quality. Thus, economic growth exhibits a scale effect that has a negative impact on the environment. However, economic growth has also a positive impact on environment through a composition effect; that is, as income grows, structure of the economy may tend to change and gradually increases cleaner activities that produce less pollution. Moreover, economic growth may be accompanied by technological progress that may replace dirty and obsolete technologies by others less pollutant. The EKC suggests that the negative impact of the scale effect may tend to prevail in initial stages of growth but it may

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[2] The EKC derives its name from the work of Kuznets (1955) who postulated a similar relationship between income inequality and economic development. See also special issues about EKC in *Environment and Development Economics*, volume 2, issue 4, November 1997; and in *Ecological Economics*, volume 25, issue 2, May 1998.

be eventually overcome by positive impact of the composition and technology effects (Vukina *et al.*, 1999). However, several counter-arguments can be made. On one hand, although it seems reasonable to believe that new technologies may lead to a more efficient use of resources, the prediction of complex consequences derived from the technological effect is far from be easy. The term 'rebound effect' has been coined by energy economics to express the fact that an increase in efficiency in the use of a natural resource may tend to stimulate its demand, thereby reducing or in extreme cases even cancelling out the mitigating effect of the efficiency increase. Moreover, technological changes are not often concerned with the efficiency of resource use, but rather involves the development of new processes and products that may pose a greater environmental threat, such as the use of new chemical substances or nuclear power. On the other hand, the composition effect is basically founded on the fact that although the environmental degradation may tend to increase as structure of the economy changes from agricultural to industrial activities, this degradation starts to fall when the structure of the economy changes from energy intensive industry to services. However, such a claim requires further empirical research as some services activities, such as transport, may generate as much or maybe more environmental pressures than many industrial activities, such as knowledge based technology intensive industries.

The second claim is that once a certain income level is achieved, consumers decide to renounce the consumption of certain private goods and services in order to 'consume' more environmental quality. However, 'environmental quality' is in most cases a public good that cannot be bought in the market but it is resolved in political spheres. Hence, the claim that individuals can decide to 'buy' environmental quality is a metaphor that cannot be taken too far (Roca, 2003). A further issue concerning individual preferences is the fact that environmental costs are sometimes displaced to other territories (see below) or to other generations. In both cases, when environmental degradation affects other individuals because of spatial or intergenerational displacements, the consumer preferences over consumption of private commodities or environmental quality can be considered no longer a main factor. In fact, the more environmental problems affect other individuals, the less likelihood is that economic growth leads to political decisions that reduce environmental pressures. It is hardly surprising then that the majority of the environmental pressures that contribute to global and long-term problems, such as greenhouse gas emissions, correlate positively with per-capita income, even at very high income levels.

Finally, international trade is probably one of the most important factors to take into account when analysing the relationship between economic growth and environment. In fact, free trade has contradictory impacts on environment, both increasing pollution and motivating reductions in it. On one hand, trade may lead to increase the size of the economy especially by exports and hence, it may raise pollution; on the other hand, international trade may enhance diffusion of clean technology, which would lead to reduce environmental pressures. However, in open economies it should be considered the possibility of EKC not being derived from a genuine environmental improvement but from and exportation of environmental problems to other territories (Arrow *et al.*, 1995; Suri and Chapman, 1998; Muradian and Martínez-Alier, 2001). Changes in the structure of production in developed economies are not accompanied by equivalent changes in the structure of consumption of these economies. Therefore, EKC actually may record displacement of dirty industries to less developed economies. Under certain circumstances, the pollution intensive industries migrate from countries with stronger environmental regulations to those with weaker regulations (Copeland and Taylor, 1995). This fact has been called the ‘displacement hypothesis’ and it is related with the so-called ‘pollution haven hypothesis’, which refers to the possibility that firms relocate its highly polluting activities to countries with lower environmental standards (Dinda, 2004; Dietzenbacher and Mukhopadhyay, 2007).

The three main chapters of this study are relevant to analyse the relationships between the economic growth and the environment. In Chapter 3 we take the technology-scale-composition effect into account. The role played by private consumption is one of the determinants of the final demand composition and it is considered in Chapter 4. Finally, in Chapter 5 we analyse the influence of international trade.

1.1.2. Approach

In Figure 1.2 the economy and the environment are depicted within the same framework. However, how the monetary world (the economy) and the physical world (the environment) can be linked within the economic science? Input-output analysis offers a suitable approach to study not only the interdependences inside the economy but also the interrelationships between the economy and the environment. As Leontief (1928) pointed out, the capability of this approach to examine this kind of interactions opens the way for studies that deal not only with economic production but also with other aspects such as the effects of production and consumption on the environment. We shall describe the basis of the input-output approach in Chapter 2; however, there are three main features worth to be mentioned in this introduction.

First, the capacity of input-output analysis for combining monetary and physical units allows for revealing physical relationships that do not need to have a market counterpart. That is, in input-output models impacts of the economic activity on the environment, which usually are not reflected in the market, can be measured in physical units whereas economic transactions can be computed in monetary terms as usually. Second, input-output analysis allows for incorporating different assumptions related to environmental policy. That is, input-output models can assume that firms and consumers are maximising their profits and utilities as other economic models usually do; however, these assumptions are not strictly necessary. We can also introduce other assumptions much closer to achieve sustainable development such as the adoption of not minimising-cost technologies but environmentally more desirable. Finally, the versatility of input-output models to be applied at different levels of aggregation allows for analysing environmental problems generated either by a single firm, an economic sector, or by a whole country within the same approach.

1.2. Aim and outline

In this study we analyse some aspects of the interdependences between the economy and the environment by applying the input-output approach. Although economic activity affects the environment in many ways, in this study we only focus on one: the atmospheric pollution. Concretely, we consider nine different gases. On one hand, the six greenhouse gases regulated by Kyoto protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs). And, on the other hand, three gases related to local environmental problems such as acidification and eutrophication: sulphur oxides (SO_x), nitrogen oxides (NO_x), and ammonia (NH_3).

The chapters that follow this introduction are four self-contained essays that examine the relation between the economic activity and emissions in Spain from different perspectives. In Chapter 2 we describe the methodology and the database we shall use in the following chapters. First, we present the basis of the input-output analysis emphasising those characteristics that make it a suitable approach to study the interdependences between the economy and the environment. Then, we describe the database and the procedure required to obtain an environmentally extended input-output table for Spain. We apply the environmentally extended input-output model presented in this chapter to describe the Spanish situation regarding atmospheric pollution in 1995 and 2000. In Chapter 3, we examine the contribution of the driving forces of the evolution of emissions in Spain from 1995 to 2000. For doing so, we decompose the change in emissions into the three main 'sources'. First, shifts in total intensity emission matrix that includes changes in technical and emission coefficients (the eco-technological effect). Second, changes in the composition of final uses (the structure effect). And third, changes in the level of final uses (the level effect). We quantify the effects of these three determinants through performing a structural decomposition analysis. Chapter 4 shows the capacity of input-output analysis to study the relationship between the economic activity and the environment at a micro level. The purpose of this chapter is to analyse the different impact on atmospheric pollution of different households with different 'economic position'. We calculate total emissions, i.e. direct plus indirect emissions, generated by private consumption of Spanish households classified by quintiles of expenditure in the year 2000. In Chapter 5 we estimate the emissions embodied in Spanish international trade. By applying a multiregional input-output model we define and compare two approaches: the responsibility emission balance and the trade emission balance. We evaluate the international responsibility of Spain in 1995 and 2000. Finally, Chapter 6 summarises the conclusions of this study.

Some previous results of this study have been presented in various international and national conferences, such as the *15th and 16th International Input-Output Conference*, the *2006 and 2008 Intermediate International Input-Output Conference*, the *9th Biennial Conference of International Society for Ecological Economics*, and the *I and II Spanish Input-Output Conference*. Moreover, some results of these chapters have been also published in international and national journals jointly with Jordi Roca. Some outcomes of Chapters 3 and 4 were published in *Ecological Economics*, 63(1), 2007; and previous versions of Chapter 5 in *Ekonomiaz*, 61(1), 2008 and *Cuadernos Aragoneses de Economía*, 18(1), 2008.

1.3. Terminology and notation

The last section of this introduction is devoted to make two remarks about the terminology and the notation used in this study.

In input-output analysis the terms ‘sector’ and ‘industry’ are generally used interchangeably. However, both words have different meanings in other contexts. ‘Sector’ usually refers to a set of enterprises, firms, or business with a common economic and productive activity; whereas ‘industry’ refers specifically to the aggregate of manufacturing enterprises. Since the analysis carried out in this study considered all kind of economic activities, i.e. agriculture, manufactures, and services, we prefer to use the term ‘sector’ because of its broader meaning. For similar reasons, we also prefer to use the term ‘product’ instead of ‘commodity’. However, in order to avoid some confusions we shall keep the terms ‘industry’ and ‘commodity’ in those established concepts as the ‘industry technology assumption’ and the ‘commodity technology assumption’.

The second remark is about the mathematical notation. In this study, matrices are indicated by bold, upright capital letters; vectors by bold, upright lower case letters; and scalars by italicised lower case letters. Vectors are columns by definition, so that row vectors are obtained by transposition, indicated by a prime. A diagonal matrix with the elements of any vector on its main diagonal and all other entries equal to zero is indicated by a circumflex.

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2. Input-output analysis: a suitable approach to study the interdependences in and between the economy and the environment

2.1. Introduction

In the late 1920's and 1930's Wassily Leontief established the foundations of input-output analysis[3], which has been continuously enriched not only by Leontief's works but also by numerous contributions of other economists[4]. Input-output analysis focuses on mutual interrelations between various parts of the economic system, which are usually called interdependences. In fact, this idea was already developed earlier by Fran François Quesnay and León Walras[5]; however, Leontief was the first to implement the general equilibrium theory (or general interdependence as he preferred to term it) empirically and to adapt it to the needs of practical economic calculus. According to Leontief himself input-output analysis can be defined as:

> "a practical extension of the classical theory of general interdependence which views the whole economy of a region, a country and even of the entire world as a single system and sets out to describe and to interpret its operation in terms of directly observable basic structural relationships." (Leontief, 1987, p. 860)

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[3] Wassily Leontief won the Prize in Economic Sciences in Memory of Alfred Nobel in 1973 "for the development of the input-output method and for its application to important economic problems" (from the Nobel Foundation website http://nobelprize.org).

[4] The aim of this chapter is not to give a detailed review of these contributions. A comprehensive introduction to Leontief's work is Leontief (1986), some contributions of other authors have been compiled in several books; for instance Kurz *et al.* (1998), Lahr and Dietzenbacher (2001), or Dietzenbacher and Lahr (2004).

[5] Quesnay published the *Tableau Economique* in 1758 and Walras the *Elements d'Economie Politique Pure* in 1874.

Probably, the hallmark of Leontief's research was his continuous emphasis on the complementarity between theoretical reasoning and empirical work; he saw them as two integrated parts rather than two separate disciplines within economics (Leontief, 1954, 1958, 1971). Since the beginning he was looking for a methodology that could bring together the general laws and the observable facts of the economy. In fact, his three seminal papers (Leontief, 1928, 1936, 1937) summarise his scientific methodology, which can be described through a three step process: first, formulation of an appropriate theoretical model; second, gathering and arrangement of the necessary data; and third, empirical application of the theoretical devices to factual data (Leontief, 1937). Thus, input-output analysis is a theoretical framework to analyse interdependences of an economic system rather than simply a particular mathematical formula or a specific body of data.

The main features of the input-output analysis open up a path to study not only the interactions amongst different parts of the economic system but also to extend the idea of interdependence to other fields with which the economy is connected such as the environment. Its flexibility to adjust the model to any level of disaggregation for which data are available and its capacity of accommodating monetary and physical units simultaneously make input-output analysis especially suitable for environmental analysis. In the 1960's and 1970's some economists tried to extend the standard input-output model to consider some of the links between the economy and the environment (Cumberland, 1966; Daly, 1968; Isard, 1969; Leontief, 1970a; Victor, 1972)[6].

Cumberland (1966) was the first to publish a theoretical input-output table that incorporated the economic and environmental interrelations. He tried to assign a monetary value for environment repercussions of economy activity to incorporate cost-benefit analysis into input-output model. However, he did not consider material flows between economy and environment.

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[6] The models mentioned are contributions within input-output approach; however, in that time there was another contemporary work worth to be mentioned for its repercussion amongst economists. It was a paper published in *The American Economic Review* by Ayres and Kneese (1969), who attempted to adapt the Walras-Cassel general equilibrium model to include some of the environmental relations. Concretely, based on the physical law of conservation of mass they showed that the production of residuals is an inherent and general part of the production and consumption process rather than a exceptional or a minor case that can be analysed as economic externalities. Although they did not use an input-output approach, Ayres and Kneese contributed to open the scope of the economy for considering the economy as an open system rather than a close one.

On the other hand, Daly (1968) and Isard (1969) were the most ambitious authors since they tried to analyse not only bidirectional interactions between the economy and the environment but also the interactions within the environment itself. Both designed a kind of input-output table composed of a matrix divided into four quadrants: the upper left quadrant recorded the economic relations; the upper right quadrant gathered the relationships from the economy to the environment, whereas the lower left quadrant focused on the relationships from the environment to the economy; finally, the lower right quadrant compiled the relationships within the ecosystem itself. However, empirical applications of these models can hardly be done because of the difficulty for compiling data regarding the last quadrant[7]. The difference between both models essentially lies in the structure of the table. Whereas Daly's model followed the standard input-output table in which each sector produces only one product, Isard proposed a product-by-sector table that allowed for compiling secondary production of environmental output such as pollution. Daly's coefficients were lacking a meaning since his total column was the result of summing up different units[8]. Isard overcame this limitation presenting a table of coefficients rather than flows. So, the technical coefficients of the upper left quadrant were directly derived from standard input-output tables and the coefficients of the upper right and lower left quadrants were calculated by considering, for instance, the amount of pollutant and/or the amount of water required per unit of economic product. As Leontief (1970a) showed latter, the one product to one sector assumption is not a limitation for environmental input-output analysis.

In 1970 Leontief published his own proposal to extend input-output model to environmental pressures (Leontief, 1970a) and in 1972 he presented some results for the United States (Leontief and Ford, 1972). Unlike Daly's and Isard's models, Leontief's model only reflects the link from economy to environment ignoring material flows in the reverse direction and within the environment. However, his simple proposal allows for estimating price effects produced by changes in anti-pollution technology and also for analysing effects of government policies aimed at regulating industrial pollution. For doing so, Leontief introduced an extra row and extra column in the standard input-output table. The row indicates the amount of pollution generated by each sector, whereas the column represents the abatement sector engaged in reducing the level of pollution. In this model, the output of this

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[7] The only attempt we know is Isard *et al.* (1968) who tried to apply his model to the economy and environment of the Philadelphia Bay region.

[8] See Table 2 in Daly (1968), p. 402.

new sector is the total amount of eliminated pollutant and the corresponding final demand is the pollution tolerated by the economy[9]. It should be mentioned, however, that before the description of the 'abatement pollution' model, Leontief presented a simpler version of it (Leontief, 1970a, parts IV and V). This simple version is one of the three categories of environmental input-output models distinguished by Miller and Blair as 'generalized input-output model' (Miller and Blair, 1985, p. 236). Notice, however, that we shall refer to this version as 'environmentally extended input-output model', which is a more descriptive name. It will be described in Section 2.4.

The last contribution was Victor (1972) who, due to the difficulty of gathering data about environmental interrelationships, limited the scope of Isard's analysis discarding the lower right quadrant. That is, he only considered material flows from the environment to the economy and from the economy to the environment. The accounting framework proposed by Victor (1972) is a conventional supply and use table framework environmentally extended, which can be implemented without great difficulty. As we shall see in Section 2.5.2, the NAMEA system of environmental accounts can be considered, to some extent, the heir of Isard's and Victor's approaches.

The purpose of this chapter is threefold. First, to present the basis of input-output analysis emphasising those characteristics that make it a suitable approach to deal with the study of economic activities' effects on the environment. Second, to explain the available data and the required procedure to obtain an environmentally extended input-output table for Spain. And third, to describe the Spanish situation regarding atmospheric pollution in 1995 and 2000.

The next two sections are devoted to the input-output framework from an analytical standpoint. In Section 2.2 we describe the input-output table and the input-output model in its full basic version emphasising those aspects particularly relevant for environmental analysis. In order to keep the exposition as simple and clear as possible in this section we shall consider a close economy. However, in a world where the economies are more and more interconnected this assumption is not adequate. For this reason in Section 2.3 we shall introduce some elements to apply the input-output framework in an open economy. Then, the environmentally extended input-output model will be presented in Section 2.4. Once the theoretical

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[9] Stone (1972) carried Leontief's model a little further by introducing consumers explicitly in the model.

and analytical aspects of the model have been explained, in Section 2.5 we shall explain the input-output framework from a statistical standpoint. That is, we shall show how this approach has been introduced in the system of national accounts considering not only the economic accounts but also the environmental accounts and the way in which both are combined in the so-called NAMEA system. In Section 2.6 we shall describe the Spanish database and the needed arrangements to apply the environmentally extended input-output model. The results obtained from this model will be shown in Section 2.7. Section 2.8 will present some conclusions. Finally, Appendices 2.A, 2.B, 2.C, and 2.D will be devoted to extra information about the input-output framework.

2.2. The input-output framework for a close economy

As mentioned above, one of the defining characteristics of input-output analysis is the close integration of the theoretical model and database. This connexion reflects the scientific methodology of Leontief according to which any empirical analysis needs to be based on a theoretical model but, at the same time, the theoretical terms of the model need to be directly observable. This section is an attempt of presenting in a general and systematic way the basis of this theoretical framework composed of a database (the input-output table), and a model (the input-output model).

With this aim in mind, in this section we consider a close economy that does not have any relationship with other economies; that is, neither exports nor imports are taken into account. We describe the standard input-output model similarly as Leontief conceived it. That is, first we present the standard input-output table that allows for computing the parameters of the model. The structure of this table is based on the general theory of interdependence and originally it was compiled in quantities.

Second, we explain the so-called full basic or standard input-output model that consists of a quantity and a price model. When the output of each sector is measured in physical units, the quantity model determines the amount of product that each sector needs to produce to meet the final demand; whereas the price model determines the unit price of each product. However, the price model is barely explained because in some cases it has been believed that there is no benefit from considering it specifically and separately from the quantity model. Thus, the quantity model has been extensively used as the whole input-output model forgetting the role of the price model in the input-output framework. The reason is quite simple. Although the input-output table has been conceived to compile information in physical units, most of the input-output tables officially elaborated are expressed completely in monetary values. In this case, as we shall see below, there is an implicit physical unit so-called 'Leontief unit'. This physical unit is defined as the quantity of product that can be bought by one monetary unit such as euros. Consequently, when the quantity model is implemented in monetary units the prices of all products result from the price model are 1. However, even under these circumstances the price model provides useful information about impacts on unit prices of technological changes, variations of factor prices, or introduction of taxes.

Finally, since nowadays researchers have to deal with input-output tables compiled in monetary values, in this section we also present the monetary input-output table and model as a particular case of the general framework.

2.2.1. The input-output table

The input-output table describes the interconnections amongst sectors of an economy for any given period of time[10]. So, each row describes the amount of sector's output that is distributed to others sectors and/or to final users; and each column indicates the amount of inputs, both intermediate and primary inputs, required to produce the total output of the corresponding sector.

Graphically, the standard input-output table is represented by a rectangular matrix with four quadrants. Although the transactions registered in the table are usually expressed in monetary values, originally the input-output table was conceived to register them in physical terms. In this case each sector and primary input should be measured in its appropriate unit, i.e. the characteristic unit that defines better the product. Then, steel can be measured in tonnes of standard product, electricity in kWh, computers in numbers of computers of average capability, labour in person-year, etc. Although some service sectors can measure its output in physical units, it may be more useful to measure it in monetary values

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[10] Both the spatial and the time dimension of the input-output table can vary according to the aim of the analysis. So, input-output tables can be defined at national, sub-national, or supra-national level; and, although they often refer to a year, they can be also compiled for a shorter period of time such as a quarter.

such as euros' worth of output. In this case, however, when the output of any sector is measured in monetary units there is a implicit physical unit behind. This physical unit is called Leontief unit, which is defined as the quantity of product whose price equals the country's unit of account of the year the input-output has been compiled (the base year). That is, the unit of measurement would be the quantity of product that we can buy for one euro[11]. Notice that if the output of each sector is compiled in its 'own' unit the input-output table should be additive across rows but not necessary by columns. Thus, the input-output table is always complemented with a column of totals. Figure 2.1 describes the standard input-output table where:

- $\mathbf{Z}$ is the intersectorial transaction matrix or intermediate consumption matrix that shows transactions amongst sectors. So, element z_{ij} of this matrix represents the flow of product from sector i to sector j.
- $\mathbf{Y}$ shows flow of products from each sector to final users such as households (private consumption), government (public consumption), and investment (fixed capital formation). Often all these categories are aggregated in one column vector so-called final demand ($\mathbf{y}$).
- $\mathbf{V}$ is the primary input matrix whose element v_{gj} represents the amount of primary input g required to produce the output of sector j. Primary inputs are those inputs that are not produced by sectors but needed in the production process such as labour, capital, and natural resources (like mineral resources, land, water, etc)[12].
- The lower right quadrant would register primary inputs delivered directly to final users (for instance, the value of compensation paid to household workers); however, in theoretical considerations this quadrant is usually supposed to be zero without loss of generality.
- Finally the column of totals. On one hand, $\mathbf{x}$ is the column vector of total output. That is, let $\mathbf{i}$ be a column vector of ones the column vector $\mathbf{x}$ is represented by $\mathbf{x} = \mathbf{Zi} + \mathbf{y}$. On the other hand, $\mathbf{f}$ is the column vector that represents the total of primary inputs used in the economy, i.e. $\mathbf{f} = \mathbf{Vi}$.

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[11] For instance, if the wage rate is 6 euros per hour of labour the implicit Leontief unit of labour is 10 minutes and the wage rate becomes 1 euro per ten minutes of labour.

[12] Capital goods, i.e. goods that are used more than one single production period, are a singular case of 'primary inputs'. In fact, it can be questioned its condition of 'primary input' since they are produced by other industries; however, this interesting discussion is beyond the scope of this study.

Figure 2.1: Standard input-output table

$\mathbf{Z}_{nxn}$	$\mathbf{Y}_{nxf}$		$\mathbf{x}_{nx1}$
$\mathbf{V}_{mxn}$	$\mathbf{0}$		$\mathbf{f}_{mx1}$

Source: own elaboration.

This input-output table represents the database framework elaborated by Leontief (Leontief, 1936) that allows to apply directly input-output models. However, the latter involves that the database needs to match the assumptions of the model. Although we shall discuss these assumptions in Appendix 2.A, now it is worth to mention those that affect the structure of the input-output table for analytical purposes. These assumptions are basically two: each sector has a characteristic mix of inputs per unit of output and each sector produces one and only one characteristic product. In other words, each sector has only one technology and secondary production is not contemplated. These two assumptions imply that no distinction is made between sectors and products in the input-output table. Thus, assuming that an economy is composed of n sectors or products the intersectorial transaction matrix must be square, i.e. $\mathbf{Z}_{nxn}$.

2.2.2. The full basic input-output model

As mentioned above, input-output analysis provides a theoretical framework for analysing different kind of interdependences. Consequently, in the input-output literature different names are given to input-output models according to the aim of each study. Generally, adjectives preceding the input-output term describe the main characteristics of the model such as multiregional input-output model, dynamic input-output model, or environmental input-output model amongst others. In this section we shall explain the basis of the so-called full basic or standard input-output model.

On one hand, the term 'basic' refers to the open, static input-output model proposed by Leontief (Leontief, 1944, 1946a, 1946b), in which final demand and factor prices are considered exogenous variables and in which changes over time are not considered endogenously in the model[13].

On the other hand, we have used the term 'full' to emphasise the fact that input-output model consists of a quantity model, a price model, and an income identity (Duchin, 2004; Duchin and Steenge, 2007). Although input-output books usually present the price model as an extension of the basic input-output model (see Bulmer-Thomas, 1982, chapter 14 or Miller and Blair, 1985, chapter 9), the increasing interest of environmental studies in applying input-output analysis brings to reconsider this separation. When in the input-output table the output of each sector is measured in its 'own' unit, the quantity model determines the amount of product that each sector needs to produce to meet the final demand, whereas the price model determines the unit price of each product. The latter should be of interest for some environmental studies that specifically incorporate environmental information measured in physical units. One way to take advantage of full potential of the input-output model it may be to present and explain its complete version, so that:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} \tag{2.1a}$$

$$\mathbf{f} = \mathbf{L}\mathbf{x} \tag{2.1b}$$

$$\boldsymbol{\mu}' = \boldsymbol{\pi}'\mathbf{L} \tag{2.2a}$$

$$\mathbf{p}' = \boldsymbol{\mu}'(\mathbf{I} - \mathbf{A})^{-1} \tag{2.2b}$$

$$\mathbf{p}'\mathbf{y} = \boldsymbol{\mu}'\mathbf{x} \tag{2.3}$$

Thus, the full basic input-output model would be defined by a system of five equations where the well known basic input-output model (2.1a and 2.1b) is now renamed as the quantity input-output model, equations (2.2a) and (2.2b) are the price input-output model, and (2.3) is the income identity. In this system $\mathbf{A}$ and $\mathbf{L}$ are the parameters of the model, $\mathbf{y}$ and $\boldsymbol{\pi}$ the exogenous variables, and $\mathbf{x}$ and $\mathbf{p}$ the variables determined by the model, i.e. the endogenous variables. The rest of this section is devoted to explain the foundations of the quantity input-output model

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[13] The first version of input-output model was the close input-output model in which all the variables are endogenous (Leontief, 1937). It is a descriptive model that establishes production and price structure of the economic system but it does not define their respective levels. Between the close and open input-output models there are the so-called partially close input-output models, which internalise some components of the final demand. There are several ways do this, one of them is based on using a Social Accounting Matrix (SAM) which provides a much richer database than a simple input-output table. On the other hand, in contraposition to the static model the dynamic input-output model introduces the investment decisions of each sector within the model (Leontief, 1970b).

since environmental applications presented in Chapters 3, 4, and 5 only use this part of the model. The price input-output model and the income identity are, however, explained in Appendix 2.C.

a) Technical coefficients

The first step in any input-output model is to calculate the parameters of the model; that is the matrix of direct input coefficients[14] $\mathbf{A}$ and the matrix of primary input coefficients $\mathbf{L}$. Generally, both matrices are obtained directly from an input-output table by dividing all intermediate and primary inputs of each sector by the total output of this sector[15]. So, let $\hat{\mathbf{x}}$ be the diagonal matrix of vector $\mathbf{x}$ we get:

$$\mathbf{A} = \mathbf{Z}(\hat{\mathbf{x}})^{-1} \qquad (2.4)$$

$$\mathbf{L} = \mathbf{V}(\hat{\mathbf{x}})^{-1} \qquad (2.5)$$

Where the element a_{ij} represents the amount of output i used as intermediate input to produce one unit of output j ($a_{ij} = z_{ij} / x_j$). And the element l_{gj} is the amount of primary input g used as input per unit of sector j's output ($l_{gj} = v_{gj} / x_j$). The technology of this economy can be designated by matrix $\mathbf{T}$ whose column j represents the average technology in use of sector j:

$$\mathbf{T} = \left[\frac{\mathbf{A}}{\mathbf{L}}\right] \qquad (2.6)$$

In Section 2.2.1 we mentioned two assumptions of the input-output model, i.e. each sector has only one production process and each sector produces one and only one characteristic product. Here we need to introduce the other two assumptions of the model. The first one claims that production processes are proportional, i.e. the output of each sector j (x_j) is proportional to its inputs (z_{ij} and v_{gj}) such that:

$$z_{ij} = a_{ij} x_j \qquad (2.7)$$

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[14] It is also known as technical coefficient, input-output coefficient, or intersectorial coefficient matrix.

[15] When matrix $\mathbf{A}$ is derived directly from an input-output table the result is a square non-negative matrix. If besides the dominant eigenvalue of this matrix is positive and less than one, i.e. $0 < \lambda < 1$, these properties are necessary and sufficient to guarantee that the full basic input-output model had a positive solution and this solution were unique. When matrix $\mathbf{A}$ is obtained from a compilation of engineering data these properties should be also held (for further details of these properties see Appendix 2.B).

$$v_{gj} = l_{gj} x_j \qquad (2.8)$$

The second assumption states that these input coefficients, i.e. a_{ij} and l_{gj}, are constant. Thus, the inherent production function in the input-output model is a function characterised by constant return to scale and, hence, non economies of scale; moreover, it also assumes the use of same technologies[16].

b) Quantity input-output model

Once we have calculated the parameters of the model we can present the first part of the full basic input-output model, i.e. the quantity model. Formally, the input-output table of Figure 2.1 can be written as a system of identities in which the equality between supply (the left part of the identity) and demand (the right part of the identity) must always be satisfied. So, for any sector i we have:

$$x_i \equiv z_{i1} + z_{i2} + \cdots + z_{in} + y_i \qquad (2.9)$$

Taking into account the assumption about proportional production, i.e. expression (2.7), the supply and demand identities can be written as an equation system of n equations. This equation system makes explicit the interdependence of intersectorial flows on total output of each sector; that is, the output of each sector is dependent on other sectors' output and on final demand:

$$x_i = a_{i1}x_1 + a_{i2}x_2 + \cdots + a_{in}x_n + y_i \qquad (2.10)$$

Considering this expression for the n sectors of the economy, we can easily expressed the equation system in matrix terms as $\mathbf{x} = \mathbf{Ax} + \mathbf{y}$ or $(\mathbf{I} - \mathbf{A})\mathbf{x} = \mathbf{y}$, from which we obtain the solution of the input-output model (2.1a):

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} \qquad (2.1a)$$

Where $\mathbf{I}$ is the identity matrix and $(\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse[17]. Expression (2.1a) tells us the amount of outputs $\mathbf{x}$ required in this economy to meet a given final demand $\mathbf{y}$. Thus, once we get $\mathbf{x}$ expression (2.1b) tells the amount of

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[16] For a formal analysis of production functions see Chung (1994).

[17] It is also known as multiplier matrix, total requirements matrix, or direct and indirect requirements matrix.

primary inputs, i.e. labour, land, water, etc., demanded to produce that particular set of outputs:

$$\mathbf{f} = \mathbf{L}\mathbf{x} \tag{2.1b}$$

c) The Leontief inverse

Once the model has been presented we can focus on analysing the famous Leontief matrix that characterises the input-output analysis. The Leontief inverse, $(\mathbf{I}-\mathbf{A})^{-1}$, is the most useful and powerful tool in input-output analysis since it is able to reveal indirect effects within the economy. Thus, whereas elements of direct input coefficient matrix $\mathbf{A}$ shows the relationship between only two sectors, each element of the Leontief inverse reveals the interdependences amongst all sectors of the economy providing a valuable economic information. However, before explaining the mechanism behind the Leontief inverse, let us describe the economic meaning of the elements of this matrix.

In input-output literature the Leontief inverse is often denoted by matrix $\mathbf{B}$, this allows for rewriting expression (2.1a) simply as:

$$\mathbf{x} = \mathbf{B}\mathbf{y} \tag{2.1a'}$$

Which can be developed such as:

$$\begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ b_{n1} & b_{n2} & \cdots & b_{nn} \end{bmatrix} \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix} \tag{2.1a''}$$

Or in its full form as:

$$\begin{matrix} x_1 = b_{11}y_1 + b_{12}y_2 + \cdots + b_{1n}y_n \\ x_2 = b_{21}y_1 + b_{22}y_2 + \cdots + b_{2n}y_n \\ \vdots \quad\quad \vdots \quad\quad \vdots \quad\quad\quad \vdots \\ x_n = b_{n1}y_1 + b_{n2}y_2 + \cdots + b_{nn}y_n \end{matrix} \tag{2.1a'''}$$

The latter expression makes clear the dependence of the output of each sector on each final demand. The b_{ij} element of the Leontief inverse represents the total output needed directly and indirectly from sector i to satisfy one unit of final demand of sector j. In other words, each element b_{ij} translates final demand for any product j into required output from a sector i.

As mentioned above, the importance of the Leontief inverse yields in the fact that it captures direct and indirect effects of exogenous changes in final demand $\mathbf{y}$. It would be helpful, therefore, to separate out direct from indirect effects. For doing so, we need to express the Leontief inverse as a approximation of a power-series expansion such that[18]:

$$(\mathbf{I}-\mathbf{A})^{-1}=\mathbf{I}+\mathbf{A}+\mathbf{A}^2+\mathbf{A}^3+\cdots \tag{2.11}$$

Inserting the power series expansion in (2.1a) and operating we get the expression:

$$\mathbf{x}=\mathbf{y}+\mathbf{A}\mathbf{y}+\mathbf{A}^2\mathbf{y}+\mathbf{A}^3\mathbf{y}+\cdots \tag{2.12}$$

This expression shows that output of any sector is built up in different phases of production, i.e. round by round. Thus, the first term on the right $\mathbf{y}$ is the initial effect, i.e. the output must cover the final demand. The next term $\mathbf{Ay}$ is the direct effect that records the fact that for meeting the final demand each sector demands intermediate inputs directly to other sectors, which have to be produced themselves. The rest of the terms $\mathbf{A}^2\mathbf{y}+\mathbf{A}^3\mathbf{y}+\cdots$ capture the indirect effects. For instance, if final demand of sector j increases by one unit the initial effect indicates that sector j must to produce one unit; however, to produce this unit sector j will demand inputs from a second sector i (i.e. the direct effect of sector j on sector i); then in order to meet this new demand from sector j, sector i will increase its production and will demand inputs from a third sector r (indirect effect of sector j on sector r via sector i), and so forth.

As it has been shown, the strength of the Leontief inverse lies in the fact that the effects of exogenous changes in the economy are analysed by taking into account all sectorial interdependences. Thus, the Leontief inverse is the basis of the so-called 'multipliers' in input-output analysis (Miller and Blair, 1985, chapter 4). Moreover, the Leontief inverse is also the basis for the impact analysis widely applied in policy

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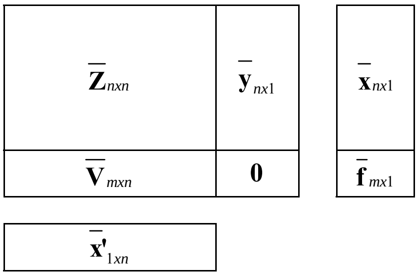
[18] If $\mathbf{A}$ is a non-negative matrix and its dominant eigenvalue is less than one, i.e. $0<\lambda<1$.

design (Baumol and Wolff, 1994). By means of this expression we know how many ‘workers’, ‘machines’, or ‘land’ are needed to satisfy, for instance, a unit increase of any sector’s final demand. As we shall describe in Section 2.4, if we combine the input-output model with information about atmospheric emissions, waste, water consumption, etc. this kind of impact analysis can be easily applied to environmental studies.

2.2.3. A special case: the input-output table and model in monetary units

Although the input-output table was conceived to register transactions in physical terms, nowadays it is usually expressed in monetary values. Theoretically, the monetary input-output table and model would simply be a special case of the general framework in which we have changed the units of measurement. From expression (2.1a) now we know how much the economy needs to meet a fixed final demand given one technology. So, multiplying the former quantities by the unit prices of each product (see Appendix 2.C) we can calculate a new input-output table all expressed in monetary values (Figure 2.2). Let us indicate monetary values by over bar we would have[19]:

Figure 2.2: Input-output table in monetary units



Source: own elaboration.

Where $\overline{\mathbf{Z}}=\hat{\mathbf{p}}\mathbf{Z}=\hat{\mathbf{p}}\mathbf{A}\hat{\mathbf{x}}$, $\overline{\mathbf{y}}=\hat{\mathbf{p}}\mathbf{y}$, $\overline{\mathbf{x}}=\hat{\mathbf{p}}\mathbf{x}$, and $\overline{\mathbf{V}}=\hat{\boldsymbol{\pi}}\mathbf{L}\hat{\mathbf{x}}$ [20]. Notice that in this monetary input-output table, elements of matrix $\overline{\mathbf{Z}}$ represent the monetary value of sales from one sector to another. In the same way, elements of matrix $\overline{\mathbf{V}}$ represent remunerations of all primary inputs. Generally, in monetary input-output tables all

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[19] Notice that we only indicate monetary values by the over bar in this section. In the rest of the study we shall use the standard notation of the input-output model in which monetary value is considered as another unit of measurement.

[20] Remember that in the Leontief’s price input-output model $\boldsymbol{\pi}$ represents the matrix of unit prices of primary inputs (see Appendix 2.C).

primary inputs may be aggregated in one row vector so-called value added ($\overline{\mathbf{v}}'$). A peculiar characteristic of the monetary input-output table (and of any input-output table all measured in the same unit) is that the column vector of total output, i.e. $\overline{\mathbf{x}} = \overline{\mathbf{Z}}\mathbf{i} + \overline{\mathbf{y}}$, must be equal the row vector of total inputs, i.e. $\overline{\mathbf{x}}' = \mathbf{i}'\overline{\mathbf{Z}} + \overline{\mathbf{v}}'$. The latter two expressions are known as the accounting equations of the input-output table. Finally, the monetary input-output table also provides a snapshot of the economy revealing some macroeconomic aggregates. For instance, the Gross Domestic Product (GDP) is represented by total value of final demand and the Gross Domestic Income (GDI) by the total of value added vector, i.e. $GDP = \sum_{i=1}^{n} y_i$ and $GDI = \sum_{j=1}^{n} v_j$. Obviously, both aggregates should be equal.

Similarly, the full basic input-output model can also be expressed in these new units. So, we would have:

$$\overline{\mathbf{x}} = (\mathbf{I} - \overline{\mathbf{A}})^{-1}\overline{\mathbf{y}} \tag{2.1a}$$

$$\overline{\mathbf{f}} = \overline{\mathbf{L}}\overline{\mathbf{x}} \tag{2.1b}$$

$$\overline{\boldsymbol{\mu}}' = \boldsymbol{\pi}'\mathbf{L}\hat{\mathbf{p}}^{-1} \tag{2.2a}$$

$$\mathbf{p}' = \overline{\boldsymbol{\mu}}'(\mathbf{I} - \overline{\mathbf{A}})^{-1} \tag{2.2b}$$

$$\mathbf{p}'\overline{\mathbf{y}} = \overline{\boldsymbol{\mu}}'\overline{\mathbf{x}} \tag{2.3}$$

Where now $\overline{\mathbf{A}} = \hat{\mathbf{p}}\mathbf{A}\hat{\mathbf{p}}^{-1}$ and $\overline{\mathbf{L}} = \boldsymbol{\pi}'\mathbf{L}\hat{\mathbf{p}}^{-1}$. When all the full basic or standard input-output model is expressed in monetary units we must remember that the implicit physical unit behind the quantity model is the Leontief unit, i.e. the amount of product that we can buy with one euro; and obviously the prices of all products will be 1. A numerical example can be found in Appendix 2.D.

The last paragraph of this section is devoted to the interpretation of input coefficients derived from a monetary input-output table. It should be noted that input coefficients are defined in terms of quantities, even though the input-output table has been compiled in monetary values. So, what is the meaning of an input coefficient derived from a monetary input-output table? The 'monetary' input coefficient $\overline{a}_{ij}$ would be expressed as:

$$\bar{a}_{ij} = \frac{\bar{z}_{ij}}{\bar{x}_j} = \frac{z_{ij} p_i}{x_j p_j} = a_{ij} \frac{p_i}{p_j} \tag{2.13}$$

Where p_i and p_j are the unit price of products i and j respectively. So, the 'monetary' input coefficients would be the physical input coefficient multiplied by relative prices. However, as we have seen in a monetary input-output table the implicit physical unit is the Leontief unit and the price of all products equal one, i.e. $p_i = p_j = 1$. Thus, in the base year expression (2.13) can be simplified and the 'monetary' input coefficients can be interpreted as usual physical input coefficients (i.e. $\bar{a}_{ij} = a_{ij}$).

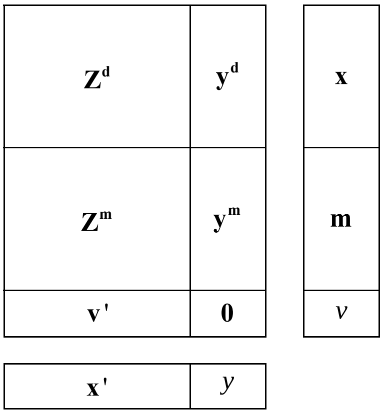
2.3. The input-output framework for an open economy

In a world where countries are more and more interconnected, exports and imports becomes important issues. In an open economy, each sector can sell its product either inside the country or to the rest of the world; just as any economic agent can buy products domestically produced or products that have been produced abroad.

Within input-output framework, exports are considered the final demand of foreign sector and they are simply placed as a new vector of the matrix of final users $\mathbf{Y}$. However, the treat of imports is not as easy and depending on the way they were introduced in the model the results may have different interpretation. Probably, the best way to consider an open economy within input-output framework is applying an interregional or a multiregional input-output model. These models are able to analyse the interconnections amongst different regions or countries and, hence, the so-called feed-back-loop effects. In Chapter 5 we will explain and apply a multiregional input-output for Spain, for a detailed description see Miller (1998).

On the contrary, most of the input-output analyses have been carried out considering a single region or country. In this case, following Dietzenbacher *et al.* (2005) we distinguish two ways of considering imports depending on how they are recorded in input-output tables. In the first type imports are recorded as in Figure 2.3. Assuming all the table is recorded in monetary values, matrix $\mathbf{Z^d}$ represents the domestic deliveries from sector i to sector j. Vector $\mathbf{y^d}$ gives the domestic deliveries from sector i to domestic final users (households, government, and investment) and also to foreign final user (gross exports). In this case vector $\mathbf{y}^\mathbf{d}$ should be called final uses instead of final demand. So, vector $\mathbf{x}$ represents the domestic output of the economy. On the other hand, matrix $\mathbf{Z}^\mathbf{m}$ denotes imports from a foreign sector i to a domestic sector j; and similarly, $\mathbf{y}^\mathbf{m}$ stands for the deliveries from a foreign sector i to the domestic final users (households, government, and investment). So, total imports of this economy should be represented by vector $\mathbf{m}$. Finally, vector $\mathbf{v}'$ is the so-called value added vector.

Figure 2.3: Imports in input-output table (type I)

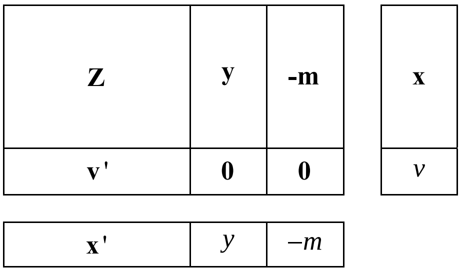


Source: own elaboration from Dietzenbacher *et al.* (2005).
Note: $\mathbf{y}^\mathbf{d}$ includes gross exports.

From this table we can obtain the matrix of domestic input coefficients $\mathbf{A}^\mathbf{d}$ as $a_{ij}^d = z_{ij}^d / x_j$, and the matrix of imported input coefficients $\mathbf{A}^\mathbf{m}$ as $a_{ij}^m = z_{ij}^m / x_j$. Each matrix gives the domestic and imported inputs per unit of gross output in sector j respectively. Assuming matrices $\mathbf{A}^\mathbf{d}$ and $\mathbf{A}^\mathbf{m}$ are fixes we can compute the domestic output as $\mathbf{x} = (\mathbf{I} - \mathbf{A}^\mathbf{d})^{-1}\mathbf{y}^\mathbf{d}$ and total imports as $\mathbf{m} = \mathbf{A}^\mathbf{m}(\mathbf{I} - \mathbf{A}^\mathbf{d})^{-1}\mathbf{y}^\mathbf{d} + \mathbf{y}^\mathbf{m}$. Notice that imported inputs are dependent on gross output; that is, the more the economy produces, the more inputs it needs to import. Usually, in this type of input-output table the gross output plus imports are called total supply and/or total uses (see Figure 2.7 in Section 2.5.1).

The second type (Figure 2.4) does not give detailed information about the imported inputs; so, matrix $\mathbf{Z}$ and vector $\mathbf{y}$ are inclusive of imports. That is matrix $\mathbf{Z}$ covers both domestically produced and imported inputs from sector i to sector j; and vector $\mathbf{y}$ represents the final purchases (including gross exports) regardless its origin, i.e. if they have been produced inside the country or abroad. In this type of tables total imports $\mathbf{m}$ are recorded as a negative column vector. Notice that in this case imports are first added in $\mathbf{Z}$ and $\mathbf{y}$ and then subtracted in $\mathbf{m}$. Thus, matrix of total (domestic and imported) input coefficients $\mathbf{A}$ is defined as $a_{ij} = z_{ij} / x_j$, where now z_{ij} would include $z_{ij}^d + z_{ij}^m$. Under the assumption of fixed coefficients, the domestic output would be computed by $\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}(\mathbf{y} - \mathbf{m})$, where $\mathbf{A}$ and $\mathbf{y}$ are inclusive of imports and $\mathbf{y}$ also includes gross exports.

Figure 2.4: Imports in input-output table (type II)



Source: own elaboration from Dietzenbacher *et al.* (2005).
Note: $\mathbf{y}$ includes gross exports.

Tables of type II not only provide less detail about imports, but also important assumptions need to be made to correctly interpret the Leontief inverse and other multipliers. That is, we need to assume either that any increase of final uses is exclusively produced inside the country, or that all changes in imports are given exogenously, or that imports are produced abroad using the same technology as the country analysed (Dietzenbacher *et al.*, 2005).

Finally, a short comment about the sort of imports considered. In this section we have only take into account competitive imports, i.e. all imported products are also produced by the country. However, the inclusion of non-competitive imports, i.e. those imported products that the country cannot produce, does not introduce any change in our analysis since both types of tables usually added them as a separate row at the bottom of the table.

2.4. The environmentally extended input-output model

The characteristics of the input-output methodology allows for extending the analysis to other spheres such as the environment. In the introduction of this chapter we pointed out the first attempts to develop environmental input-output models, which can be applied not only for the analysis of pollution but also of material balances, water consumption, waste, etc. In this section, however, we describe the environmentally extended input-output model that we shall use in the following chapters to analyse air emissions.

In the same way the full basic or standard input-output model requires an input-output table, the environmentally extended input-output model also needs the corresponding table. However, the increasing use of input-output analysis in some environmental studies has originated a variety of input-output tables with different names that may be a little misleading. Then, let us to comment them before describing the environmentally extended input-output table. When all entries in the input-output table are measured in monetary values it is usually called monetary input-output table, which only registers the monetary flows of the economy. When each sector of the input-output table is measured in its appropriate unit, it is called mixed-unit input-output table. One kind of mixed-unit input-output table is the hybrid input-output table in which some rows of a monetary input-output table, specially energy sectors, are measured in physical units. Another kind of input-output table is the so-called physical input-output table, this table only registers product flows and they are usually expressed in the same physical unit such as tonnes. Environmental input-output analyses can use hybrid and/or physical input-output tables, although more frequently they use monetary input-output tables extended with environmental information in physical units[21]. The latter is the sort of input-output table we shall use in our applications.

Assuming a close economy, the theoretical structure of this environmentally extended input-output table for air emissions would be represented by Figure 2.5 where $\mathbf{Q}$ is a matrix of direct atmospheric emissions. Considering k different gases, the elements of this matrix q_{lj} represent the amount of pollutant l generated by sector j measured in physical units.

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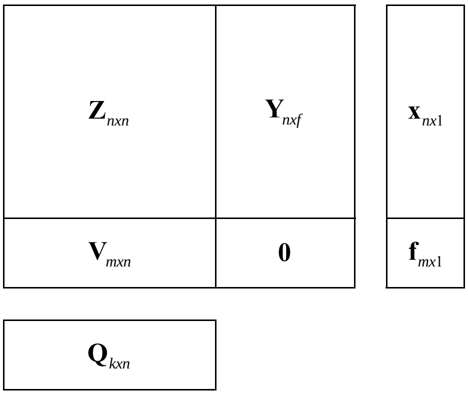
[21] An example of a monetary input-output table that is environmentally extended is the NAMEA system described in Section 2.5.2. See Weisz and Duchin (2006) for a study on the differences between physical and monetary input-output tables in environmental input-output analysis.

Figure 2.5: Environmentally extended input-output table for air emissions



Source: own elaboration.

The quantity input-output model can easily be extended to account for air emissions. From the matrix of direct emissions $\mathbf{Q}$ and the gross output vector $\mathbf{x}$, we can specify the emission coefficient matrix $\mathbf{W}$ as:

$$\mathbf{W} = \mathbf{Q}(\hat{\mathbf{x}})^{-1} \tag{2.14}$$

Where each element w_{lj} represents the emissions of pollutant l emitted per unit of sector j's output. Thus, similarly to expression (2.1b) the total amount of atmospheric emissions associated with a given vector of total output can be expressed by vector $\mathbf{r}$ as:

$$\mathbf{r} = \mathbf{W}\mathbf{x} \tag{2.15}$$

Or as a function of final demand as:

$$\mathbf{r} = \mathbf{W}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} \tag{2.16}$$

Where $\mathbf{W}(\mathbf{I} - \mathbf{A})^{-1}$ can be defined as the matrix of total emission intensity $\mathbf{J}$, which shows total emissions, i.e. direct and indirect ones, required to satisfy one unit of final demand of each sector:

$$\mathbf{r} = \mathbf{J}\mathbf{y} \tag{2.17}$$

Before finishing this section we would like to point out two final remarks. Although they are not exclusive of the environmental expression (2.16), we think is better to allude to them now. The first comment refers to the interpretation of this expression when we consider open economies. As we mentioned in Section 2.3, in the case of a model derived from a type II input-output table, matrix $\mathbf{A}$ and vector $\mathbf{y}$ would be inclusive of imports and $\mathbf{y}$ would also include gross exports. Since in expression (2.16) total imports are not subtracted, the application of this expression in an open economy would imply that we are computing not only the emissions generated by the domestic gross output but also those emissions linked to imports. However, this interpretation can only be done under one of the next two assumptions. First, we can assume that other countries have the same technology and direct emission coefficients as the country analysed[22]. In this case, the emissions embodied in imports can be defined as the emissions effectively generated abroad in order to provide total country's imports. Or second, we can assume that the foreign emissions represent the emissions actually generated by this country if it had decided to produce all imported products by itself, i.e. they were the emissions avoided by the country because it purchases some products abroad. Since the same technology assumption is difficult to be held, in this study we prefer the second interpretation, which we shall call self-sufficiency assumption.

The second remark is more general and it refers to fixed capital goods. Theoretically, fixed capital goods are those goods used in production process more than one production period (usually one year) such as buildings, machines, etc. This implies that sectors need to have a certain capital stock that is necessary for production. They need to invest in fixed capital goods to substitute the depreciation of old capital goods and, sometimes, to increase the capacity of production. The former is called 'replacement capital' and it depends on the output level of current year, i.e. $\mathbf{x}^t$; whereas the latter is the 'expansion capital' and it depends on the increase of output between two periods, i.e. $(\mathbf{x}^{t+1} - \mathbf{x}^t)$. However, in the basic input-output model both kind of investment expenditures are considered exogenously as a part of the final demand, i.e. they are included in the gross capital formation category without considering their connection with output levels. This implies that from the basic input-output model an increase of household consumption yields an increase of output but we do not know what will be the next effect on investment. Although the treatment of capital goods in input-output models is in itself

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[22] This assumption is often applied when specific knowledge of foreign technology is not available (Munksgaard *et al.*, 2000). However, the technologies employed in countries from which imports originate may differ markedly and, in fact, such a consideration is increasingly common in the literature (see Chapter 5).

interesting and important and also it should be relevant to study the effects of its consideration on environmental analysis, its application clearly overcomes the scope of this study[23].

2.5. The input-output framework in national accounts

The input-output table described in Section 2.2.1 is the best database for analytical purposes. However, the real data that sometimes the researcher has to face are different. In fact, the requirements imposed by the model entail that the input-output table were not appropriate to describe the reality. Mainly, input-output table has to be constructed taking into account that each sector only produces one product by means of only one production process, i.e. no secondary production is considered. However, actually it is not true for all sectors as some of them produce more than one product or carry out more than one activity. This fact led United Nations to develop a comprehensive framework that described the economic relationships between economic agents and/or economic transactions with a minimum manipulation of statistical data[24]. The result was the publication in 1968 of *System of National Accounts* (SNA), which is based in the so-called supply and use tables[25]. Although each country has its own special features, in Section 2.5.1 we try to describe the supply and use framework from a general perspective taking into account, however, that this study has been developed for a state-member of the European Union. Then, in Section 2.5.2 we explain how the environment has been included in the official statistics.

2.5.1. The supply and use tables

Following the guidelines of national account systems, such as the current SNA (Commission of the European Communities *et al.*, 1993) and the *European System*

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[23] One way of taking the consumption of fixed capital into account is through the dynamic input-output model in which the 'replacement' and 'expansion' capital can be included (see Bulmer-Thomas, 1982, pp. 173-178 and pp. 222-224; and Miller and Blair, 1985, pp. 340-351). Another way is by extending the input-output model with fixed assets (see Chen *et al.*, 2005) in this case, however, only the depreciation of capital is taking into account.

[24] The integration of input-output framework into the system of national accounts in this way was mainly due to the work of Richard Stone (Stone, 1961) who won the Prize in Economic Sciences in Memory of Alfred Nobel in 1984 for his contribution to the development of the systems of national accounts.

[25] The terms supply and use tables corresponds to the current 1993 SNA. At the beginning, in the 1968 SNA, this framework was known as the commodity-industry tables, in which the commodity table was the current supply table and the industry table the supply one (United Nations, 1999).

of National and Regional Accounts (ESA 95) (European Commission, 1996), input-output data are compiled in two different tables, the supply table and the use table. The essential of this supply and use framework is the distinction between products and sectors in such a way that they do not need to be the same. So, secondary production can be easily accommodate since one sector can produce more than one product[26]. Figure 2.6 shows a simplified chart based on the Spanish supply and use tables.

Figure 2.6a: Simplified Spanish supply table

	Sectors (NACE)	**Imports**	**Total supply at bp**	**Total margins**	**Total net taxation**	**Total supply at pp**
Products **(CPA)**	Output by product and by sector at basic prices (Make matrix)	Total imports by products at c.i.f.	Total supply by products at basic prices	Trade and transport margins by products	Taxes less subsidies on products	Total supply by products at purchases prices
	Total output by sector at basic prices					

Figure 2.6b: Simplified Spanish use table

	Sectors (NACE)	**Final uses**	**Total uses at bp**
Products **(CPA)**	Intermediate consumption by product and by sector at basic prices (Use matrix)	Final uses by final demand components at basic prices	Total use by products at basic prices
	Trade and transport margins	Trade and transport margins	
Net taxation	Taxes less subsidies on products	Taxes less subsidies on products	
Value added	Components of value added by sector		
	Total output by sector at basic prices	**Total final uses at purchases prices**	

Source: own elaboration from INE (2005).

Note: 1) bp and pp stand for basic prices and purchases' prices respectively, and c.i.f. stands for cost, insurance, and freight.
2) the Spanish use matrix and final use matrix are inclusive of imports; however, this information is also broken down into domestically produced and imported products.

The supply table describes the supply of products in the economy distinguishing whether they have been produced by domestic sectors (the make matrix) or have been imported. It also includes information related with trade and

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[26] In these tables two different classifications are used respectively for products (CPA) and sectors (NACE Rev. 1). CPA is the acronym of *Classification of Product by Activity* in the European Economic Community; whereas NACE stands for *Industrial Classification of Economic Activities* within the European Community. The CPA and NACE classifications correspond to *Central Product Classification* (CPC) and *International Standard Industrial Classification of all Economic Activities* (ISIC) of United Nations Statistics Division. The CPA and CPC, however, differ in the criterion to group products. That is, the CPC classifies products based on physical characteristics and nature of goods and services, whereas the CPA groups products according to its industrial origin. This distinction yields the fact that the structure of the CPA and NACE classifications fits in until the structure level 4, which is really convenient when a symmetrical input-output table has to be constructed from the supply and use framework.

transport margins, and net taxes on products, which makes possible to change the valuation of the input-output tables[27].

On the other hand, the use table describes where the products are used by sectors as intermediate consumption (the use matrix) or by final demand components as a final use (the final use matrix). Some countries, as it is the case of Spain, offer this information differentiating the origin of these products. That is, there are domestic and imported use matrices and domestic and imported final demand matrices. Others, however, do not distinguish the origin of the products and hence only total use and total final use matrices are available. The use table also shows the components of gross value added, which is obtained as the difference between output and intermediate consumption[28]; hence each column of the use table shows the cost of production of the corresponding sector. Both, the supply and use tables, are compiled in monetary units and they are closely linked since the basic principle in deriving them is that total supply of a product must equal total use of this product.

Supply and use tables are built on the base of production accounts, which are compiled by collecting information from enterprises by means of statistical surveys and census. Thus, the supply and use tables result to be a comprehensive and detailed statistical framework. However, its use adds another step for the input-output researcher who should construct a symmetrical input-output table when it is not provided by statistical offices[29]. That is, for analytical purposes we need to design units of homogeneous production that did not include any secondary production. These units, specially designed for economic analysis, cannot usually be observed directly from the reality and hence they should be obtained by rearranging the information contained in the supply and use tables. These 'virtual' units of production are called 'homogeneous branches' in ESA 95 (European Commission, 1996, paragraphs 2.114 and 2.115) and they closely correspond to the theoretical 'sectors' of input-output model. The next section is devoted to describe briefly how

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[27] This information allows to change the valuation of supply and use tables and, therefore, of input-output tables; however, without the so-called transformation matrices these transformations cannot be done directly. For a discussion about the valuation change applied to the Spanish input-output framework see Lucena and Serrano (2006).

[28] Usually the components of the value added are compensation of employees, other taxes less subsidies on production, and gross operating surplus which, in the Spanish case, includes mixed income and consumption of fixed capital.

[29] The symmetrical input-output table is also part of the system of nationals accounts, however, whereas supply and use tables are provided almost yearly, the symmetrical input-output table has a larger recurrence (Commission of the European Communities *et al.*, 1993, paragraphs 15.7 and 15.8; European Commission, 1996, paragraph 9.01).

to obtain a symmetrical input-output table suitable for the input-output model from the supply and use framework.

a) From supply and use tables to a symmetrical input-output table

When input-output tables are not provided by statistical offices or other official organisms they can be derived from the supply and use tables. This can be done by using a variety of approaches and, therefore, there will be as many different 'input-output tables' as methods employed[30]. Since each of these 'input-output tables' would be appropriate for different studies and purposes, there is no simple answer to the question of which kind of table should be more suitable (Bulmer-Thomas, 1982, p. 153). Amongst all the potential 'input-output tables' only the sector-by-sector and product-by-product can be defined as symmetrical input-output tables, i.e. one-to-one relationship between sector and product respectively. Whereas the former is based on market relations, i.e. it assumes that either the sale structure of product or of sector is fixed; the latter is based on the technological relations required by standard input-output models. For this reason, in this section we shall only focus on the method to obtain a product-by-product input-output table.

Figure 2.7 shows the structure of a standard symmetrical input-output table based on the Spanish experience. The procedure is based on the transformation of the supply and use tables (two product-by-sector tables) in such a way that there will be only one relationship product-by-product. This procedure basically implies, first, the allocation of secondary products in the supply table to those sectors of which they are the principal products; and, second, the transfer of inputs associated with secondary production from the sector in which it has been produced to the homogeneous branch to which it principally belongs.

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[30] For a description of the different methods see United Nations (1999) chapter 4.

Figure 2.7: Simplified Spanish symmetrical input-output table

	Homogenous branch (sectors)	**Final uses**	**Total uses**
Homogenous branch **(products)**	Intermediate consumption at basic prices	Final uses by final demand components at basic prices	**Total use at basic prices**
	Trade and transport margins	Trade and transport margins	
Net taxation	Taxes less subsidies on products	Taxes less subsidies on products	
Value added	Components of value added		
	Total output at basic prices	**Total final uses at purchases prices**	
Imports	Total imports at c.i.f.		
	Total supply at basic prices		

Source: own elaboration from INE (2005).
Note: the Spanish use matrix and final use matrix are inclusive of imports; however, this information is also broken down into domestically produced and imported products.

In an ideal world, all the information required to make this rearrangement of inputs would be available; however, this kind of information is usually incomplete and/or difficult to obtain. Therefore, the construction of a symmetrical input-output table requires ultimately to make some assumptions about the technology of secondary production. There are principally two mathematical methods, one based on the commodity technology assumption and the other on the industry technology assumption[31]. The former assumes that each product is produced using the same production process irrespective of the sector that produces it, whereas the latter assumes that each sector produces different products using the same production process. The importance of the role played by the technology assumptions is conditioned by the importance of the secondary production in the economy, which depends on the economic structure and also on the product breakdown. Theoretically, the commodity technology assumption is preferable to the industry one because the former captures better the input-output philosophy of fixed coefficients[32]; however, in practice its application frequently yields to obtain negative coefficients.

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[31] For a detailed and formal description of the commodity and the industry technology assumptions see United Nations (1999) chapter 4, Bulmer-Thomas (1982) chapter 9, and Miller and Blair (1985) chapter 5.

[32] Moreover, the coefficients obtained by applying the commodity technology assumption fulfil the criteria formulated by ten Raa *et al.* (1984) and Jansen and ten Raa (1990), i.e. material balance, financial balance, scale variance, and price invariance.

Since the simple application of one of the above assumptions presents different problems, the best strategy for compiling symmetrical input-output tables is to apply the so-called mixed technology assumption; that is, when supplementary information is available one can apply the commodity or the industry technology assumption according to the product characteristics. However, usually the researcher does not have at his/her disposal the information about the structure of each national sector to decide which assumption should be applied to each sector and, therefore, the industry technology assumption is mostly applied in practice just as we do in this study[33].

Finally, a last remark about which should be the best valuation of the symmetrical input-output table. Since homogeneity is one of the most important assumptions of input-output analysis, the symmetrical input-output table should be as homogeneous or uniform as possible not only regarding production process, but also regarding the valuation for the supplied and used products. Given that basic prices are more homogeneous than producers' and purchasers' prices, it seems logical that symmetrical input-output tables should be derived in basic prices (United Nations, 1999, paragraphs 3.5 and 3.6; European Commission, 1996, paragraph 9.54).

2.5.2. The environment in national accounts

In the same way as the full basic input-output model needs the input-output table as a starting point, environmental input-output models also need a database that considers interactions between the economy and the environment. However, conventional national accounts only consider those activities that take place in the market (Commission of the European Communities *et al.*, 1993, paragraph 3.34; European Commission, 1996, paragraph 1.12). Thereby, the scope and coverage of economic accounting, just as we described in previous section, cannot include activities nor issues without a market dimension such as the environment.

The appropriateness of the economic accounting for measuring environmental concepts has been questioning since the 1960's. However, it was in the late 1980's and early 1990's when some advances took place. Concretely, in 1992 the United

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[33] In order to overcome these drawbacks Konijn (1994) proposed the activity-by-activity input-output table, in which each different production process that produces a same product is defined as an activity. On the other hand, a mathematical algorithm to apply the commodity technology assumption without negative results has been proposed by Almon (2000). However, the application of both approaches requires additional information about the different production processes and/or input structure in each sector.

Nations Conference on Environment and Development held in Rio de Janeiro stressed the need for green accounting and adjusting the national accounting framework to reflect natural resource deterioration. Before the Rio Conference, however, five leading international institutions[34] had been exploring the feasibility of amending the SNA to incorporate environmental issues. After a series of workshops, they concluded that the basic structure of the SNA was largely adequate to consider new information about natural resources and environmental pressures (El Serafy, 1999).

According to this decision, the economic information would remain environmentally unadjusted and it would be estimated rightly all along in the 'economic accounts'. On the other hand, the environmental information, expressed either in monetary or in physical units, should be estimated consistently with the economic accounts and would be placed outside the core of the national accounts in the so-called 'satellite accounts'. Thereby, the economic and environmental worlds would be statistically joined within the System of Economic and Environmental Accounts (SEEA). This union has been materialised by the publication in 1993 of the manual *Integrated Environmental and Economic Accounting* (United Nations, 1993), which has been revised and updated in subsequent editions the last in 2003 (United Nations *et al.*, 2003). By the time being, some of the topics covered by this 'handbook' are still subject on debate and, therefore, it should not be considered as a definitive manual but as the basis for harmonising concepts and definitions and as a report of the best practices of different experiences.

During the 1990's the concepts and methodologies of the SEEA have been largely discussed and, in fact, different countries have been testing several approaches. One of these approaches is the National Accounting Matrix including Environmental Accounts framework, which is broadly known by its acronym NAMEA. This system is followed by the countries of the European Union (EU) and, unlike the conventional economic trend of accounting environmental issues in market values, the NAMEA focuses on collecting environmental information in physical units and combining it with the monetary economic accounts[35].

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[34] These five institutions were the Commission of the European Communities–Eurostat, the International Monetary Fund, the Organisation for Economic Co-operation and Development, the United Nations, and the World Bank.

[35] Although the notion of confronting monetary and physical data also lay at the heart of the 1993 SEEA, it may be the main difference. Keuning and Steenge (1999) listed more differences between the NAMEA and the conventional SEEA system.

a) The NAMEA framework

In the early 1990's, Statistics Netherlands based on the experience of previous environmental input-output models, developed the NAMEA framework with the aim of describing the connection between the economy and the environment. This framework was afterwards adopted by the EU members within the Eurostat environmental accounting project in 1994 (Keuning and Steenge, 1999)[36]. In the NAMEA system, the environmental information is compiled consistently with the way economic activities are represented in national accounts. Thereby, the core of the framework, i.e. the national accounting matrix (NAM), is extended with environmental accounts (EA) in physical units without impacting any of the SNA accounting conventions[37].

The economic data in the NAM is based on the input-output framework of SNA described above. The environmental information in the EA should be consistently compiled with the NAM, hence the most frequent way of presenting the NAMEA accounts is by means of environmentally extended supply and use tables[38]. The remarks about the suitability of supply and use tables structure or symmetrical input-output structure made in Section 2.5.1 are also applicable for the NAMEA framework: the former is more suitable for statistical purposes, whereas the latter it is for analytical ones. It should be mentioned, however, that official NAMEA input-output tables are the exception rather than the rule. Although the NAMEA system can include almost all kind of environmental problems such as energy or water consumption, land use, waste generation, or air emissions, in this study we only focus on the latter.

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[36] By that time a conceptual extension of this system was also elaborated. It is known as the System of Economic and Social Accounting Matrices and Extensions (SESAME) in which economic, social and environmental statistics are integrated in the same matrix (Keuning and Timmerman, 1995; Keuning 1997). A simplified version of the SESAME is the Social Accounting Matrix including Environmental Accounts (SAMEA), which is a NAMEA table completed with information about income flows amongst agents. For an example of a Spanish SAMEA see Rodríguez *et al.* (2007).

[37] For a more extensive and detailed review of the NAMEA approach see de Haan and Keuning (1996), Keuning *et al.* (1999), European Commission (2001), and the special issue on 'Environmental extensions of national accounts: the NAMEA framework' in *Structural Change and Economic Dynamics*, volume 10, issue 1, January 1999.

[38] Following the SEEA terminology these tables are called 'hybrid supply and use tables', in which the term 'hybrid' is used "to denote a single matrix containing both national accounts in monetary terms and environmental accounts in physical units showing the absorption of natural resources and ecosystem inputs and the generation of residuals." (United Nations *et al.*, 2003, paragraph 4.4). However, this terminology could lead to some confusion since an 'hybrid input-output table' can also refer to a monetary input-output table in which some rows are measured in physical units (see Section 2.4).

Figure 2.8 shows a simplified NAMEA for air emissions. Following the NAMEA conventions, relationships from the nature to the economic activity (e.g. natural resources, water, or land used by sectors) should be registered in the 'nature row', whereas relationships from the economy to the nature (e.g. waste, atmospheric or water pollution) should be registered in the 'nature column'. Although this approach is entirely correct from a bookkeeping perspective, it has led to some analytical confusions and has stimulated a methodological debate on how to treat the information gathered in the 'nature column', basically residuals, in input-output models[39].

Figure 2.8: Simplified NAMEA for air emissions

	Products (CPA)	**Sectors (NACE)**	**Value added**	**Households**	**Government**	**Gross Capital Formation**	**Rest of the world**	**Monetary totals**	**Nature**
Products (CPA)		Products used by sector (Use matrix)		Household consumption	Government expenditure	Investment expenditure	Exports	Total uses by products	
Sectors (NACE)	Products made by sectors (Make matrix)							Total output by sector	Emissions generated by sectors
Value added		Components of value added							
Households									Emissions generated by households, etc. and imported emissions
Government									
Gross Capital Formation									
Rest of the world	Imports								
Monetary totals	Total supply by product	Total inputs by sector							
Nature									
Other information		For instance employment in hours, etc.							

Source: own elaboration from United Nations *et al.* (2003).
Note: total supply by product minus imports would yield total domestic output by product.

The fact is that in order to take 'the best snapshot' of the reality, atmospheric emissions as well as other residuals are considered as a by-product of production

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[39] For instance Dietzenbacher (2005) reviews the discussion about waste treatment and introduces an alternative that reconciles the existing methods.

processes and other economic activities. However, since atmospheric emissions are outside the production boundary established by national account systems[40] they should not be considered an output of the production process but a merely outflow or a consequence of the economic activity. Consequently, from an analytical input-output point of view Figure 2.8 is somewhat misleading and it should be more appropriate to record those residuals as a negative input instead of as an output (Dietzenbacher, 2005). That is, atmospheric emissions as well as waste or water pollution should be placed in the nature row in which 'uses from nature' would be positive entries and 'disposals to nature' would be negative entries[41]. Thus, from an analytical perspective input-output tables should be environmentally extended by rows rather than by columns as did Leontief in his environmental input-output model (see Figure 2.5).

2.6. The Spanish database

After presenting the main features of input-output framework and environmental accounts into the SNA, this section is devoted to describe the characteristics of Spanish database and to explain the data preparation required to adapt it to the environmentally extended input-output model.

The Spanish NAMEA for air emissions is organised according to the supply and use table structure. However, the information is not presented together in the same table as theoretically is recommended (see Figure 2.8) but separately. Concretely, in this study we use the Spanish input-output framework base 1995 (INE, 2005) and the Spanish environmental accounts for air emissions base 1995 (INE, 2006) for 1995 and 2000. Both databases are described below. Nevertheless, before going into them it is necessary to make some remarks about the accounting base.

It is known that base years are changed periodically into national account systems. These changes are used to update weighting measurements as well as to introduce some methodological variations. The last accounting change in Spain was introduced on May 2005 establishing 2000 as the new base year. The criteria used in

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[40] See Commission of the European Communities *et al.* (1993) paragraph 1.20 and European Commission (1996) paragraphs 1.12 and 1.13.

[41] Notice that the sign of the entries has only a statistical meaning. However, this way of accounting would allow for recording better the fact that some production processes would need, for instance, CO_2 as inputs, i.e. the so-called capture and storage planning used by oil-rings.

the input-output framework base 2000 are essentially similar to the 1995 criteria. However, the different treatment of 'Financial Intermediation Services Indirectly Measured' (FISIM)[42] sector is worth to be mentioned since it affects to input-output tables[43]. In the previous 1995 base the FISIM sector were considered as a fictitious sector whose production did not affect to GDP of the economy. This was so because this 'fictitious sector' had a negative value added of the same amount that its intermediate consumption. In the current 2000 base, however, this 'fictitious sector' disappears. From now on, the indirect payments obtained from the different price of deposit and loan services will be included as an intermediate consumption of each sector and as a final consumption of different final demand components. This new treatment will obviously affect to GDP of the economy[44]. One of the motivations of this change has been to solve some conceptual and practical problems that had to be faced when calculating the Leontief's inverse matrix with this 'fictitious sector' in the previous 1995 base. However, this new base only offers data from 2000 but not for previous years. So, since in this study we need to use and compare 1995 and 2000 information, we have decided to use the input-output framework base 1995 for both years.

Similarly, the Spanish environmental accounts for air emissions changed its base on November 2006. This new base not only enlarges the previous series 1995-2000 to 1990 and 1995-2003, but also includes certain new features regarding the previous 1995 base. Concretely, for the year 2002 it includes an estimation of energy consumption table in physical terms that links directly energy to atmospheric emissions[45]. Likewise, the new base includes an estimation of transposition table of NAMEA atmospheric emissions that shows the equivalence between total emissions of NAMEA and of air inventories such as the Intergovernmental Panel on Climate Change (IPCC) (see Section 2.6.2 below). Moreover, it has been added a new contaminant PM10 defined as particles in suspension with an aerodynamic diameter of up to 10 μm (micrometers). In this study, however, in order to keep the

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[42] The FISIM represents those indirect payments that financial institutions obtain due to the different price between deposit and loan services.

[43] The input-output framework base 2000 also includes a greater number of sectors. Concretely, 'Accommodation and catering', 'Services annexed to transport' and 'Other business services' sectors have been divided into two groups each.

[44] According to INE (see http://www.ine.es/daco/daco42/cne00/sifmi_b2000.pdf) this new methodology has provoked an increase of the Spanish GDP of 7,472 millions of euros, which represents a growth about 1.2%.

[45] Although the new table only gives information about total energy in terajoules without differentiating types of energies, this novelty is of relevance since the last energy input-output table for Spain are for 1980 and 1985 (INE, 1989, 1991).

agreement and homogeneity between both bases we perform all the calculus and estimations using the environmental data from the base 1995.

2.6.1. The Spanish input-output framework base 1995

Consistently with the ESA 95 (European Commission, 1996), the Spanish input-output framework consists of supply and use tables and a symmetrical input-output table. Whereas the former are compiled yearly, the latter are published every five years[46].

Within the 1995 base, supply and use tables are available from 1995 until 2000, whereas the symmetrical input-output table is only published for 1995. The supply and use tables cover 110 CPA products, 72 NACE sectors plus the 'fictitious sector' FISIM, and 7 categories of final uses. The symmetrical input-output table arranged these products and sectors into 70 homogeneous branches plus the FISIM sector. All the economic transactions registered in supply and use tables and symmetrical input-output table are valued at basic prices. Figures 2.6 and 2.7 show the structure of these tables.

Another characteristic of the Spanish input-output framework worth to be mentioned is the treat of imports. As mentioned above, both the symmetrical input-output table and the use table give information not only about the total intermediate consumption and total final consumption by sectors but also they distinguish which part of this consumption has been domestically produced or imported. This fact allows for organising the information about imports as in type I input-output table (see Section 2.3).

2.6.2. The Spanish environmental accounts for air emissions base 1995

On the other hand, the Spanish environmental accounts for air emissions gather information about direct emissions produced by 46 NACE sectors and by households. The former are emissions associated with the production of goods and services, whereas the latter are related to transport, heating, and other household purposes[47].

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[46] For a review of Spanish input-output tables see Cañada and Toledo (2001). Their report reaches until 1996, from then, INE has published the 1997, 1998, 1999, 2000, 2001, and 2004 supply and use tables and the symmetrical input-output table for the year 2000 (see http://www.ine.es).

[47] Transport emissions are allocated to households only when they use private automobiles; thus, emissions caused by public transport are attributed to respective transport sectors. Households' heating

The environmental data are reported in physical units and for eleven air pollutants. In this study, however, we only consider the six greenhouse gases regulated by Kyoto protocol, i.e. dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs); and three gases related to local environmental problems such an acidification, i.e. sulphur oxides (SO_x measured in SO_2 equivalent units), nitrogen oxides (NO_x), and ammonia (NH_3). In the 1995 base, this information is published yearly from 1995 to 2000.

Since the environmental data should be compiled consistently with economic data, the structure of the supply and use tables implies that Spanish emissions are allocated to heterogeneous sectors, i.e. we know the emissions generated by each sector regardless the different products it produces. This fact has important consequences in the way environmental information from NAMEA should be interpreted. For instance, emissions associated with electricity production are allocated to any sector that produces electricity as a secondary product and not to the NACE 40.1 'Production and distribution of electricity', whose principal activity is in fact the production of electricity. The same principle prevails for transport emissions and any secondary product.

Having reached this point, it is important to mention that total emissions reported by the Spanish NAMEA for air emissions are different from those totals reported by other sources such as the IPCC and/or European harmonised system of air emission (CORINAIR)[48] inventories. Although these differences do not affect our analysis, we think it is worth to mention it. The differences are essentially related to definitions used by national accounts and by the two inventories. That is, NAMEA refers to those emissions generated only by economic activities carried out by residents within the economic territory, whereas the air emission inventories basically present emissions from all sources on the national territory. This implies that NAMEA totals will equal those totals of air emission inventories only if: first, we add those emissions generated by nature itself and subtract those emissions absorbed by the nature; and second, we add those emissions generated by non-residents within the economic territory and subtract those emissions generated by

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emissions are those generated by direct use of fuels. Logically, emissions due to household electricity purchases are not allocated to households but to electricity producers.

[48] CORINAIR stands for CORe INventory of AIR emissions. It is an European Environment Agency's project performed since 1995 aimed at collecting and publishing information on air emissions. Before 1995, the CORINAIR project was developed under another programme of the EU called CORINE (CO-oRdination d'INformation Environnementale) (from the European Environment Agency http://www.eea.europa.eu/).

residents outside the economic territory. The second adjustment would affect essentially tourist driving and international transport activities.

2.6.3. The Spanish environmentally extended input-output table

As mentioned above, to apply the environmentally extended input-output model presented in Section 2.4 the economic and environmental information should be transformed in such a way that we obtained an environmentally extended input-output table suitable to compute the model. Due to the smaller disaggregation of the Spanish environmental accounts for air emissions, the resulting input-output tables for 1995 and 2000 will comprise 46 NACE sectors valued at basic prices, and nine gases. For doing so, we have followed the next steps.

Firstly, according to NAMEA and national accounts principles air emissions related to incineration and decomposition of waste in landfills (mainly CO_2 and CH_4) should be placed under NACE 90 'Sewage and refuse disposal services, sanitation and similar services'. However, the Spanish NAMEA aggregates the emissions of NACE 90, plus those generated by NACE 91 'Membership organisation services', NACE 92 'Recreational, cultural, and sporting services', and NACE 93 'Other services', in one sector named 'Other community, social and personal service activities'. Due to the nature of these four sectors, one can logically infer that the most part of the CH_4 emissions (and also CO_2 but their emissions are smaller) should be generated almost exclusively by NACE 90; however, this information is hidden because of the above aggregation. Consequently, an increase of household expenditures on 'Recreational, cultural, and sporting services' (NACE 92), for instance, should cause an increase of CH_4 emissions even though this sector did not emit this gas. The consequences of this example will not be important if CH_4 emissions of 'Other community, social and personal service activities' sector were relatively small compared with the total CH_4 emissions of the economy; however, in 1995 and 2000 those percentages were 28.30% and 31.28% respectively (INE, 2006). Therefore, following the experience of Dutch NAMEA we create a new category of source of air emissions (Keuning *et al.*, 1999). Then, as well as the conventional sources distinguished in the Spanish NAMEA, i.e. 'sectors' and 'households', we also distinguish 'other sources' that will include all emissions related to incineration and decomposition of waste in landfills. However, because we do not have any information about the amount of emissions generated by NACE 90, we assume that all CH_4 emissions of the 'Other community, social and personal service activities' sector correspond to NACE 90 and we reallocate them to the new category 'other sources'[49].

The second step is to arrange economic and environmental information of the supply and use tables into a symmetrical input-output table by homogeneous branches. For doing so, we consider the economic and the environmental data separately. On one hand, we allocate the secondary products of the supply table to that sector of which it constitutes the principal product. Then, applying the industry technology assumption we rearrange the corresponding intermediate consumption and value added. Finally, once we obtain a symmetrical input-output table we aggregate it to the required dimension 46x46[50]. It should be mentioned that in order to avoid the practical problems derived from the FISIM sector, in this last step we aggregate this sector to NACE 65 'Financial intermediation services, except insurances and pension funding services' following the recommendation of United Nations (1999).

On the other hand, since the atmospheric emissions are aggregated to 46 sector we only need to rearrange the emissions of heterogeneous sectors to homogenous branches applying the industry technology assumption. However, it should be mentioned that in order to fit both classifications, of input-output framework and of environmental accounts, we need to make two adjustments. First, we aggregate two NAMEA sectors into one, i.e. 'Extraction of crude petroleum and natural gas' and 'Extraction of uranium and thorium ores'[51]. And second, we add a new sector 'Private households with employed persons', which does not produced any direct emissions. Thus, the 46 sectors considered in this study are shown in Figure 2.9.

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[49] This method has been applied only for CH_4 because CO_2 emissions from NACE 90 sector were not quantitatively important with respect to total CO_2 emissions.

[50] Since the Spanish input-output framework base 1995 offers a symmetrical input-output table for 1995 we have only aggregated it into 46 sectors.

[51] Emissions compiled in the Spanish NAMEA generated by the 'Extraction of uranium and thorium ores' sector are zero.

Figure 2.9: Sectors considered in this study based on the Spanish NAMEA, 1995 and 2000

S1	Agriculture, hunting, and related services activities
S2	Forestry, logging, and related services activities
S3	Fishing
S4	Mining of coal and lignite; extraction of peat
S5	Extraction of crude petroleum, natural gas; uranium and thorium ores
S6	Mining of metal ores
S7	Other mining and quarrying
S8	Manufacture of food products, beverages, and tobacco
S9	Manufacture of textile
S10	Manufacture of wearing apparel; dressing, and dyeing of fur
S11	Tanning and dressing of leather; manufacture of luggage, handbags, saddler, harness, and footwear
S12	Manufacture of wood and of products of wood and cork, except furniture
S13	Manufacture of pulp, paper, and paper products
S14	Publishing, printing, and reproduction of recorded media
S15	Manufacture of coke, refined petroleum products, and nuclear fuel
S16	Manufacture of chemicals and chemicals products
S17	Manufacture of rubber and plastic products
S18	Manufacture of other non-metallic mineral products
S19	Manufacture of basic metals
S20	Manufacture of fabricated metal products, except machinery and equipment
S21	Manufacture of machinery and equipment
S22	Manufacture of office machinery and computers
S23	Manufacture of electrical machinery and apparatus
S24	Manufacture of radio, television and communication equipment and apparatus
S25	Manufacture of medical, precision and optical instruments, watches and clocks
S26	Manufacture of motor vehicles, trailers, and semi-trailers
S27	Manufacture of other transport equipment
S28	Manufacture of furniture
S29	Recycling
S30	Electricity, gas, steam, and hot water supply
S31	Collection, purification, and distribution of water
S32	Construction
S33	Wholesale and retail trade; repair of motor vehicles, motorcycles, and personal and household goods
S34	Hotels and restaurants
S35	Land transport; transport via pipelines
S36	Water transport
S37	Air transport
S38	Supporting and auxiliary transport activities; activities of travel agencies
S39	Post and telecommunications
S40	Financial intermediation
S41	Real estate, renting, and business activities
S42	Public administration and defence; compulsory social security
S43	Education
S44	Health and social work
S45	Other community, social, and personal service activities
S46	Private households with employed persons

Source: own elaboration from Spanish NAMEA.

2.6.4. The IPCC conversion

As mentioned above, we consider nine different atmospheric pollutants, i.e. the six greenhouse gases (CO_2, CH_4, N_2O, SF_6, HFCs, and PFCs) and three local gases (SO_2, NO_x, and NH_3). However, for the sake of clarity in this study the three last greenhouse gases, i.e. SF_6, HFCs, and PFCs, are considered as one specific group named 'synthetic greenhouse gases' and measured in CO_2 equivalent units. We also present results for total emissions of the six greenhouse gases in units of CO_2 equivalent. For doing so, all greenhouse gas emissions have been aggregated in accordance with the global warming potential (GWP100) of each gas as established by the IPCC (IPCC, 1997).

The GWP100 is defined as the capacity that has one gas for keeping the warm in the atmosphere during, in this case, 100 years. For instance, each molecule of CO_2 has a warm potential of 1, whereas it is 21 for CH_4, 310 for N_2O, and 23,900 for SF_6. The HFCs and the PFCs are groups of different gases and, for this reason, they do not have one conversion factor but different values depending on each gas. The values for the HFCs group range from 140 to 11,700, while for the PFCs they oscillate between 6,500 and 9,200. Since the NAMEA database does not report information for different gases of HFCs and PFCs groups, we need to estimate a specific GWP100 for those two groups for Spain. For doing so, we have considered the information supplied by the Spanish greenhouse gas inventory 1990-2004 (Ministerio de Medio Ambiente, 2006)[52] about emissions and GWP100 of all HFCs and PFCs gases. We have calculated a warm potential for HFCs and PFCs based on the weight average of each group, thus the GWP100 obtained are 6,812.65 and 6,728.51 respectively.

2.7. Atmospheric pollution in Spain 1995 and 2000: a description

This section presents a description of Spanish situation regarding emissions in 1995 and 2000[53]. The purpose is to display some results straightforwardly obtained by applying the environmentally extended input-output model. The next three chapters will show how the potentiality of this approach can be carried a little bit further.

Table 2.1 shows Spanish direct emissions inclusive of imports in 1995 according to emission source. So, the first column indicates the amount of emissions that would have been generated directly by sectors if all imports, i.e. intermediate and final products, would have been produced in Spain[54]. Obviously, they are not

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[52] In March of 2007, the Spanish ministry of environment published the greenhouse gas inventory 1990-2005 in which they updated the emissions to the year 2005 and also revised the 1990-2004 data. The revisions of the former data has been motivated by different factors, amongst others: methodological changes, update of base information and mistake corrections. However, this revision has led to minor changes that range from -0.6% to 0.3% of the aggregate emissions in CO_2 equivalent units. Concretely, for 1995 and 2000 these changes have been estimated in 0.13% and 0.05% respectively (Ministerio de Medio Ambiente, 2007).

[53] Alcántara (1995) offers an analysis for the period 1980-1990.

[54] As mentioned in Section 2.4 they can also be interpreted as if all Spanish imports have been produced abroad using the same technology as Spain.

the emissions actually generated by Spanish sectors[55]; however, when analysing global environmental pressures the relevant concept is how many emissions should be needed to keep the economical standard independently where they have been produced. The second column records all direct emissions generated by Spanish households mainly because of the use of private transport and heating. Finally, the third column shows the emissions of CH_4 related to incineration and decomposition of waste in landfills. The results for the year 2000 are presented in Table 2.2.

Table 2.1: Direct emissions inclusive of imports according to source, Spain 1995

Units: thousand tonnes and %

	Direct emissions from sectors (1)	% (1/4)	Direct emissions from households (2)	% (2/4)	Direct emissions from other sources (3)	% (3/4)	Total emissions of the economy (4)
Greenhouse gases							
CO_2	297366.81	86.81	45200.00	13.19	0.00	0.00	**342566.81**
CH_4	1586.49	76.23	39.94	1.92	454.70	21.85	**2081.14**
N_2O	98.29	96.28	3.80	3.72	0.00	0.00	**102.08**
Synthetic gases*	7322.19	99.62	27.93	0.38	0.00	0.00	**7350.12**
Total in eq_CO_2	**368474.33**	**86.65**	**47243.18**	**11.11**	**9548.72**	**2.25**	**425266.23**
Other gases							
SO_2	2482.50	98.43	39.72	1.57	0.00	0.00	**2522.22**
NO_x	1535.07	83.18	310.42	16.82	0.00	0.00	**1845.49**
NH_3	419.22	99.41	2.49	0.59	0.00	0.00	**421.71**

Source: own elaboration from 1995 Spanish NAMEA.
*: Synthetic gases are total SF_6, HFCs, and PFCs emissions measured in thousand tonnes of equivalent CO_2.

Table 2.2: Direct emissions inclusive of imports according to source, Spain 2000

Units: thousand tonnes and %

	Direct emissions from sectors (1)	% (1/4)	Direct emissions from households (2)	% (2/4)	Direct emissions from other sources (3)	% (3/4)	Total emissions of the economy (4)
Greenhouse gases							
CO_2	399426.67	87.62	56430.00	12.38	0.00	0.00	**455856.67**
CH_4	1842.69	74.83	34.47	1.40	585.28	23.77	**2462.44**
N_2O	118.92	95.33	5.82	4.67	0.00	0.00	**124.74**
Synthetic gases*	13563.11	99.67	44.32	0.33	0.00	0.00	**13607.44**
Total in eq_CO_2	**488551.80**	**87.27**	**59003.72**	**10.54**	**12290.80**	**2.20**	**559846.32**
Other gases							
SO_2	2304.74	98.91	25.49	1.09	0.00	0.00	**2330.23**
NO_x	1972.04	86.88	297.74	13.12	0.00	0.00	**2269.77**
NH_3	534.00	99.10	4.84	0.90	0.00	0.00	**538.84**

Source: own elaboration from 2000 Spanish NAMEA.
*: Synthetic gases are total SF_6, HFCs, and PFCs emissions measured in thousand tonnes of equivalent CO_2.

As these tables show, the main source is the production activity carried out by sectors. The household activity generates predominantly CO_2 and NO_x, two of the primary gases produced by private transport. It is also important to highlight the

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[55] This information can directly be obtained from the Spanish NAMEA (INE, 2006).

appreciable amount of CH_4 emissions due to the waste management in landfills, almost one fourth of its total.

Comparing both years (Table 2.3), total emissions of the economy have increased considerably in all gases, especially the synthetic greenhouse gases; the only exception to this is the case of SO_2. The causes underlying to different evolutions can be caused, amongst others, by a technological change or different impact of variations in the composition of final uses. However, this simple comparison does not tell anything about them. This fact will be analysed in more detail in Chapter 3.

Table 2.3: Variation of direct emissions inclusive of imports according to source, Spain 1995-2000

Units: %

	Direct emissions from sectors (1)	Direct emissions from households (2)	Direct emissions from other sources (3)	Total emissions of the economy (4)
Greenhouse gases				
CO_2	34.32	24.85	0.00	**33.07**
CH_4	16.15	-13.69	28.72	**18.32**
N_2O	20.99	53.47	0.00	**22.20**
Synthetic gases*	85.23	58.70	0.00	**85.13**
Total in eq_CO_2	**32.59**	**24.89**	**28.72**	**31.65**
Other gases				
SO_2	-7.16	-35.84	0.00	**-7.61**
NO_x	28.47	-4.09	0.00	**22.99**
NH_3	27.38	94.50	0.00	**27.77**

Source: own elaboration from 1995 and 2000 Spanish NAMEA.
*: Synthetic gases are total SF_6, HFCs, and PFCs emissions measured in thousand tonnes of equivalent CO_2.

Tables 2.1 and 2.2 have revealed sectors as the main source of emissions; however, households and other final users may be considered indirectly responsibles for the emissions initially assigned to producers. Through a simply application of the input-output analysis these emissions can easily be reallocated to final users; that is, the same amount of direct emissions inclusive of imports generated by sectors can be imputed or attributed to households, government, investment, etc. (Tables 2.4 and 2.5). These 'imputed' emissions are total emissions (direct plus indirect) that have been generated by each sector in order to satisfy the demand of each final user. We have considered five different final uses: final consumption expenditure by households, by non-profit institutions serving households (NPISH), and by government; gross capital formation; and exports. We have also calculated the emissions that should be attributed to total Spanish imports. If we subtract them from total emissions of final uses, we will obtain the emissions generated by final demand, i.e. final demand inclusive of net exports, which are the emissions actually produced by sectors inside the country.

Table 2.4: Final users' contribution to direct emissions from sectors, Spain 1995

Units: thousand tonnes

	Final consumption expenditure by:			Gross capital formation	Exports	Final uses	Imports	Final demand
	Households	NPISH	Government					
	(1)	(2)	(3)	(4)	(5)	(6=1+2+3+4+5)	(7)	(8=6-7)
Greenhouse gases								
CO_2	138816.27	785.72	19636.65	62685.12	75443.04	**297366.81**	93662.81	**203704.00**
CH_4	1071.85	2.32	41.51	96.52	374.29	**1586.49**	474.51	**1111.98**
N_2O	59.25	0.43	5.83	8.15	24.63	**98.29**	30.23	**68.06**
Synthetic gases*	2497.82	34.08	791.52	1276.78	2722.00	**7322.19**	3736.96	**3585.24**
Total in eq_CO_2	**182189.48**	**1000.64**	**23108.57**	**68514.28**	**93661.36**	**368474.33**	**116735.86**	**251738.47**
Other gases								
SO_2	1232.89	7.30	193.19	449.40	599.72	**2482.50**	722.73	**1759.77**
NO_x	832.57	3.27	78.79	251.13	369.31	**1535.07**	483.94	**1051.14**
NH_3	288.29	0.86	11.65	19.18	99.24	**419.22**	115.35	**303.87**

Source: own elaboration from 1995 Spanish NAMEA.
*: Synthetic gases are total SF_6, HFCs, and PFCs emissions measured in thousand tonnes of equivalent CO_2.

Table 2.5: Final users' contribution to direct emissions from sectors, Spain 2000

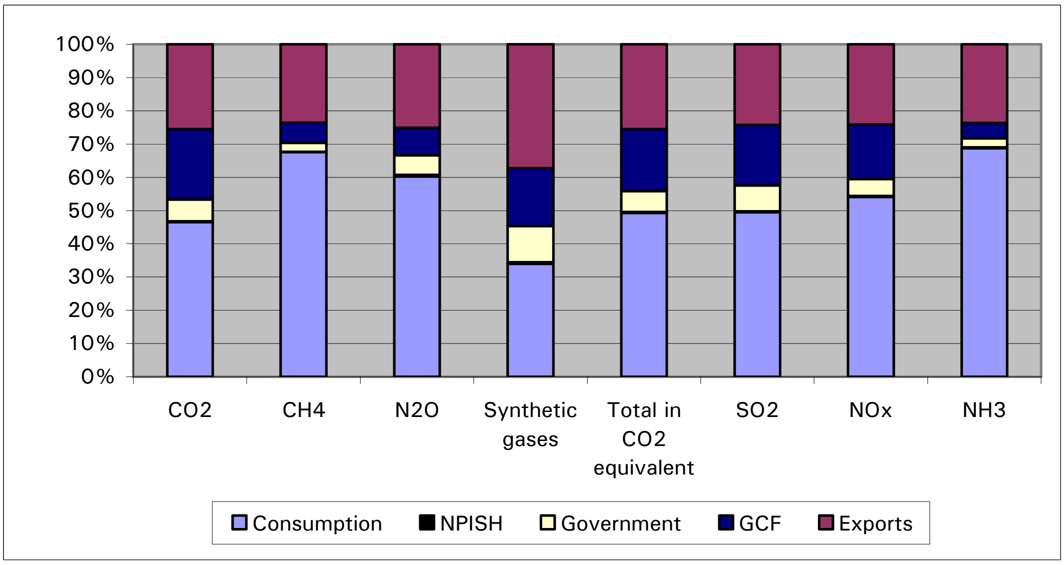
Units: thousand tonnes

	Final consumption expenditure by:			Gross capital formation	Exports	Final uses	Imports	Final demand
	Households	NPISH	Government					
	(1)	(2)	(3)	(4)	(5)	(6=1+2+3+4+5)	(7)	(8=6-7)
Greenhouse gases								
CO_2	170612.51	946.23	25237.97	82006.68	120623.29	**399426.67**	160794.67	**238632.00**
CH_4	1121.05	2.75	53.35	117.37	548.17	**1842.69**	591.32	**1251.37**
N_2O	65.52	0.44	6.83	9.91	36.21	**118.92**	39.74	**79.18**
Synthetic gases*	4593.13	53.80	1435.78	2138.29	5342.12	**13563.11**	7327.69	**6235.43**
Total in eq_CO_2	**219060.26**	**1195.60**	**29911.05**	**89682.68**	**148702.21**	**488551.80**	**192860.34**	**295691.46**
Other gases								
SO_2	1039.98	6.18	173.57	427.19	657.82	**2304.74**	804.88	**1499.86**
NO_x	945.96	3.96	102.91	327.74	591.46	**1972.04**	830.61	**1141.43**
NH_3	332.73	1.21	17.59	25.74	156.73	**534.00**	150.05	**383.94**

Source: own elaboration from 2000 Spanish NAMEA.
*: Synthetic gases are total SF_6, HFCs, and PFCs emissions measured in thousand tonnes of equivalent CO_2.

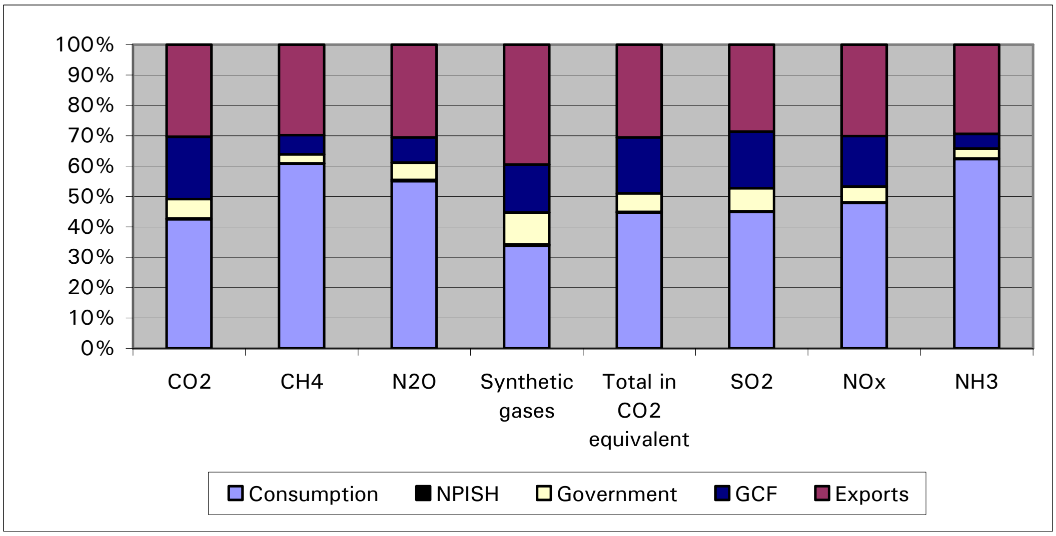
If we only consider the emissions attributed to final uses (Figures 2.10 and 2.11), the most important component in almost all gases is household consumption; only exports reaches this position in the case of synthetic greenhouse gases. Exports is the second component in importance of emissions. Gross capital formation's contribution (around 20%) is only relevant in those gases linked with energy use, i.e. CO_2, SO_2 and NO_x, and in synthetic greenhouse gases. Finally, the contribution of government expenditures (less than 10% in almost all gases) is less important and of NPISH is barely perceptible.

Figure 2.10: Percentage of final users' contribution to direct emissions from sectors, Spain 1995



Source: own elaboration from 1995 Spanish NAMEA.

Figure 2.11: Percentage of final users' contribution to direct emissions from sectors, Spain 2000



Source: own elaboration from 2000 Spanish NAMEA.

Considering both direct and 'imputed' or indirect emissions, household consumption is by far the main cause of Spanish emissions; for instance, in 1995 it generated 53.84% of total greenhouse gas emissions of the economy measured in CO_2 equivalent units and 49.57% in 2000. It was followed by exports with 22.07% and

26.60%, respectively. Chapters 4 and 5 are devoted to analyse some aspects of these two final uses: in Chapter 4 we shall analyse total emissions generated by household consumption and in Chapter 5 we shall study the role played by international trade in Spanish emissions.

Finally, the environmentally extended input-output analysis also allows for identifying the 'leading' pollutant sectors not only in terms of output, but also in terms of final uses, which could even be more important. Tables 2.6 and 2.7 show for 1995 and 2000 respectively, which are those 'leading' sectors considering both the emission intensity of output and the emission intensity of final uses. In these tables we do not reproduce all sectors considered in the analysis (see Figure 2.9) but only the top five pollutant sectors in each gas.

Table 2.6: Emission intensities of output and final uses, Spain 1995

Units: tonnes/million euros

	Greenhouse gases										Other gases					
	CO_2		CH_4		N_2O		Synthetic gases*		Total in CO_2 equivalent		SO_2		NO_x		NH_3	
Output intensity	**S30**	3997.79	**S4**	36.45	**S1**	1.48	**S16**	113.25	**S30**	4052.67	**S30**	59.01	**S3**	32.97	**S1**	9.30
	S18	2315.13	**S1**	32.20	**S2**	0.48	**S19**	55.19	**S18**	2352.46	**S15**	23.12	**S36**	27.89	**S2**	3.01
	S3	1849.56	**S2**	10.43	**S16**	0.38	**S23**	12.22	**S3**	1867.61	**S36**	16.03	**S30**	15.09	**S45**	0.62
	S15	1719.13	**S5**	5.42	**S45**	0.19	**S20**	1.84	**S15**	1788.65	**S18**	9.33	**S5**	11.43	**S16**	0.60
	S36	1412.54	**S30**	1.17	**S15**	0.19	**S9**	1.54	**S1**	1485.73	**S19**	6.19	**S6**	9.47	**S8**	0.06
Final uses intensity	**S30**	4707.26	**S1**	39.00	**S1**	1.83	**S16**	158.06	**S30**	4883.47	**S30**	67.14	**S3**	34.95	**S1**	11.23
	S18	3124.66	**S4**	37.11	**S8**	0.82	**S19**	81.78	**S18**	3214.65	**S15**	29.76	**S36**	29.85	**S8**	4.85
	S15	2882.48	**S8**	17.10	**S16**	0.58	**S17**	46.89	**S15**	3063.08	**S36**	19.42	**S30**	18.33	**S2**	3.22
	S3	2242.83	**S2**	11.24	**S2**	0.53	**S23**	42.39	**S3**	2332.92	**S18**	16.88	**S5**	13.13	**S34**	1.39
	S19	1949.79	**S30**	6.12	**S9**	0.32	**S9**	34.17	**S1**	2143.08	**S19**	14.94	**S15**	12.55	**S9**	1.22

Source: own elaboration from 1995 Spanish NAMEA.
*: Synthetic gases are total SF_6, HFCs, and PFCs emissions measured in tonnes of equivalent CO_2.

Table 2.7: Emission intensities of output and final uses, Spain 2000

Units: tonnes/million euros

	Greenhouse gases										Other gases					
	CO_2		CH_4		N_2O		Synthetic gases*		Total in CO_2 equivalent		SO_2		NO_x		NH_3	
Output intensity	**S30**	4184.67	**S4**	36.83	**S1**	1.58	**S16**	137.55	**S30**	4242.50	**S30**	45.09	**S3**	28.34	**S1**	10.12
	S18	1862.46	**S1**	32.08	**S2**	0.47	**S17**	22.94	**S18**	1890.70	**S36**	10.51	**S36**	22.22	**S2**	2.98
	S3	1620.79	**S2**	9.46	**S16**	0.26	**S19**	19.16	**S3**	1637.27	**S15**	9.16	**S30**	14.54	**S45**	0.68
	S5	1321.74	**S5**	2.21	**S45**	0.14	**S23**	17.34	**S1**	1528.63	**S18**	5.95	**S6**	11.38	**S16**	0.46
	S36	1154.69	**S30**	1.04	**S30**	0.11	**S9**	14.20	**S5**	1393.82	**S19**	3.55	**S5**	10.75	**S8**	0.06
Final uses intensity	**S30**	5158.35	**S1**	38.15	**S1**	1.91	**S16**	189.43	**S30**	5333.70	**S30**	52.01	**S3**	30.28	**S1**	12.00
	S18	2606.35	**S4**	37.32	**S8**	0.75	**S17**	83.43	**S18**	2683.40	**S36**	12.30	**S36**	24.01	**S8**	4.53
	S15	2106.56	**S8**	14.62	**S2**	0.59	**S9**	60.53	**S15**	2213.26	**S15**	12.22	**S30**	19.36	**S2**	3.65
	S3	2001.57	**S2**	11.65	**S16**	0.41	**S23**	43.79	**S1**	2165.33	**S18**	10.76	**S6**	13.23	**S34**	1.07
	S19	1659.22	**S30**	5.63	**S9**	0.23	**S19**	41.91	**S3**	2087.90	**S19**	9.67	**S5**	11.84	**S45**	0.97

Source: own elaboration from 2000 Spanish NAMEA.
*: Synthetic gases are total SF_6, HFCs, and PFCs emissions measured in tonnes of equivalent CO_2.

These tables show the capacity of input-output analysis to reveal indirect effects that cannot be directly observed in the economy. Whereas output intensity tells us how many emissions produces each sector per unit of product, final uses intensity shows total emissions that each sector produces directly and indirectly in order to satisfy one unit of final uses. So, when considering all the interdependences in the economy, sometimes new sectors turned up to be one of the most pollutants.

Regarding those gases related to energy, i.e. CO_2, SO_2, and NO_x, the most pollutant sectors in terms of emission intensity of output in 1995 and 2000 are 'Electricity, gas, steam, and hot water supply' (S30), 'Water transport' (S36), 'Manufacture of other non-metallic mineral products' (S18), and 'Fishing'(S3). From the standpoint of final uses, these sectors are still the sectors with the highest emission intensity; however, in the case of CO_2 emissions 'Manufacture of basic metals' (S19) springs up as a new polluting sector in both years.

If we look at CH_4, N_2O, and NH_3 emissions we can see that from 1995 to 2000 there have not been almost any change. From a production perspective the most polluting sectors are 'Agriculture, hunting, and related services activities' (S1), 'Forestry, logging, and related services activities' (S2), 'Other community, social, and personal service activities' (S45), and 'Manufacture of chemicals and chemicals products' (S16). However, from the final uses perspective it should be pointed out that as well as 'Agriculture, hunting, and related services activities' (S1), and 'Forestry, logging, and related services activities' (S2), 'Manufacture of food products, beverages, and tobacco' (S8) appears to be also relevant. That is, when considering total emissions the most pollutant sectors are those directly related to agricultural activities but also those indirectly connected such as the manufacture of food.

Finally, about the synthetic greenhouse gases 'Manufacture of chemicals and chemicals products' (S16), 'Manufacture of basic metals' (S19), and 'Manufacture of electrical machinery and apparatus' (S23) are amongst the top five sectors both from the output and final uses emission intensities and in both years. 'Manufacture of rubber and plastic products' (S17) becomes to be relevant from the final uses standpoint in 1995 and 2000. In that last year, this sector is also one of the most polluting sectors from an output perspective; however, it is important to highlight that the final uses intensity almost quadruplicates the output intensity.

2.8. Final remarks

In this chapter we have explained the basis of the full basic input-output model showing that it is a suitable approach to analyse the interrelationships between the economy and the environment.

The description of the full basic input-output model has been done emphasising those characteristics that can be useful for environmental input-output analysis in general. Since one of the main features of this approach is its applicability using national account database, we have explained how an input-output table can be derived from the supply and use tables. We have paid special attention to the environmentally extended input-output table and its counterpart in national accounts of EU members, the NAMEA system. Since the three next chapters of this study are different applications to Spain, we have described the characteristics of the Spanish database and we have explained the data preparation required to adapt it to the environmentally extended input-output model. Finally, some results have been displayed in order to describe the Spanish situation regarding atmospheric emissions.

Although the main source of direct emissions are the economic sectors, they simply produce products that are going to be used finally as investment or as a final consumption of households, NPISH, government, or even foreign sector. Thus, all emissions generated by sectors can be attributed to final users as indirect emissions. Considering both direct and indirect emissions of final users, private consumption and exports are the most pollutant components of final uses. We have also calculated the emission intensity of output, i.e. the amount of pollutant generated by one unit of output, and the emission intensity of final uses, i.e. the total amount of pollutant generated directly and indirectly by each sector in order to satisfy one unit of final uses. The latter, takes all the interdependences into account and reveals the indirect effects within the economy.

The next three chapters are different applications of the environmentally extended input-output model presented here. Whereas in Chapter 3 we analyse the contribution of technical changes and variations in the structure and level of final uses on the increase of atmospheric pollution from 1995 to 2000 in Spain, Chapter 4 and Chapter 5 will be focus on the analysis of the impact of private consumption and international trade on atmospheric pollution.

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Appendix

2.A. Some remarks about input-output assumptions

In Section 2.2 we presented the full basic input-output model for a close economy and we pointed out its basic assumptions. All of these assumptions refer to the technology of the economy represented by matrix $\mathbf{T}$, i.e. (*i*) each sector has only one production process; (*ii*) each sector produces only one characteristic product (homogeneous production); (*iii*) production processes are proportional; and (*iv*) technological coefficients are constant. In this appendix we give some rationale for these assumptions.

The two first assumptions are difficult to be held in real world since some sectors produce more than one good[56] and some products are produced in more than one sector usually by means of different production processes. However, this fact has been also included in the input-output framework by the so-called supply and use tables, which allow for constructing not only product-by-product or sector-by-sector models but also product-by-sector or sector-by-product models according to the aim of the analysis[57]. Nevertheless, in the standard input-output model it is supposed that each column of matrix $\mathbf{T}$ represents the average technology in use of the corresponding sector. In fact, the interpretation of the 'average' technology allows for the existence of different technologies in one sector since the use of an average avoids the complication of having to distinguish products and technologies where such distinction is not the main purpose of the study (Duchin and Steenge, 2007).

Then, the model assumes that production processes are proportional and coefficients of production are constant, i.e. $z_{ij} = a_{ij} x_j$ and $v_{kj} = l_{kj} x_j$. The former implies production functions with constant returns to scale; however, from a theoretical perspective this additional assumption is not strictly necessary since the relation between inputs and output could be expresses as $z_{ij} = d_{ij} + m_{ij} x_j$ instead of $z_{ij} = a_{ij} x_j$. Keeping m_{ij} and d_{ij} constants this expression allows for non-constant returns to scale (decreased or increased depending on d_{ij}). Whereas a_{ij} is the

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[56] For a detailed analysis of different kind of joint-production and secondary products see Bulmer-Thomas (1982) chapter 9 and United Nations (1999) chapter 4.

[57] See Miller and Blair (1985) chapter 5.

average direct input coefficient, m_{ij} can be interpreted as the marginal input coefficient (Bulmer-Thomas, 1982, p. 56). However, as far our knowledge no input-output model have been applied with this expression.

On the other hand, the so-called fixed coefficient assumption has probably been the most criticised feature of input-output analysis and it has been also the assumption more discussed. It has been justified in various ways. The first rationale claims that each column of matrix **T** represents the most efficient technology available to produce each product and it will remain the optimal even if there are variations in the composition of final demand. Although it can be a theoretical argument, it is quite improbable in the reality. Thus, another rationale is proposed in more realistic terms. This second rationale was preferred by Leontief and it asserts that although these technologies are not necessary optimal, they are effectively in place and cannot be quickly changed given the existing stock of fixed capital. However, time to time the technology effectively changes and these changes should be captured by a new input-output table. This second rationale, known as the Leontief's justification, allows sectors to change its technology as a response to relative price or consumer preferences. That is, new data about the mix of inputs used in each sector will replace the technical coefficients of the previous input-output table. So, it should be noted that the Leontief's justification does not imply inter-temporal stability whereas the non-substitution theorem proposed by Samuelson does (Bulmer-Thomas, 1982, pp. 55-56)[58]. Moreover, some empirical studies have shown that actually technical coefficients slowly evolving over time; one example is the study of Tilanus (1966) for the Dutch economy. So, the temporal stability of technical coefficients confers to input-output analysis the capacity of carrying out short-run exercises and applying updating techniques.

The latter raises the question about how innovation and technological changes are tackled within input-output framework. In fact, if two technologies were available, the full basic input-output model presented in this chapter could determine which of them involve the lower cost in terms of the overall use of primary inputs. Once it has been settle on the cost-minimising technology, prices

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[58] The non-substitution theorem expresses the conditions of validity of the fixed coefficient assumption. It states that when only one scarce primary input is considered, relative price cannot change and, therefore, a particular set of technologies will remain unchanged for any change in final demand. However, when more than one scarce factor are considered this theorem it breaks down. In that time, there was a deep discussion about this issue to which Leontief answered publishing *Studies in the Structure of the American Economy* in 1953 (Leontief, 1953).

will be determined. For instance, the introduction of a technology improvement will bring about a reduction in the coefficients of matrices **A** and **L** and, consequently, all prices will fall. In this way the input-output model can be used to represent the economic implications of any innovation process. Furthermore, it should be noticed that since input-output analysis does not directly assume profit maximising, it can be assumed the adoption of more expensive technologies but environmentally more desirable than the ones they replace. That is, with a different objective function, for instance minimising emissions rather than costs, a different choice of technologies could be selected.

2.B. Economic meaning of the non-negative matrices' properties

When the idea of general equilibrium model was popularised, Wassily Leontief conceived of doing the empirical groundwork for it and, in fact, at the end of the World War II he attempted to do so using the United States economy as an example (Leontief, 1951). For doing so, Leontief went to the Bureau of Labour Statistics (BLS) to gather the data he needed. Actually, Leontief was attempted to check whether for any given final demand the input-output problem could yield a solution and if so, whether such a solution was unique.

Nowadays these questions seem to be irrelevant, since we only need to compute the model and see the result. However, at that time inverting a matrix was not only a difficult and tedious task but also unfeasible for matrices of big order, e.g. 20x20 or more[59]. Thus, the study of the existence and uniqueness problem produced an increasing interest amongst economists in finding the necessary and sufficient conditions that would guarantee the solution of the input-output model. Oddly, many of the results 'discovered' by economists were already discussed at the beginning of the 20th century by two German mathematicians, Perron and Forbenius, and amongst Russian mathematicians. The aim of this appendix is not to analyse all these theorems[60] but to point out the economic implications that lay in the input-output model. As we shall see, these theorems and conditions are founded in the

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[59] David Salsburg in his book entitled *The lady tasting tea* tells a nice anecdote about the problems Leontief had to inverted a 24x24 matrix. He was working with Jerome Cornfield in the BLS and they decided to send that matrix to Harvard University to compute its inverse in the Mark I (one of the first computers developed during the World War II). However, the budgetary policy of the BLS only allowed to pay for goods but not for services. The clever solution founded by them was to buy a new 'capital good' for the project, i.e. "one matrix, inverted" (Salsburg, 2001, pp. 176-179).

[60] An excellent mathematical approach is Takayama (1985) chapter 4.

mathematical properties and theory of non-negative matrices (Duchin and Steenge, 2007).

Let us to return to the basic relation of the input-output analysis, i.e. $\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}$. From a mathematical viewpoint, it would be of interest to find a solution for this expression; however, from an economic viewpoint, besides, we need that this solution were unique and positive. It will be so, if $(\mathbf{I} - \mathbf{A})^{-1}$ exists and it is semi-positive[61], i.e. $(\mathbf{I} - \mathbf{A})^{-1} \geq 0$. We know that $(\mathbf{I} - \mathbf{A})$ can be inverted if $(\mathbf{I} - \mathbf{A})$ is non-singular, i.e. $\left|\mathbf{I} - \mathbf{A}\right| \neq 0$. So, the main question is which properties does matrix $\mathbf{A}$ need to have to guarantee that $(\mathbf{I} - \mathbf{A})$ were non-singular and, therefore, the existence and uniqueness of the positive solution for $\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}$? The answer is simple $\mathbf{A}$ needs to be a non-negative matrix and its dominant eigenvalue should be positive and less than unit, i.e. $0 < \lambda < 1$.

That is, applying the mathematical theory of non-negative matrices to our input-output context we can say that if $\mathbf{A}$ is a non-negative matrix and $0 < \lambda < 1$, $(\mathbf{I} - \mathbf{A})$ is non-singular and $(\mathbf{I} - \mathbf{A})^{-1} \geq 0$; therefore, there will be a unique positive solution to the input-output problem. However, which is even more important for input-output analysis is the fact that because matrix $\mathbf{A}$ is generally estimated empirically from an input-output table for a particular year, it is usually a non-negative matrix. Thus, what we need to check whether the dominant eigenvalue of matrix $\mathbf{A}$ is positive and less than unit. One way to verify it is throughout the so-called Brauer-Solow conditions. These conditions assert that if all column sums or all row sums of the elements of the matrix $\mathbf{A}$ are less than unit, then $0 < \lambda < 1$. Dietzenbacher (2005) show an easier method to verify it; that is, if all the elements of the final demand vector were positive, i.e. $\mathbf{y} >> 1$, then $0 < \lambda < 1$.

But those properties not only guarantee the solution of the input-output model but also have other implications with interesting economic interpretation. For instance, the dominant eigenvalue of matrix $\mathbf{A}$ is a measure of the size of the intermediate inputs produced in the economy in relation to total production. In other words, it indicates the surplus of an economy in a way that the larger λ is, the smaller net output the economy has. This surplus can be used in the economy in

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[61] Whereas a non-negative matrix allows for the zero matrix, in a semi-positive matrix only some of its elements can be zero but not all of them. On the other hand, a strictly positive matrix only allows positive elements.

different ways, it can be consumed, invested, or used with other purposes such as environmental protection. Moreover, if one element of $\mathbf{A}$ decrease, λ gets smaller. This statement has a counterpart economic interpretation, i.e. a technological innovation will have as a result a lower λ. In this way, if we have different matrices representing different economies λ can be used as an indicator of the economical efficiency.

Second, we mentioned that if the column sums of $\mathbf{A}$ are less than unit, then $0 < \lambda < 1$. The economic implication of the column sum condition is the well-known Leontief units. That is, when we have a monetary input-output table, as usually, and we wanted to apply the quantity input-output model we can chose the physical units in such a way that all the prices will be 1. In other words, this property assures that there exists a set of prices such that any sector has a positive value added, i.e. there will revenue left to pay for primary inputs.

Third, if $\mathbf{A}$ is non-negative and $0 < \lambda < 1$ all the successive principal minors of the determinant of $(\mathbf{I} - \mathbf{A})$ should be positive. This is known as the Hawkins-Simon condition, which assures that any group of sectors in the economy requires less inputs than outputs produced by the group itself, i.e. each subsystem in the economy is productive[62].

Fourth, if $\mathbf{A}$ is non-negative and $0 < \lambda < 1$ the series $\sum_{k=0}^{\infty} \mathbf{A}^k \mathbf{y}$ is convergent and it is equal to $(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}$. That is, we can express the Leontief inverse as a approximation of a power-series expansion such a way we can separate the direct effects from the indirect ones, i.e. $(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} = \mathbf{y} + \mathbf{A}\mathbf{y} + \mathbf{A}^2\mathbf{y} + \mathbf{A}^3\mathbf{y} + \cdots$ (see Section 2.2.2).

And finally, if matrix $\mathbf{A}$ is in addition indecomposable[63], the Leontief inverse will be strictly positive, i.e. $(\mathbf{I} - \mathbf{A})^{-1} > 0$. This is so, in order not to break the economic logic that an increase in final demand ($\Delta \mathbf{y}$) should result in an increase of output ($\Delta \mathbf{x}$).

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[62] For the geometrical interpretation of this condition see Dorfman *et al.* (1958). For a two sector economy it implies that two linear schedules must intersect each other in the first quadrant.

[63] Matrix $\mathbf{A}$ will be indecomposable if by permuting its columns and rows it is impossible to decompose this matrix $\mathbf{A}$ in four sub-matrices in such a way that the sub-matrices of the upper left and lower right quadrants were square and the sub-matrix of the lower left quadrant were zero (see Takayama, 1985, chapter 4).

2.C. The price input-output model and the income identity

Before explaining the price input-output model and the income identity proposed by Leontief, it is worth noting that the quantity input-output model presented in Section 2.2.2 is also compatible with other price theories such as that proposed by Piero Sraffa (1960)[64]. Although the analysis of different price theories is undoubtedly an interesting topic, we will restrict our exposition to the price model proposed by Leontief since the aim of this chapter is simply to explain the foundation of the full basic or standard input-output model.

Remember that the full basic or standard input-output model is expressed by a system of five equations, which represent the quantity input-output model, the price input-output model, and the income identity. Since in the quantity input-output model each sector and primary input is measured in its appropriate unit, let say tonnes, kWh, Leontief units, or person-year; the price input-output model will determine the price per unit of each sector's product.

Similarly to expression (2.9), the value of output of any sector j must be equal to the value of its inputs. That is, for each sector j the value of its sales should equal the cost of production given by the cost of intermediate inputs plus the cost of primary inputs. So, let π_g be the unit price of primary input g (for instance, wage per person-year, rents of land per hectare and per year, or return on capital per year) and p_j be the price per unit of sector's j output, we can write an equation for each sector such that its receipt equals its outlays:

$$p_j x_j = p_1 z_{1j} + p_2 z_{2j} + \cdots + p_n z_{nj} + \sum_{g=1}^{m} \pi_g v_{gj} \qquad (2.C.1)$$

Then, using again the assumption about proportional production, i.e. expressions (2.7) and (2.8), we may divide expression (2.C.1) by x_j to obtain the next expression, which expresses the price of one unit of output j as the unit cost of production[65]:

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[64] There are also other price formation models based on input-output framework (see Dietzenbacher, 1990).

[65] The prices from input-output model are called 'long- run' or 'supply' prices (Bulmer-Thomas, 1982, p. 224).

$$p_j = p_1 a_{1j} + p_2 a_{2j} + \cdots + p_n a_{nj} + \sum_{g=1}^{m} \pi_g l_{gj} \tag{2.C.2}$$

As in the quantity model, we can express the system of n equations in matrix terms as $\mathbf{p}' = \mathbf{p}'\mathbf{A} + \boldsymbol{\pi}'\mathbf{L}$ or $\mathbf{p}'(\mathbf{I} - \mathbf{A}) = \boldsymbol{\pi}'\mathbf{L}$. Defining $\boldsymbol{\pi}'\mathbf{L}$ as a vector of primary cost per unit of output, we get a vector of coefficients $\boldsymbol{\mu}'$ whose elements represent the total monetary value of all primary inputs required for unit of sector j's output:

$$\boldsymbol{\mu}' = \boldsymbol{\pi}'\mathbf{L} \tag{2.2a}$$

We can straightforwardly derive the solution of the price input-output model (2.2b), i.e. the prices per physical unit of output:

$$\mathbf{p}' = \boldsymbol{\mu}'(\mathbf{I} - \mathbf{A})^{-1} \tag{2.2b}$$

This expression indicates that product prices are proportional to the cost of primary inputs. Moreover, since **L** is assumed to be constant, this expression also reveals that unit price of each product results from the amounts of the primary input 'embodied' in the production of other products. That is, if labour were the only primary input we could know how much labour would be embodied in one unit of product and, therefore, prices could be explained in terms of a 'labour theory of value'.

Finally, to complete the full basic input-output model we need to add the income or GDP identity (2.3). This identity is derived from the respective solutions of the quantity and price models, i.e. expressions (2.1a) and (2.2b). Post-multiplying expression (2.2b) by the final demand vector **y** and replacing expression (2.1a) we get:

$$\mathbf{p}'\mathbf{y} = \boldsymbol{\mu}'\mathbf{x} \tag{2.3}$$

This expression assures that the value of final demand $\mathbf{p}'\mathbf{y}$ equals total value added $\boldsymbol{\mu}'\mathbf{x}$[66]. This identity should be satisfied not only in the base year for which

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[66] This identity should be known by those familiarised with the linear programming representation of the full basic input-output model, in which the quantity model is the primal programme that maximise the total value added and the price model is the dual programme that minimise the value of net final demand (the optimal solution of the dual programme will be the shadow price that should be equal to the opportunity cost of its inputs). A good reference of input-output model and linear programming is Dorfman *et al.* (1958).

the data have been compiled, but also under scenarios with different parameters and/or exogenous variables.

As in the quantity input-output model, the Leontief inverse, i.e. $\mathbf{B}=(\mathbf{I}-\mathbf{A})^{-1}$, applied to the price input-output model also provides useful economic information. So, expression (2.2b) can be simply written as any of the following expressions:

$$\mathbf{p}'=\boldsymbol{\mu}'\mathbf{B} \tag{2.2b'}$$

$$\begin{bmatrix} p_1 & p_2 & \cdots & p_n \end{bmatrix}=\begin{bmatrix} \mu_1 & \mu_2 & \cdots & \mu_n \end{bmatrix}\begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ b_{n1} & b_{n2} & \cdots & b_{nn} \end{bmatrix} \tag{2.2b''}$$

$$\begin{aligned} p_1 &= \mu_1 b_{11} + \mu_2 b_{21} + \cdots + \mu_n b_{n1} \\ p_2 &= \mu_1 b_{12} + \mu_2 b_{22} + \cdots + \mu_n b_{n2} \\ \vdots \quad & \quad \vdots \qquad \vdots \qquad\quad \vdots \\ p_n &= \mu_1 b_{1n} + \mu_2 b_{2n} + \cdots + \mu_n b_{nn} \end{aligned} \tag{2.2b'''}$$

Now, each b_{ij} translates any change of unit of cost for primary inputs of sector i into a variation of unit price of product j[67]. However, the importance of the Leontief inverse also yields in the fact that it is able to capture and separate out direct from indirect effects. Then, inserting the power series expansion in the solution of price input-output model (2.2b) we would obtain the expression of the value chain (Duchin, 2004):

$$\mathbf{p}'=\boldsymbol{\mu}'+\boldsymbol{\mu}'\mathbf{A}+\boldsymbol{\mu}'\mathbf{A}^2+\boldsymbol{\mu}'\mathbf{A}^3+\ldots \tag{2.C.3}$$

Now, this expression shows that the price of any product is built up round by round in different phases of production. That is, price of product j is equal to the cost for primary inputs paid in sector j to produce one unit of output, plus the value added paid in other sectors to produce the direct inputs needed to produce this unit of product j, plus the value added paid in other sectors to produce the indirect inputs required, etc. This concept allows for disaggregating the price of any product into the value added received by each sector that takes part directly or

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[67] Since $\boldsymbol{\mu}'=\boldsymbol{\pi}'\mathbf{L}$ and $\mathbf{L}$ is supposed to be constant, we can say that variations in $\boldsymbol{\mu}'$ reflects changes in the unit price of primary inputs $\boldsymbol{\pi}'$ indeed.

indirectly in its production. If the value added is disaggregated according to its primary inputs, i.e. $\boldsymbol{\mu}' = \boldsymbol{\pi}'\mathbf{L}$, the process will be even more detailed.

2.D. Numerical example of input-output table and model in monetary units

The following example illustrates the fact that the input-output table and model expressed in monetary units are a simple case of the general framework in which the units of measurement have changed.

For the sake of clarity, we assume a simply economy with only one primary input, let say labour, and in which both intermediate inputs and labour are paid *post factum.* Consider the following input-output table in which each sector is measured in its own physical unit. That is, sector 1 'Agriculture' is measured in tonnes of wheat, sector 2 'Manufacture' in square meters of cloth, and labour in person-year:

	Agriculture	Manufacture	Final demand	Total
Agriculture	25	20	55	100
Manufacture	14	6	30	50
Labour	80	180		

Matrices of direct and primary input coefficients $\mathbf{A}$ and $\mathbf{L}$, and the Leontief inverse $(\mathbf{I}-\mathbf{A})^{-1}$ are:

$$\mathbf{A} = \begin{pmatrix} 0.25 & 0.40 \\ 0.14 & 0.12 \end{pmatrix} \qquad \mathbf{L} = \begin{pmatrix} 0.80 & 3.60 \end{pmatrix} \qquad (\mathbf{I}-\mathbf{A})^{-1} = \begin{pmatrix} 1.46 & 0.66 \\ 0.23 & 1.24 \end{pmatrix}$$

It is easy to check that given a final demand as in the table, the production of this economy should be:

$$\mathbf{x} = (\mathbf{I}-\mathbf{A})^{-1}\mathbf{y} = \begin{pmatrix} 100 \\ 50 \end{pmatrix}$$

Let us fix the cost of one person-year equal to 1.5 monetary units (e.g. euros); then, we can know what is the price of a tonne of wheat and a square meter of cloth in this economy:

$$\mathbf{p}' = \boldsymbol{\mu}'(\mathbf{I}-\mathbf{A})^{-1} = \begin{pmatrix} 3.00 & 7.50 \end{pmatrix}$$

Finally, we can check that the income identity is satisfied:

$$\mathbf{p}'\mathbf{y} = \boldsymbol{\mu}'\mathbf{x} = 390$$

Now if we multiply the rows of the previous input-output table by 3, 7.5, and 1.5 respectively, we obtain a monetary input-output table:

	Agriculture	Manufacture	Final demand	Total
Agriculture	75	60	165	300
Manufacture	105	45	225	375
Labour	120	270		
Total	300	375		

We can check the quantity and price input-output models and the income identity as before:

$$\bar{\mathbf{x}} = (\mathbf{I} - \bar{\mathbf{A}})^{-1}\bar{\mathbf{y}} = \begin{pmatrix} 300 \\ 375 \end{pmatrix}$$

$$\mathbf{p}' = \bar{\boldsymbol{\mu}}'(\mathbf{I} - \bar{\mathbf{A}})^{-1} = \begin{pmatrix} 1.00 & 1.00 \end{pmatrix}$$

$$\mathbf{p}'\bar{\mathbf{y}} = \bar{\boldsymbol{\mu}}'\bar{\mathbf{x}} = 390$$

Notice that the monetary input-output table and model are only a change of units since the GDP of the economy remains the same.

3. Environmental structural decomposition analysis for Spain

3.1. Introduction

As shown in Chapter 2 (Table 2.3), emissions of greenhouse gases and of NO_x and NH_3, increased considerably in Spain from 1995 to 2000. This fact may rise the question about which are the fundamental economic factors that could explain the evolution of these atmospheric pollutants. A useful tool to assess the driving forces underlying the change in emissions is decomposition analysis.

The purpose of the decomposition analysis is to break down the variation of some variables into changes in its determinants to reveal the contribution of each one. Traditionally, two approaches have been applied to assess the influence, for instance, of economic growth, technological changes, and/or shifts in the structure of final demand, on a variety issues. These two approaches are index decomposition analysis (IDA) and structural decomposition analysis (SDA). The SDA is distinguished from the IDA because the former uses input-output models and/or input-output tables to decompose those changes. Although the analysis of changes in the production structure within the input-output framework has its roots in the works of Leontief (1951), Leontief (1953), and Chenery *et al.* (1962)[68]; the term of SDA was not formally defined until 1987 by Rose and Chen[69]. Probably, the most

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[68] See Rose and Casler (1996) and Rose (1999) for a critical review of SDA approach.

[69] The term of SDA was used for first time "in a paper by Rose and Chen (1987), that received limited circulation" cited by Rose and Casler (1996).

used definition of SDA is that proposed by Rose and Chen themselves that states that SDA is "the analysis of economic change by means of a set of comparative static changes in key parameters in an input-output table" (Rose and Chen, 1991, p. 3).

The decomposition analysis methodology has been applied to various issues but specially to those related with energy demand and environmental pressures (Ang, 1994, 1995; Ang and Lee, 1994, 1996). The world oil crisis of the 1970's stimulated the research on understanding the mechanisms underlying industrial energy use and on how to assess the effects of structural changes on the industrial demand of energy. This line of research has continued to analyse not only the contribution of different factors on energy use but also on environmental pressures such as emissions related to fossil fuel combustion and/or other types of physical flows. These environmental decomposition analyses have increased specially after 1995 because of important methodological advances developed since this year. Indeed, Ang and Zhang (2000) list more than a hundred energy and environmental decomposition analyses until 1999, most of them applying IDA[70].

The first environmental SDA was performed by Leontief and Ford (1972) and since then more than thirty environmental SDA studies have been published (see Hoekstra and van den Bergh, 2002; Hoekstra 2005, chapter 6). Some recent works can be added to this detailed review. Hammar and Löfgren (2001) analysed the determinants of sulphur emissions from oil consumption in Swedish manufacturing industry from 1976 to 1995. Mukhopadhyay and Forssell (2005) evaluated the sources of changes of emissions from fossil fuel combustion (CO_2, SO_2, and NO_x) and analyse their impact on human health in India from 1973-1974 to 1996-1997. Hoekstra and van den Bergh (2005) perform a SDA of two physical flows, i.e. iron and steel and plastics, using Dutch hybrid input-output tables of 1990 and 1997; these results are used in Hoekstra and van den Bergh (2006) to study the impact of structural change on physical flows in the Dutch economy by executing forecasting and backcasting analyses. One of the last studies is Dietzenbacher and Stage (2006) in which the use of hybrid input-output tables to perform SDA of changes in energy uses is examined. They show that the use of mixed-unit coefficients can lead to arbitrary results depending on the choice of monetary or physical units rather than

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[70] Ang and Zhang (2000) use the term 'input-output decomposition methodology' to refer to the SDA approach.

on the underlying economic factors. In this paper they propose a solution for this problem.

To the best of our knowledge, there are virtually no previous SDA studies of atmospheric pollution in Spain[71]. Only, Alcántara and Roca (1995) examined energy use and CO_2 emissions in Spain between 1980 and 1990. By using an input-output perspective and energy balances they approximated primary energy required and associated CO_2 emissions to provide different forms of final energy and to distribute the primary energy into three uses, i.e. economic sectors, transport and residential use[72].

In this chapter we perform a SDA in order to break down into three main determinants the variation of atmospheric pollution in Spain from 1995 to 2000. We differentiate changes in emission and technical coefficients (eco-technological effect), changes in sectorial composition of final uses (structure effect), and changes in the aggregate of final uses (level effect)[73]. We distinguish nine different gases: the six greenhouse gases regulated by the Kyoto protocol (CO_2, CH_4, N_2O, SF_6, HFCs, and PFCs) and three local gases (SO_2, NO_x, and NH_3). The results are displayed by total economy and also by sectors. They show that from 1995 to 2000 all the gases increased their emissions with the only exception of SO_2. The most influence source on the emission growth in this period was the level of final use, whereas the eco-technological effect (with the exception of NH_3) had the opposite impact. Concerning the structure effect, we find that changes are not very important: this effect provoked a modest reduction of CH_4, N_2O, and NH_3 emissions, and a modest increase in the rest of the gases.

The remainder of the chapter is organised as follows. Section 3.2 presents the theoretical background of decomposition analysis and particularly of the environmental specification of the structural decomposition analysis performed in this chapter. After analysing the deflation procedure of an input-output table in Section 3.3, we present the results of the environmental SDA for Spain in Section 3.4. Section 3.5 provides some concluding remarks. Finally, in Appendix 3.A we

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[71] However, there are some SDA studies for Spain focused on other issues (see Fernández, 2006; Sánchez-Chóliz and Duarte, 2006; Llop, 2007).

[72] An extension of this analysis is Alcántara and Roca (2004) and for a recent application to Catalonia see Alcántara *et al.* (2008).

[73] These three effects correspond to the technology, composition, and scale effects mentioned in Chapter 1 regarding the environmental Kuznets curve debate.

describe the deflation procedure of the 2000 Spanish symmetrical input-output table, which is presented in Appendix 3.B.

3.2. Theoretical background of decomposition analysis

Decomposition analysis is the term used to refer to a variety of comparative static methods aimed at assessing the driving forces or determinants that underlie the changes of a variable. There are two main decomposition approaches: the index decomposition analysis (IDA) and the structural decomposition analysis (SDA). The IDA has been widely used in empirical analysis, especially in environmental studies, because the requirement of data is less demanding than the SDA. On the other hand, however, the SDA enables to decompose technological and final demand effects more specifically, since it is based on input-output models and/or input-output tables (Hoekstra and van den Bergh, 2003). This section takes a closer look at the theoretical background of the decomposition analysis and particularly at the environmental specification of the SDA used in this chapter.

3.2.1. General features of decomposition analysis

The mathematical idea underlying the decomposition analysis is that changes in variable z of any function such as $z = f(w_1^t, w_2^t, \ldots, w_n^t)$ can be expressed as changes in its determinants $w_1^t, w_2^t, \ldots, w_n^t$ using total differentiation:

$$dz = \frac{\partial z}{\partial w_1} dw_1 + \frac{\partial z}{\partial w_2} dw_2 + \cdots + \frac{\partial z}{\partial w_n} dw_n \tag{3.1}$$

Since input-output models usually face with a multiplicative functional relationship in discrete time, from now on we shall focus on this specific mathematical function. So, variable z can be expressed by the product of different determinants such as:

$$z = w_1 \cdot w_2 \tag{3.2}$$

One of the possible ways of decomposing the above expression is[74]:

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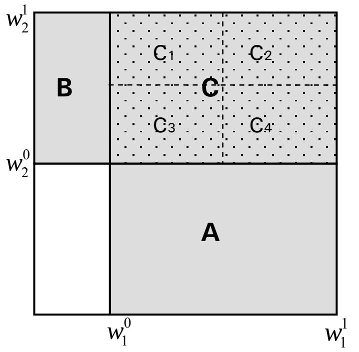
[74] Ang (1994) summarises the general framework of decomposition analysis taking into account that both sides of the decomposition expression can be expressed in absolute or relative changes. On one hand, if we consider an absolute change of variable z (Δz) we get two additive decompositions,

$$\Delta z \approx w_2 \Delta w_1 + w_1 \Delta w_2 \qquad (3.3)$$

This expression, in which both variable and determinant changes are in absolute terms, is the most used in SDA analysis[75]. Although the specification of the decomposition obviously depends on the purpose of the study, there are two reasons that may justify this majority election within input-output approach. First, it seems more appropriate to consider absolute changes in the variable when we assess time-section studies, e.g. to analyse the growth of energy use in one country; and relative changes when we do cross-section analysis, e.g. to compare the variation of energy use in different countries. And second, it is necessary to consider absolute changes in determinants when some data are zero, such as is likely in input-output tables (Hoekstra and van den Bergh, 2002).

However, as it is well know in theory of index numbers the problem is that such a decomposition is not unique but, on the contrary, there are many possible alternatives. The best way to illustrate this drawback is probably by means of representing the above additive decomposition graphically (Figure 3.1):

Figure 3.1: Decomposition of a two determinant change



Source: own elaboration based on Sun (1998)

Let w_1^0 and w_2^0 be the observed determinants at initial time $t=0$ and w_1^1 and w_2^1 be these determinants at final time $t=1$. So, variable z should be $z^0 = w_1^0 \cdot w_2^0$

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depending if determinant changes are in absolute or relative terms. On the other hand, if we consider a relative change of variable z ($\Delta z / z$) we get two possible multiplicative decompositions, one if there is an absolute determinant change and another if the determinant change is relative. Moreover, implicitly the counterfactual calculation from the above expression (3.3) assumes that changes in variables are independent from each other. Dietzenbacher and Los (2000) analyse the situation when changes in one determinant induces changes in other determinant. If this relationship is not taken into account the result of decomposition analysis may be biased.

[75] Dietzenbacher *et al.* (2000), however, uses a multiplicative decomposition expression to decompose labour productivity growth of six Western European countries between 1975 and 1985.

and $z^1 = w_1^1 \cdot w_2^1$, respectively. What is entailed in the graphical decomposition analysis is to decompose the grey area (ABC) that represents the variation in variable z, i.e. $\Delta z = z^1 - z^0$, into the effect of w_1 change and the effect of w_2 change.

As shown in Figure 3.1, clearly area $A = w_2^0 \Delta w_1$ is effect of change in determinant w_1, whereas area $B = w_1^0 \Delta w_2$ is effect of change in determinant w_2[76]. However, the dotted area C represents the joint effect of changes in determinants w_1 and w_2, i.e. $C = \Delta w_1 \Delta w_2$. This area is known as 'interaction term' or 'joint effect' and the problem is how to assign it to different determinants. If there were perfect and/or complete information this task would be easier; however, this is not typically the case and this 'interaction term' is usually divided amongst the determinants applying 'accountant' criteria. There are different alternatives of assigning it and each of them would assign different contributions to each determinant giving different decomposition results. Some of them may lead to 'complete' decompositions, that means the sum of diverse effects is equal to the variation in the variable that is being decomposed. On the contrary, when the sum of the effects are greater or lesser than the variable variation we get 'approximate' decompositions. In this case, the difference between the 'complete' and the decomposition that has been obtained is known as a 'residual'. Notice that the bigger the variation of the determinants is, the higher the 'joint effect' is. And, also that the more determinants we have, the worse the problem of the non-uniqueness decomposition is, because the number of possible complete decompositions increases.

Figure 3.2 below summaries the decomposition options applying the most common indices: Laspeyres that uses the initial year as a reference, Paasche that uses the final year as a reference, and Mashall-Edgeworth that uses the average of the initial and final year as a reference. As shown in this figure, we obtain 'approximate' decompositions either we apply the Laspeyres or the Paasche indices in both determinants. When we use the Marshall-Edgeworth index in both determinants we get a 'complete' decomposition and the 'joint effect' is equally distributed between them[77]. We also reach a 'complete' decomposition when we

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[76] Δw_1 and Δw_2 represent the difference between periods such as $w_1^1 - w_1^0$ and $w_2^1 - w_2^0$.

[77] The result of the decomposition applying the Marshall-Edgeworth index in both determinants is the same as the average decomposition of the above two alternatives, i.e. the Laspeyres-Laspeyres and the Paasche-Paasche decompositions. However, this coincidence is not true when we consider more than two determinants as is generally the case of environmental structural decomposition analyses (Fernández, 2004).

combine the Laspeyres and the Paasche indices, however, in these cases we assign all the ‘joint effect’ to the determinant that uses the Paasche index.

Figure 3.2: Effect of changes of only 2 determinants

Effect of change of determinant w_1		Effect of change of determinant w_2		Residual
Index	Size	Index	Size	
Laspeyres	A	Laspeyres	B	C
Paasche	A + C	Paasche	B + C	-C
Laspeyres	A	Paasche	B + C	None
Paasche	A + C	Laspeyres	B	None
Marshall-Edgeworth	A + C_3 + C_4	Marshall-Edgeworth	B + C_1 + C_2	None

Source: own elaboration based on Hoekstra and van den Bergh (2002)

Some new alternatives have been developed in the literature, however, not all of them hold the three properties particularly relevant for decomposition analysis, i.e. completeness, time reversal, and zero-value robustness tests[78]. The approaches proposed by Sun (1998) and Dietzenbacher and Los (1998) fulfil the three of them[79]. Both specifications will be presented in the next section.

3.2.2. Environmental specification of the structural decomposition analysis

After presenting the theoretical background of decomposition analysis, now we describe the specification of the structural decomposition analysis used in this chapter. As mentioned in Chapter 2, the environmentally extended input-output model can be simply represented by:

$$\mathbf{r} = \mathbf{J}\mathbf{y} \tag{3.4}$$

Where $\mathbf{J}$ is the matrix of total emission intensity of the economy composed by the emission coefficient matrix $\mathbf{W}$ and the Leontief inverse $\mathbf{B}$, and $\mathbf{y}$ is the vector of final uses[80]. However, since the aim of this chapter is to break down the growth of pollution into three determinants, i.e. the eco-technology, the final use structure,

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[78] The completeness property refers to a decomposition with no residual. The time reversal indicates that the decomposition should yield the same result if we reverse the time period of the determinants. Finally, the zero-robustness property allow to apply decomposition with zero values, as it is likely in input-output tables (Hoekstra and van den Bergh, 2003).

[79] Notice that the refined Divisia index pass the zero-value robust test as values converges zero but not for zero values (Hoekstra and van den Bergh, 2003).

[80] Remember that this expression considers both emissions produced domestically and emissions related to imported commodities under the self-sufficiency assumption (see Section 2.4 in Chapter 2).

and the final use level, we need to split the final use vector into two components: a vector that represents the structure ($\boldsymbol{\psi}$) and a scalar that indicates the level (φ).

Therefore, given $\mathbf{i'}$ as a row vector of ones the above expression (3.4) in any period t can be written as:

$$\mathbf{r}^t = \mathbf{J}^t \left(\frac{\mathbf{y}^t}{\mathbf{i'y}^t} \right) \left(\mathbf{i'y}^t \right) = \mathbf{J}^t \boldsymbol{\psi}^t \varphi^t \tag{3.5}$$

Considering $t = 0$ the initial time and $t = 1$ the final time, the variation of emissions in this period of time can be expressed as:

$$\mathbf{r}^1 - \mathbf{r}^0 = \mathbf{J}^1 \boldsymbol{\psi}^1 \varphi^1 - \mathbf{J}^0 \boldsymbol{\psi}^0 \varphi^0 \tag{3.6}$$

Thereby, we can decompose the change of emissions into the contribution of the three determinants: the so-called eco-technological effect $\mathbf{J}^{effect}$, $\boldsymbol{\psi}^{effect}$ that gathers changes in final use structure, and φ^{effect} that gathers changes in final use level:

$$\Delta \mathbf{r} = \mathbf{J}^{effect} + \boldsymbol{\psi}^{effect} + \varphi^{effect} \tag{3.7}$$

Notice that the eco-technological effect $\mathbf{J}^{effect}$ includes the joint effect of variations in the emission coefficient matrix $\mathbf{W}$ and the Leontief inverse $\mathbf{B}$. Other studies, however, consider these two technological effects separately that, in fact, are strongly related[81]. Nevertheless, in this chapter we consider this eco-technological effect globally because in environmental terms we are concerned with the total variation in emissions due to technological changes and it is not important if this variation is due to changes in emission or technological coefficients[82]. That is, we analyse changes in the total intensity of emissions or in the emission 'cost' to provide different types of commodities. It should be mentioned that since each sector includes a range of different goods and services, changes in the intrasectorial composition would affect intensities even if there were not technical changes. This is

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[81] For instance, Wier and Hasler (1999) distinguish two effects, which are called 'emission factor' and 'input mix'. Similarly, de Haan (2001) also differentiates two effects but in this case he uses the terms of 'eco-efficiency' and 'structure of production'.

[82] In order to compare this variation with that reported elsewhere we computed the relative weight of changes in $\mathbf{W}$ and in $\mathbf{B}$ for Spain 1995-2000. For the majority of gases changes in $\mathbf{B}$ were significant but still much smaller than changes in $\mathbf{W}$.

a general limitation of the SDA that becomes more significant with increasing levels of aggregation in input-output tables[83].

As pointed out in previous section, there are several methods for decomposing the total emission variation into its different factors. Nevertheless, in this chapter we apply two of them that lead to a complete decomposition and also fulfil the time reversal and the zero-value robust properties, i.e. the Sun (1998) and Dietzenbacher and Los (1998) approaches. In fact, both techniques can be interpreted as two different approaches to the same method.

a) Sun (1998) approach

The idea of Sun (1998) involves to calculate the effects with the Laspeyres approach and then sharing out the joint effect or interaction term amongst the different effects in line with the "jointly created and equally distributed" principle (Sun, 1998, p. 88). This method, called the 'refined Laspeyres method' by Ang and Zhang (2000), is based on the idea previously proposed by Vogt in 1978. As Hoekstra and van den Bergh (2003, p. 44) cited: "This idea was originally discussed in Vogt (1978), which noted that each index is the result of a discrete evaluation of a continuous function". That is, if it is assumed that the variation that is being decompose is continuous, each index could represent a time path between two discrete points. Since it could be an infinite number of possible paths, the number of indices to decompose the variation could be also infinite. Vogt defined the straight path between the two points with the name of 'natural index' that coincides with the idea of Sun (1998).

Formally, this method implies splitting the residuals of a Laspeyres decomposition equally amongst the three determinants. Notice that in the case of three determinants there are 4 joint effects, i.e. $\Delta\mathbf{J}\Delta\boldsymbol{\psi}\Delta\varphi$, $\Delta\mathbf{J}\Delta\boldsymbol{\psi}\varphi^0$, $\Delta\mathbf{J}\ \boldsymbol{\psi}^0\Delta\varphi$, and $\mathbf{J}^0\Delta\boldsymbol{\psi}\ \Delta\varphi$, that should be equally distributed amongst the determinants that cause them. Therefore, the decomposition specification applying the Sun (1998) proposal for this chapter would be:

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[83] The aggregation and disaggregation issue has been widely discussed within input-output approach. Amongst other works see Theil (1957), Ara (1959), Fisher (1958), Leontief (1967), Neudecker (1970), and Dietzenbacher and Hoen (1999).

$$\mathbf{J}^{effect} = (\Delta\mathbf{J}\boldsymbol{\psi}^0\varphi^0) + \tfrac{1}{2}(\Delta\mathbf{J}\Delta\boldsymbol{\psi}\varphi^0) + \tfrac{1}{2}(\Delta\mathbf{J}\boldsymbol{\psi}^0\Delta\varphi) + \tfrac{1}{3}(\Delta\mathbf{J}\Delta\boldsymbol{\psi}\Delta\varphi) \tag{3.8}$$

$$\boldsymbol{\psi}^{effect} = (\mathbf{J}^0\Delta\boldsymbol{\psi}\varphi^0) + \tfrac{1}{2}(\Delta\mathbf{J}\Delta\boldsymbol{\psi}\varphi^0) + \tfrac{1}{2}(\mathbf{J}^0\Delta\boldsymbol{\psi}\Delta\varphi) + \tfrac{1}{3}(\Delta\mathbf{J}\Delta\boldsymbol{\psi}\Delta\varphi) \tag{3.9}$$

$$\varphi^{effect} = (\mathbf{J}^0\boldsymbol{\psi}^0\Delta\varphi) + \tfrac{1}{2}(\Delta\mathbf{J}\boldsymbol{\psi}^0\Delta\varphi) + \tfrac{1}{2}(\mathbf{J}^0\Delta\boldsymbol{\psi}\Delta\varphi) + \tfrac{1}{3}(\Delta\mathbf{J}\Delta\boldsymbol{\psi}\Delta\varphi) \tag{3.10}$$

b) Dietzenbacher and Los (1998) approach

The idea of Dietzenbacher and Los (1998) is based on the fact that if each of the *n* determinants can either be expressed by the Laspeyres or Paasche indices then, there should be *n*! different complete decompositions as a result of all possible Laspeyres-Paasche combinations. They claimed that, although all these possible forms are "equivalent, in the sense that no form is to be preferred on theoretical grounds to the others" (Dietzenbacher and Los, 1998, p. 314), their outcomes can differ greatly. Therefore, one possibility to get a complete decomposition is to calculate the average of all *n*! expressions.

In this chapter, as we have 3 determinants we obtain 6 (3!) different complete decompositions resulting of combining Laspeyres and Paasche indices such that:

$$\mathrm{D1} = (\Delta\mathbf{J}\boldsymbol{\psi}^0\varphi^0) + (\mathbf{J}^1\Delta\boldsymbol{\psi}\varphi^0) + (\mathbf{J}^1\boldsymbol{\psi}^1\Delta\varphi) \tag{3.11}$$

$$\mathrm{D2} = (\Delta\mathbf{J}\boldsymbol{\psi}^0\varphi^0) + (\mathbf{J}^1\Delta\boldsymbol{\psi}\varphi^1) + (\mathbf{J}^1\boldsymbol{\psi}^0\Delta\varphi) \tag{3.12}$$

$$\mathrm{D3} = (\Delta\mathbf{J}\boldsymbol{\psi}^1\varphi^0) + (\mathbf{J}^0\Delta\boldsymbol{\psi}\varphi^0) + (\mathbf{J}^1\boldsymbol{\psi}^1\Delta\varphi) \tag{3.13}$$

$$\mathrm{D4} = (\Delta\mathbf{J}\boldsymbol{\psi}^0\varphi^1) + (\mathbf{J}^1\Delta\boldsymbol{\psi}\varphi^1) + (\mathbf{J}^0\boldsymbol{\psi}^0\Delta\varphi) \tag{3.14}$$

$$\mathrm{D5} = (\Delta\mathbf{J}\boldsymbol{\psi}^1\varphi^1) + (\mathbf{J}^0\Delta\boldsymbol{\psi}\varphi^0) + (\mathbf{J}^0\boldsymbol{\psi}^1\Delta\varphi) \tag{3.15}$$

$$\mathrm{D6} = (\Delta\mathbf{J}\boldsymbol{\psi}^1\varphi^1) + (\mathbf{J}^0\Delta\boldsymbol{\psi}\varphi^1) + (\mathbf{J}^0\boldsymbol{\psi}^0\Delta\varphi) \tag{3.16}$$

We calculate the average of the six decompositions; however, as Dietzenbacher and Los (1998) states when the number of determinants is very large, the average of the so-called polar decompositions, i.e. the first $\mathrm{D1}$ and the last $\mathrm{D6}$, could be a good approximation to the average of all decomposition[84].

It should be noticed that the average of the *n*! decomposition of Dietzenbacher and Los (1998) approach leads to the same result as the Sun (1998) approach,

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[84] de Haan (2001) extends this analysis showing that the average of any two symmetrical decompositions, which he calls 'mirror' decompositions, can be also a good approximation of the average of the *n*! solutions.

although the former could be less intuitive when the number of determinants is high (Hoekstra and van den Bergh, 2003; Fernández, 2004). Figure 3.3 illustrates this graphically. This figure shows both approaches for the general expression of two determinants, i.e. $z = w_1 \cdot w_2$. The average of areas B_1, C_1, and B_2 in Figure 3.3b leads the same dotted area in Figure 3.3a. Similarly, the average of areas A_1, A_2, and C_2 in Figure 3.3b corresponds to the grey area of Figure 3.3a.

Figure 3.3a: Decomposition by Sun (1998)

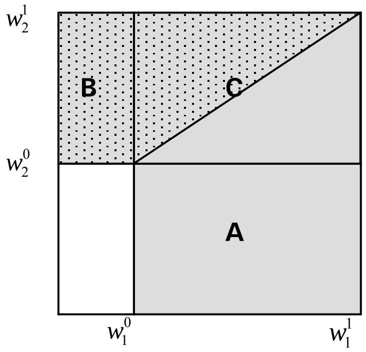
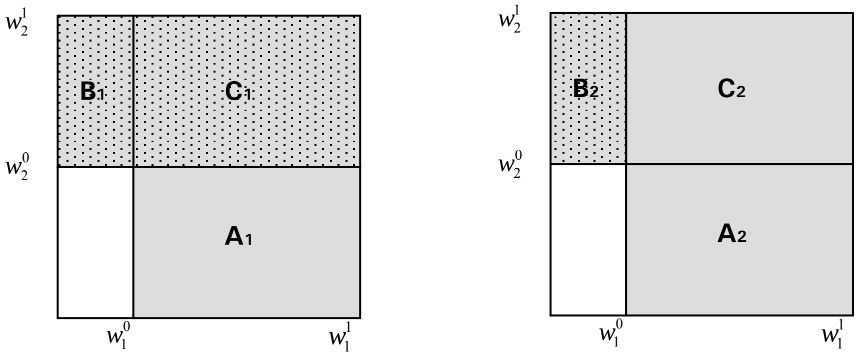


Figure 3.3b: Decomposition by Dietzenbacher and Los (1998)



Source: own elaboration.

3.3. Data set: deflating an input-output table

As it is widely known, an input-output table is a double-entry system of accounting concerning the flow of products from sectors to either other sectors or final uses. Usually, these transactions are registered in current prices; that is, the value of any transaction is equal to the price per unit of quantity in one year multiplied by the number of units involved in the transaction of this same year. This implies that when analysing changes between different input-output tables over time, the observed changes can be caused by either variations in prices or variations in quantities. The latter is especially relevant when we evaluate technological changes as in structural decomposition analyses, since the observed changes in technical coefficients may be reflecting changes in cost structure rather than in production structure. So, in order to avoid the influence of price variations it is recommended to used input-output tables in constant prices, i.e. an input-output table that describes an economic situation of any year valued at prices of a base year. However, data in constant prices cannot be observed from the real world and, consequently, they should be derived from the available data in current prices. Undoubtedly, the deflation of an input-output table is not straightforward because of theoretic and data availability drawbacks.

In this chapter we basically use the 1995 and 2000 Spanish databases described in Chapter 2 (INE, 2005a, 2006). Since the INE does not provided input-output tables in constant prices we use the 1995 symmetrical input-output table in current prices and we estimate a 2000 symmetrical input-output table in 1995 constant prices. In this section, first, we describe the main difficulties that came up against when deflating an input-output table and then, we explain the procedure to obtain a 2000 Spanish symmetrical input-output table in 1995 constant prices.

3.3.1. Deflation drawbacks

In an ideal world all the information related with transaction values would be available. However, mainly because the acquisition of data is difficult and expensive, the reality is far from this situation and, hence, data in constant prices should be estimated according to the available statistical information[85].

Preferably, the deflation should be carry out applying different Paasche price indices for each type of transaction at the lowest level of aggregation as possible. Within the input-output framework, it should be desirable to compile supply and use tables in both current and constant prices. The latter means that before entering data in the system each transaction, output, taxes, margins, intermediate and final consumption should be deflated independently. According to European Commission (2001) each of these categories should be deflated applying different price indices such as production price indices, intermediate consumption price indices,

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[85] For a detailed analysis of the deflation process see European Commission (2001) and European Commission (2008). The latter is focused on the deflation of supply and use tables (see chapter 9).

consumption price indices, capital goods price indices, and/or imports and exports price indices. However, these price indices either are not always available or do not cover all kind of products or transactions. In those cases second best alternatives, which are not free of difficulties, can be applied using other ready information[86]. Then, supply and use tables in current and constant prices should be compiled and sequentially balanced and corrected.

Altogether it is a really difficult and tedious task, specially from the researcher standpoint who needs to use input-output tables at constant prices. Consequently, deflated input-output tables have been mostly estimated applying the double deflation method (United Nations, 1999)[87]. This method consists in deflating all the components of an input-output table applying the implicit deflator of value added to each sector by rows. Even though this method is generally accepted and predominantly adopted in input-output literature, it presents certain drawbacks.

According to Dietzenbacher and Hoen (1998) the double deflation method entails three main problems. First, if each sector only produced one good, it would be acceptable to deflate each row applying the implicit deflator of the value added of each sector. However, sectors usually produce various goods that are delivered to other sectors in different proportions and, therefore, a different price index should be applied within a row. Second, "since the value added is obtained as the difference of variables, its measurement error equals the sum of the measurement errors of these variables" (Dietzenbacher and Hoen, 1998, p. 114). The third drawback is related with the aggregation problem. Within input-output analysis it is well known that aggregation after inversion and inversion after aggregation processes lead to different results. Similarly, the input-output table at constant prices obtained by double deflation will be different if it has been aggregated and then deflated or if it has been deflated and then aggregated. With all the information available the latter procedure is preferable; however, the almost only alternative for the researcher is deflating an aggregated input-output table since published and accessible information is largely aggregated.

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[86] For instance, the production price index in Spain is a fixed weight Laspeyres index not a Paasche one and, besides, it only covers industrial sectors. This means that the market production of neither agriculture, fishing, services nor some energy sectors can be deflated by this price index. The alternative, therefore, for those sectors is to deflate them by applying consumer price indices. In this case, however, it would be applied a fixed weight Laspeyres index, which considers purchaser's prices to transactions valued at basic prices.

[87] Notice that different deflation methods may lead to different results. Other deflation methods have been proposed by Durand (1994) and Dietzenbacher and Hoen (1998).

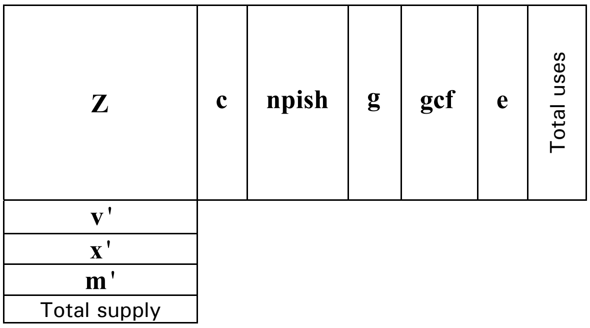
Consequently, Dietzenbacher and Hoen (1998) propose an alternative approach for deflating input-output tables taking into account the point of view of the user. The aim of this ‘heuristic approach’, as they called it, is not to provide an estimation for the valued added or the gross domestic production but to obtain an intersectorial transaction matrix at constant prices, which is undoubtedly the aim of the deflation process from the input-output perspective. The heuristic approach is based on the fact that although the deflated input-output tables are not provided, statistical offices usually supply other deflated data. The idea of this method is to use this information so that knowing the total row and column of the input-output table at constant prices, the deflated intersectorial transaction matrix can be obtained by applying the RAS procedure[88]. According to their results[89], when the sectorial value added in constant prices is provided, the heuristic approach yield a better estimation than double deflation method. Moreover, applying the heuristic approach each cell of the intersectorial transaction matrix gets a specific price index and the estimation errors are smoothed out over the entire table.

3.3.2. The Spanish 2000 input-output table at 1995 constant prices

In this chapter we estimate the 2000 Spanish symmetrical input-output table at 1995 constant following the above heuristic approach according to the available information for Spain. However, since the ‘correct’ or official Spanish input-output table at constant prices is unknown, it is not possible to analyse how far is the estimated table from the ‘real’ one.

Figure 3.4: Deflation process of the 2000 Spanish symmetrical input-output table

1st step: 2000 symmetrical input-output table



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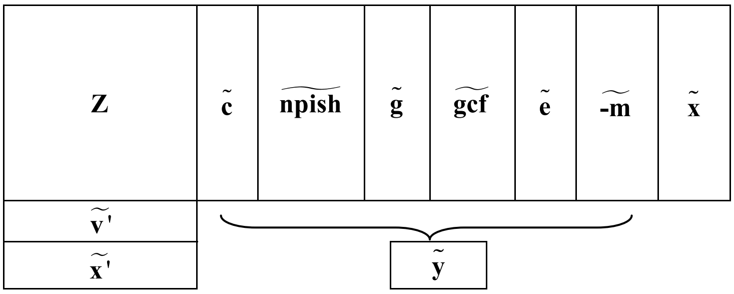
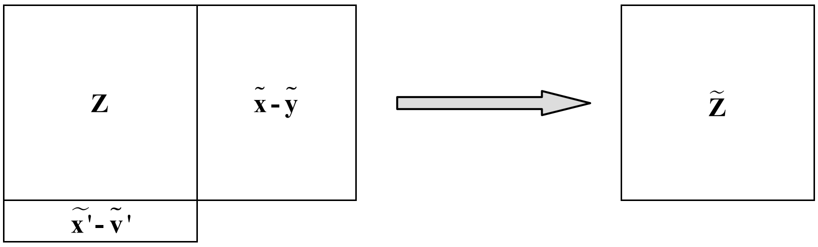
[88] See Appendix 3.A.

[89] Dietzenbacher and Hoen (1998) applied the heuristic and the double deflation methods to estimate a 1988 transaction matrix at 1987 constant prices. They compared both methods with the deflated matrix officially published by the Statistics Netherlands.

2^{nd} step: Individual deflation process of each component



3^{rd} step: RAS method



Source: own elaboration.

As shown in Figure 3.4, the procedure of deflating the Spanish intersectorial transaction matrix $\mathbf{Z}$ has been carried out in three steps. First, the 2000 symmetrical input-output table is estimated from the supply and use tables as described in Chapter 2. Second, from the information in constant prices provided by the INE (Figure 3.5) we deflate the sectorial output vector $(\mathbf{x})$, the sectorial value added vector $(\mathbf{v})$, the import vector $(\mathbf{m})$, and each component of final uses, i.e. final consumption expenditure by household $(\mathbf{c})$, final consumption expenditure by non-profit institutions serving households $(\mathbf{npish})$, final consumption expenditure by government $(\mathbf{g})$, gross capital formation $(\mathbf{gcf})$, and exports $(\mathbf{e})$. Finally, applying the RAS method we obtained the transaction matrix in constant prices $\tilde{\mathbf{Z}}$[90].

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[90] See Appendix 3.A for a detailed description of the deflation procedure. The estimated 2000 symmetrical input-output table at 1995 constant prices for Spain is provided in Appendix 3.B.

Figure 3.5: Information provided by the Spanish national account framework to deflate an input-output table, 2000 data in 1995 constant prices

Value added by sectors including FISIM sector	
Total Gross domestic product	Total of final consumption expenditure by household
	Total of final consumption expenditure by NPISH
	Total of final consumption expenditure by government
	Total of gross capital formation
	Total imports
	Total exports
Final consumption expenditure by household by COICOP	
Purchases on the domestic territory by non-residents	
Direct purchases abroad by residents	
Final consumption expenditure of government by components	
Gross capital formation by components	
Net taxes on products	Value added type taxes (VAT)
	Taxes and duties on imports except VAT
	Taxes on products expect VAT and import taxes

Source: own elaboration from INE (2005b, 2005c).

3.4. Empirical results

This section presents the results of the environmental SDA. We report the influence of three components, i.e. the eco-technology ($\mathbf{J}$), the final use structure ($\boldsymbol{\psi}$) and the final use level (φ), on the variation of emissions of nine gases, i.e. the six greenhouse gases (CO_2, CH_4, N_2O, SF_6, HFCs, and PFCs)[91] and three local gases (SO_2, NO_x, and NH_3), in Spain during the period 1995-2000. We execute the SDA applying the approaches proposed by Sun (1998) and Dietzenbacher and Los (1998) obtained, as pointed out above, the same results both for the economy (Section 3.4.1) and by sectors (Section 3.4.2).

Notice that in this chapter we only consider domestic and imported emissions produced by sectors and neither direct emissions from households nor CH_4 emissions from waste management are considered. It should be said, however, that the emissions we do consider represent over 80 per cent of the total emissions of the economy for all the gases (Tables 2.1 and 2.2 of Chapter 2)[92].

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[91] As mentioned in Chapter 2, the so-called 'greenhouse synthetic gases' SF_6, HFCs, and PFCs have been grouped and the six greenhouse gases have been unified measuring their emissions in CO_2 equivalent units according with the global warming potentials established by the Intergovernmental Panel of Climate Change (IPCC, 1997).

[92] The only exception is CH_4 that represents 76.18% and 74.79% because part of CH_4 emissions have been considered as a direct emissions from the waste management (see Section 2.6 in Chapter 2).

3.4.1. Structural decomposition analysis for the economy

Table 3.1 shows the decomposition of the emission variation in Spain from 1995 to 2000 as a percentage of total direct emissions in 1995. In connection with the results of Chapter 2, all the atmospheric emissions increased during this period, the only exception to this was SO_2.

Certainly, in almost all gases the effect of final use level is the most important effect, which increases the emissions as expected. In the grater part of the gases, the second important effect is the eco-technological effect that contributes to the reduction of emissions. However, this effect was only strong enough to counteract the level effect in the case of SO_2, whereas for CO_2, CH_4, N_2O, and NO_x it was important but much less than the level effect. The only exceptions to the beneficial effects of eco-technology are NH_3 and, particularly, the group of synthetic greenhouse gases[93]. Regarding the structure effect of final uses, we can conclude that this effect is relatively small in comparison with the other two effects for virtually all the gases. In most of the gases, changes in final use structure lead to increase emissions; however, we found that the final use structure effect is responsible for modest reduction in CH_4, N_2O and NH_3 emissions, which are mostly connected with agriculture and food activities.

Table 3.1: Decomposition of the emission changes, Spain 1995-2000 as percentage of the total amount of emissions by all industries in 1995

Units: %

	Eco-technological effect	Final use structure effect	Final use level effect	Total effect
	$\mathbf{J}^{effect} / \mathbf{r}_{95}$	$\psi^{effect} / \mathbf{r}_{95}$	$\varphi^{effect} / \mathbf{r}_{95}$	$\Delta\mathbf{r} / \mathbf{r}_{95}$
Greenhouse gases				
CO_2	-9.72	5.38	29.56	25.22
CH_4	-11.24	-4.17	28.05	12.65
N_2O	-6.86	-1.40	29.02	20.76
Synthetic gases*	39.88	12.72	36.86	89.46
Total in CO_2 equivalent	**-8.64**	**4.10**	**29.52**	**24.99**
Other gases				
SO_2	-38.20	5.26	25.89	-7.06
NO_x	-17.49	2.20	28.11	12.82
NH_3	4.25	-5.08	29.96	29.13

Source: own elaboration from 1995 and 2000 Spanish NAMEA.
*: Synthetic gases are total SF_6, HFCs, and PFCs emissions measured in tonnes of equivalent CO_2.

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[93] However, the differences between the three gases are important and it should be pointed out the decreasing of emissions due to technological effect in the case of PFCs.

In general terms, the results obtained for Spain are in line with those obtained in other studies for other countries[94], although it should be mentioned that the comparison amongst studies is difficult because of the time period of reference, the methodological option, and/or the different environmental issues analysed.

3.4.2. Sectorial structural decomposition analysis

The results of the SDA by sectors for greenhouse gases are shown in Table 3.2 and for local gases in Table 3.3. In the sectorial SDA, the total emissions of the economy of each gas has been used as a reference; hence, the total of each column fits with the results of Table 3.1. The sectorial SDA allows us to concentrate on specific sectors whose behaviour could remain hidden when analysing all sectors together. This additional information could indicate which sectors would need a deeper analysis in order to propose some specific measures.

For instance, (S26) ‘Manufacture of motor vehicles, trailers and semi-trailers’ and (S33) ‘Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and households goods’ are the sectors that contribute more to increase emissions of those gases related to energy, i.e. CO_2, SO_2, and NO_x. If we focus on the three gases linked with agricultural and food activities, i.e. CH_4, N_2O, and NH_3, we realise that (S1) ‘Agriculture, hunting, and related services activities’ and (S8) ‘Manufacture of food products, beverages, and tobacco’ followed by (S33) ‘Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and households goods’ are the main responsible sectors for the increase of those emissions due essentially to the level effect of final uses. Finally, in the case of synthetic greenhouse gases the principal pollutant sectors are (S16) ‘Manufacture of chemicals and chemical products’, (S26) ‘Manufacture of motor vehicles, trailers, and semi-trailers’, (S33) ‘Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and households goods’, and lastly (S32) ‘Construction’.

As we can see (S33) ‘Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and households goods’ is revealed as a general pollutant sector in all gases. On the contrary, (S4) ‘Mining of coal and lignite; extraction of peat’ and (S5) ‘Extraction of crude petroleum, natural gas; uranium and thorium ores’ are the only two sectors that have decreased the emissions in all gases without exception. Sector (S34) ‘Hotels and restaurants’ also deserves a special comment

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[94] See Hoekstra and van den Bergh (2002).

since this sector contributes the more to reduce the emissions of almost all gases. There are only two exceptions: NO_x emissions in which (S15) 'Manufacture of coke, refined petroleum products, and nuclear fuel' is ahead of and synthetic greenhouse gases in which the emissions of sector (S34) have augmented.

Figure 3.6: Sectors in which the structure of the final demand have a positive effect on diminishing the emissions

S2	Forestry, logging, and related services activities
S4	Mining of coal and lignite; extraction of peat
S5	Extraction of crude petroleum, natural gas; uranium, and thorium ores
S6	Mining of metal ores
S8	Manufacture of food products, beverages, and tobacco
S11	Tanning and dressing of leather; manufacture of luggage, handbags, saddler, harness, and footwear
S19	Manufacture of basic metals
S28	Manufacture of furniture
S31	Collection, purification, and distribution of water
S32	Construction
S33	Wholesale and retail trade; repair of motor vehicles, motorcycles, and personal and household goods
S34	Hotels and restaurants
S36	Water transport
S41	Real estate, renting, and business activities
S42	Public administration and defence; compulsory social security
S43	Education
S44	Health and social work
S45	Other community, social and personal service activities

Source: own elaboration.

If we look now at the three effects considered, we see that in connection with results of Table 3.1 the effect of final use level is always positive irrespectively the atmospheric pollutant or the sector analysed. On the other hand, the effect of final use structure of each sector follows the same behaviour through gases. Figure 3.6 lists all sectors in which the structure effect has a positive result in diminishing the emissions in all gases. Concerning the structure effect it should be mentioned the case of CH_4, N_2O, and NH_3. According to Table 3.1 this effect has caused a small decrease of the emissions of only these three gases. This reduction has been mainly due to (S8) 'Manufacture of food products, beverages, and tobacco' and (S34) 'Hotels and restaurants', which are the sectors indirectly connected with agricultural activities.

Regarding the eco-technological effect, it is the only one that presents different results through both sectors and gases as it was expected. However, the results are so different that is difficult to set a clear tendency. Maybe it should be worthy to comment the two extreme cases: the SO_2 and synthetic greenhouse gases. On one hand, SO_2 was the only gas in which the eco-technological effect was strong enough to counteract structure and level effects and hence to diminish total SO_2 emissions. In this gas the eco-technological effect provokes a downward tendency in all sectors,

Table 3.2: Sectorial SDA for greenhouse gases, Spain 1995-2000 (continues ...)

Units: %

		CO_2				CH_4				N_2O			
		$\mathbf{J}^{effect}/\mathbf{r}_{95}$	$\boldsymbol{\psi}^{effect}/\mathbf{r}_{95}$	$\varphi^{effect}/\mathbf{r}_{95}$	$\Delta\mathbf{r}/\mathbf{r}_{95}$	$\mathbf{J}^{effect}/\mathbf{r}_{95}$	$\boldsymbol{\psi}^{effect}/\mathbf{r}_{95}$	$\varphi^{effect}/\mathbf{r}_{95}$	$\Delta\mathbf{r}/\mathbf{r}_{95}$	$\mathbf{J}^{effect}/\mathbf{r}_{95}$	$\boldsymbol{\psi}^{effect}/\mathbf{r}_{95}$	$\varphi^{effect}/\mathbf{r}_{95}$	$\Delta\mathbf{r}/\mathbf{r}_{95}$
S1	Agriculture, hunting, and related services activities	-0.0054	0.0608	0.7320	**0.7874**	-1.7980	0.5756	6.9444	**5.7221**	-0.0109	0.4517	5.4416	**5.8823**
S2	Forestry, logging, and related services activities	0.0066	-0.0026	0.0058	**0.0098**	0.0280	-0.0134	0.0301	**0.0447**	0.0290	-0.0107	0.0239	**0.0423**
S3	Fishing	-0.1606	0.1306	0.2553	**0.2253**	-0.0047	0.0208	0.0405	**0.0566**	-0.0011	0.0287	0.0560	**0.0836**
S4	Mining of coal and lignite; extraction of peat	-0.0003	-0.0084	0.0014	**-0.0073**	0.0128	-0.1072	0.0177	**-0.0767**	0.0000	-0.0022	0.0004	**-0.0018**
S5	Extraction of crude petroleum, natural gas; uranium and thorium ores	0.0004	-0.0012	0.0003	**-0.0005**	-0.0003	-0.0006	0.0002	**-0.0007**	0.0001	-0.0002	0.0001	**-0.0001**
S6	Mining of metal ores	0.0063	-0.0032	0.0056	**0.0087**	0.0006	-0.0003	0.0006	**0.0008**	0.0014	-0.0007	0.0012	**0.0020**
S7	Other mining and quarrying	-0.0272	0.0017	0.0236	**-0.0019**	-0.0114	0.0004	0.0054	**-0.0057**	-0.0006	0.0005	0.0068	**0.0067**
S8	Manufacture of food products, beverages, and tobacco	-0.2311	-0.6912	2.4376	**1.5153**	-3.1894	-2.8505	10.0692	**4.0293**	-0.5690	-2.2930	8.0852	**5.2233**
S9	Manufacture of textile	-0.1333	0.0011	0.2877	**0.1556**	-0.2724	0.0011	0.2956	**0.0244**	-0.2559	0.0013	0.3267	**0.0720**
S10	Manufacture of wearing apparel; dressing, and dyeing of fur	-0.0876	0.0032	0.3681	**0.2837**	-0.2176	0.0025	0.2937	**0.0786**	-0.1956	0.0029	0.3338	**0.1411**
S11	Tanning and dressing of leather; manufac. of luggage, handbags, saddler, harness, and foot.	-0.0923	-0.0072	0.2036	**0.1041**	-0.1113	-0.0089	0.2511	**0.1309**	-0.1148	-0.0074	0.2109	**0.0887**
S12	Manufacture of wood and of products of wood and cork, except furniture	-0.0025	0.0325	0.0494	**0.0795**	0.0185	0.0200	0.0304	**0.0689**	0.0230	0.0217	0.0329	**0.0775**
S13	Manufacture of pulp, paper, and paper products	0.0181	0.0077	0.1899	**0.2156**	-0.0179	0.0032	0.0784	**0.0637**	-0.0288	0.0036	0.0891	**0.0639**
S14	Publishing, printing, and reproduction of recorded media	-0.1605	0.0048	0.1922	**0.0366**	-0.0776	0.0017	0.0664	**-0.0096**	-0.1078	0.0024	0.0959	**-0.0096**
S15	Manufacture of coke, refined petroleum products, and nuclear fuel	-2.2011	0.7881	1.2033	**-0.2097**	-1.2306	0.1670	0.2564	**-0.8072**	-0.5689	0.2278	0.3476	**0.0066**
S16	Manufacture of chemicals and chemicals products	-0.9120	0.8449	1.6119	**1.5448**	-0.4323	0.1970	0.3764	**0.1412**	-2.1449	1.1331	2.1641	**1.1524**
S17	Manufacture of rubber and plastic products	-0.1183	0.1746	0.2281	**0.2843**	-0.0682	0.0593	0.0775	**0.0685**	-0.1398	0.1370	0.1791	**0.1763**
S18	Manufacture of other non-metallic mineral products	-0.4597	0.5680	0.9113	**1.0196**	-0.0649	0.0385	0.0618	**0.0353**	-0.0957	0.0940	0.1509	**0.1493**
S19	Manufacture of basic metals	-0.2773	-0.1230	0.7848	**0.3845**	-0.1645	-0.0220	0.1413	**-0.0453**	-0.2137	-0.0357	0.2287	**-0.0206**
S20	Manufacture of fabricated metal products, except machinery and equipment	-0.1730	0.3737	0.4513	**0.6519**	-0.0903	0.0741	0.0896	**0.0734**	-0.1017	0.1179	0.1425	**0.1587**
S21	Manufacture of machinery and equipment	-0.7733	0.9970	0.9402	**1.1638**	-0.2233	0.1986	0.1873	**0.1626**	-0.3740	0.3580	0.3376	**0.3215**
S22	Manufacture of office machinery and computers	-0.0822	0.3103	0.2490	**0.4771**	-0.0371	0.0646	0.0518	**0.0793**	-0.0716	0.1210	0.0970	**0.1463**
S23	Manufacture of electrical machinery and apparatus	-0.1416	0.3109	0.3637	**0.5330**	-0.0807	0.0603	0.0705	**0.0501**	-0.0835	0.1055	0.1235	**0.1454**
S24	Manufacture of radio, television and communication equipment and apparatus	-0.1892	0.6760	0.3850	**0.8719**	-0.0732	0.1261	0.0717	**0.1245**	-0.1138	0.2447	0.1391	**0.2700**
S25	Manufacture of medical, precision and optical instruments, watches and clocks	-0.0825	0.1669	0.1868	**0.2711**	-0.0400	0.0340	0.0381	**0.0321**	-0.0555	0.0606	0.0678	**0.0729**
S26	Manufacture of motor vehicles, trailers, and semi-trailers	-0.8632	2.6047	2.6275	**4.3690**	-0.5579	0.5679	0.5729	**0.5829**	-0.8372	1.0577	1.0670	**1.2875**
S27	Manufacture of other transport equipment	-0.0539	0.3931	0.3034	**0.6426**	-0.0461	0.0774	0.0597	**0.0909**	-0.0677	0.1542	0.1189	**0.2054**
S28	Manufacture of furniture	-0.2331	-0.0021	0.5222	**0.2869**	-0.0752	-0.0007	0.1665	**0.0906**	-0.1233	-0.0010	0.2486	**0.1243**
S29	Recycling	*	*	*	*****	*	*	*	*	*	*	*	*
S30	Electricity, gas, steam, and hot water supply	-1.2183	0.5095	2.2468	**1.5380**	-0.8040	0.1085	0.4807	**-0.2148**	-0.0428	0.0485	0.2136	**0.2192**
S31	Collection, purification, and distribution of water	-0.0513	-0.0697	0.0776	**-0.0434**	-0.0220	-0.0130	0.0146	**-0.0204**	-0.0137	-0.0196	0.0218	**-0.0115**
S32	Construction	-1.2207	-0.7629	3.9294	**1.9458**	-0.4505	-0.1785	0.9203	**0.2913**	-0.3466	-0.2478	1.2761	**0.6816**
S33	Wholesale and retail trade; repair of motor vehicles, motorcy., and personal and hous. goods	0.9408	-0.3650	1.6520	**2.2278**	2.1572	-0.1586	0.7056	**2.7042**	2.1169	-0.1931	0.8629	**2.7867**
S34	Hotels and restaurants	-0.7434	-1.2149	1.5697	**-0.3886**	-3.0978	-2.9643	3.8429	**-2.2192**	-1.6853	-2.4434	3.1587	**-0.9699**
S35	Land transport; transport via pipelines	-0.1388	0.0074	0.4907	**0.3594**	-0.0685	0.0021	0.1393	**0.0728**	0.0070	0.0019	0.1237	**0.1325**
S36	Water transport	-0.0633	-0.1352	0.1690	**-0.0294**	-0.0331	-0.0133	0.0169	**-0.0295**	-0.0238	-0.0223	0.0280	**-0.0181**
S37	Air transport	-0.0123	0.3904	0.3780	**0.7561**	-0.1084	0.0376	0.0364	**-0.0344**	-0.0443	0.0698	0.0675	**0.0930**
S38	Supporting and auxiliary transport activities; activities of travel agencies	-0.0514	0.0274	0.1438	**0.1198**	-0.0622	0.0098	0.0518	**-0.0006**	-0.0288	0.0104	0.0546	**0.0361**
S39	Post and telecommunications	0.2147	0.1364	0.1081	**0.4592**	0.0411	0.0305	0.0242	**0.0958**	0.0710	0.0373	0.0296	**0.1378**
S40	Financial intermediation	-0.1794	0.1759	0.1958	**0.1923**	-0.0892	0.0507	0.0565	**0.0180**	-0.0467	0.0568	0.0632	**0.0733**
S41	Real estate, renting, and business activities	0.3915	-0.0816	0.9396	**1.2495**	0.1409	-0.0231	0.2656	**0.3835**	0.2269	-0.0379	0.4364	**0.6253**
S42	Public administration and defence; compulsory social security	0.0587	-0.4063	0.6908	**0.3432**	-0.0886	-0.1466	0.2502	**0.0151**	0.0389	-0.1522	0.2587	**0.1453**
S43	Education	0.0029	-0.1486	0.3004	**0.1547**	0.0540	-0.0540	0.1088	**0.1088**	0.0845	-0.0608	0.1222	**0.1459**
S44	Health and social work	-0.2116	-0.2680	0.6920	**0.2124**	-0.2020	-0.1177	0.3047	**-0.0150**	-0.5844	-0.3561	0.9220	**-0.0185**
S45	Other community, social, and personal service activities	-0.0114	-0.0232	0.4542	**0.4197**	0.2174	-0.0251	0.4918	**0.6840**	-0.3678	-0.0643	1.2637	**0.8315**
S46	Private households with employed persons	0.0000	0.0000	0.0000	**0.0000**	0.0000	0.0000	0.0000	**0.0000**	0.0000	0.0000	0.0000	**0.0000**

Source: own elaboration from 1995 and 2000 Spanish NAMEA.

*: Information not available because in 1995 NAMEA there is not information about Recycling sector.

Table 3.2: Sectorial SDA for greenhouse gases, Spain 1995-2000 (... finished)

Units: %

		Synthetic gases				Total in CO₂ equivalent			
		$\mathbf{J}^{effect} / \mathbf{r}_{95}$	$\psi^{effect} / \mathbf{r}_{95}$	$\varphi^{effect} / \mathbf{r}_{95}$	$\Delta\mathbf{r} / \mathbf{r}_{95}$	$\mathbf{J}^{effect} / \mathbf{r}_{95}$	$\psi^{effect} / \mathbf{r}_{95}$	$\varphi^{effect} / \mathbf{r}_{95}$	$\Delta\mathbf{r} / \mathbf{r}_{95}$
S1	Agriculture, hunting, and related services activities	1.0202	0.0516	0.6161	**1.6879**	-0.1476	0.1395	1.6809	**1.6727**
S2	Forestry, logging, and related services activities	0.0111	-0.0013	0.0029	**0.0126**	0.0104	-0.0042	0.0094	**0.0157**
S3	Fishing	0.0925	0.0224	0.0434	**0.1583**	-0.1283	0.1101	0.2152	**0.1970**
S4	Mining of coal and lignite; extraction of peat	0.0007	-0.0044	0.0007	**-0.0030**	0.0009	-0.0167	0.0028	**-0.0130**
S5	Extraction of crude petroleum, natural gas; uranium and thorium ores	0.0000	-0.0001	0.0000	**-0.0001**	0.0003	-0.0011	0.0003	**-0.0005**
S6	Mining of metal ores	0.0083	-0.0021	0.0036	**0.0099**	0.0054	-0.0027	0.0048	**0.0074**
S7	Other mining and quarrying	0.0513	0.0015	0.0208	**0.0736**	-0.0220	0.0015	0.0205	**0.0000**
S8	Manufacture of food products, beverages, and tobacco	2.4329	-0.5308	1.8528	**3.7549**	-0.4735	-1.0157	3.5830	**2.0938**
S9	Manufacture of textile	1.8774	0.0030	0.7648	**2.6451**	-0.1161	0.0012	0.3012	**0.1863**
S10	Manufacture of wearing apparel; dressing, and dyeing of fur	1.8131	0.0064	0.7294	**2.5489**	-0.0705	0.0031	0.3657	**0.2984**
S11	Tanning and dressing of leather; manufacture of luggage, handbags, saddler, harness, and footwear	0.6668	-0.0122	0.3417	**0.9962**	-0.0808	-0.0075	0.2113	**0.1230**
S12	Manufacture of wood and of products of wood and cork, except furniture	0.0739	0.0263	0.0399	**0.1401**	0.0030	0.0304	0.0462	**0.0796**
S13	Manufacture of pulp, paper, and paper products	0.1103	0.0055	0.1343	**0.2501**	0.0128	0.0069	0.1703	**0.1900**
S14	Publishing, printing, and reproduction of recorded media	0.0908	0.0049	0.1916	**0.2873**	-0.1437	0.0044	0.1729	**0.0336**
S15	Manufacture of coke, refined petroleum products, and nuclear fuel	0.0274	0.0897	0.1365	**0.2536**	-1.9341	0.6717	1.0257	**-0.2366**
S16	Manufacture of chemicals and chemicals products	11.2701	5.4904	10.4277	**27.1881**	-0.7285	0.9025	1.7210	**1.8950**
S17	Manufacture of rubber and plastic products	2.2599	0.7069	0.9200	**3.8867**	-0.0683	0.1716	0.2242	**0.3275**
S18	Manufacture of other non-metallic mineral products	0.2046	0.1033	0.1651	**0.4730**	-0.3807	0.4717	0.7567	**0.8478**
S19	Manufacture of basic metals	-2.3000	-0.1699	1.0969	**-1.3730**	-0.3020	-0.1076	0.6869	**0.2773**
S20	Manufacture of fabricated metal products, except machinery and equipment	-0.5711	0.4728	0.5713	**0.4731**	-0.1676	0.3274	0.3954	**0.5553**
S21	Manufacture of machinery and equipment	-1.0547	1.4123	1.3318	**1.6894**	-0.6962	0.8802	0.8301	**1.0141**
S22	Manufacture of office machinery and computers	0.1150	0.4855	0.3900	**0.9906**	-0.0734	0.2759	0.2214	**0.4240**
S23	Manufacture of electrical machinery and apparatus	0.3968	0.6964	0.8141	**1.9073**	-0.1206	0.2789	0.3263	**0.4846**
S24	Manufacture of radio, television and communication equipment and apparatus	0.0772	0.9034	0.5159	**1.4965**	-0.1672	0.5951	0.3389	**0.7669**
S25	Manufacture of medical, precision and optical instruments, watches and clocks	0.0634	0.2479	0.2773	**0.5886**	-0.0735	0.1477	0.1653	**0.2394**
S26	Manufacture of motor vehicles, trailers, and semi-trailers	3.6237	4.7302	4.7714	**13.1253**	-0.7443	2.3348	2.3553	**3.9459**
S27	Manufacture of other transport equipment	0.5077	0.6225	0.4815	**1.6117**	-0.0432	0.3493	0.2697	**0.5758**
S28	Manufacture of furniture	0.5359	-0.0029	0.7046	**1.2375**	-0.1945	-0.0019	0.4710	**0.2746**
S29	Recycling	*	*	*	*	*	*	*	*
S30	Electricity, gas, steam, and hot water supply	0.0402	0.0195	0.0857	**0.1455**	-1.0586	0.4254	1.8760	**1.2428**
S31	Collection, purification, and distribution of water	0.0249	-0.0382	0.0419	**0.0286**	-0.0440	-0.0598	0.0666	**-0.0372**
S32	Construction	2.6104	-0.5129	2.6183	**4.7158**	-1.0026	-0.6625	3.4119	**1.7467**
S33	Wholesale and retail trade; repair of motor vehicles, motorcycles, and personal and household goods	6.3761	-0.4289	1.9046	**7.8518**	1.2561	-0.3334	1.5062	**2.4289**
S34	Hotels and restaurants	1.6500	-0.8218	1.0398	**1.8681**	-0.9866	-1.4669	1.8961	**-0.5574**
S35	Land transport; transport via pipelines	0.3518	0.0020	0.1284	**0.4821**	-0.1106	0.0064	0.4214	**0.3171**
S36	Water transport	0.0395	-0.0200	0.0245	**0.0440**	-0.0552	-0.1125	0.1407	**-0.0270**
S37	Air transport	0.1282	0.0560	0.0542	**0.2383**	-0.0209	0.3254	0.3150	**0.6195**
S38	Supporting and auxiliary transport activities; activities of travel agencies	0.3001	0.0197	0.1019	**0.4217**	-0.0435	0.0242	0.1273	**0.1080**
S39	Post and telecommunications	0.2129	0.0663	0.0527	**0.3318**	0.1871	0.1173	0.0929	**0.3973**
S40	Financial intermediation	0.0814	0.0743	0.0826	**0.2382**	-0.1551	0.1527	0.1700	**0.1676**
S41	Real estate, renting, and business activities	1.7371	-0.0732	0.8346	**2.4985**	0.3820	-0.0725	0.8350	**1.1444**
S42	Public administration and defence; compulsory social security	0.5052	-0.2378	0.4001	**0.6675**	0.0526	-0.3584	0.6095	**0.3036**
S43	Education	0.2709	-0.0791	0.1575	**0.3494**	0.0196	-0.1314	0.2655	**0.1536**
S44	Health and social work	1.6494	-0.6472	1.6541	**2.6563**	-0.2046	-0.2692	0.6951	**0.2213**
S45	Other community, social, and personal service activities	0.5006	-0.0170	0.3305	**0.8141**	-0.0100	-0.0266	0.5221	**0.4855**
S46	Private households with employed persons	0.0000	0.0000	0.0000	**0.0000**	0.0000	0.0000	0.0000	**0.0000**

Source: own elaboration from 1995 and 2000 Spanish NAMEA.

*: Information not available because in 1995 NAMEA there is not information about Recycling sector.

Table 3.3: Sectorial SDA for other three gases, Spain 1995-2000

Units: %

		SO_2				NO_x				NH_3			
		$\mathbf{J}^{effect}/\mathbf{r}_{95}$	$\psi^{effect}/\mathbf{r}_{95}$	$\varphi^{effect}/\mathbf{r}_{95}$	$\Delta\mathbf{r}/\mathbf{r}_{95}$	$\mathbf{J}^{effect}/\mathbf{r}_{95}$	$\psi^{effect}/\mathbf{r}_{95}$	$\varphi^{effect}/\mathbf{r}_{95}$	$\Delta\mathbf{r}/\mathbf{r}_{95}$	$\mathbf{J}^{effect}/\mathbf{r}_{95}$	$\psi^{effect}/\mathbf{r}_{95}$	$\varphi^{effect}/\mathbf{r}_{95}$	$\Delta\mathbf{r}/\mathbf{r}_{95}$
S1	Agriculture, hunting, and related services activities	-0.5163	0.0297	0.3608	**-0.1257**	-0.6345	0.1440	1.7382	**1.2477**	0.6745	0.6571	7.9131	**9.2447**
S2	Forestry, logging, and related services activities	-0.0007	-0.0009	0.0021	**0.0005**	0.0116	-0.0085	0.0192	**0.0223**	0.0441	-0.0153	0.0344	**0.0631**
S3	Fishing	-0.1355	0.0438	0.0858	**-0.0059**	-0.5835	0.3869	0.7568	**0.5602**	0.0297	0.0195	0.0380	**0.0872**
S4	Mining of coal and lignite; extraction of peat	-0.0024	-0.0081	0.0015	**-0.0090**	0.0001	-0.0094	0.0016	**-0.0077**	0.0001	-0.0006	0.0001	**-0.0004**
S5	Extraction of crude petroleum, natural gas; uranium and thorium ores	-0.0002	-0.0003	0.0001	**-0.0005**	0.0005	-0.0019	0.0005	**-0.0009**	0.0000	0.0000	0.0000	**0.0000**
S6	Mining of metal ores	-0.0009	-0.0012	0.0022	**0.0000**	0.0113	-0.0069	0.0121	**0.0164**	0.0008	-0.0002	0.0004	**0.0009**
S7	Other mining and quarrying	-0.0519	0.0017	0.0235	**-0.0267**	-0.0257	0.0016	0.0225	**-0.0017**	0.0023	0.0002	0.0022	**0.0046**
S8	Manufacture of food products, beverages, and tobacco	-2.1532	-0.4141	1.4753	**-1.0920**	-2.4228	-1.2052	4.2653	**0.6372**	0.4213	-3.2097	11.3086	**8.5202**
S9	Manufacture of textile	-0.5173	0.0011	0.2777	**-0.2385**	-0.1939	0.0010	0.2619	**0.0690**	-0.1898	0.0012	0.3001	**0.1114**
S10	Manufacture of wearing apparel; dressing, and dyeing of fur	-0.5438	0.0030	0.3460	**-0.1949**	-0.1912	0.0028	0.3290	**0.1406**	-0.1151	0.0025	0.2914	**0.1788**
S11	Tanning and dressing of leather; manufac. of luggage, handbags, saddler, harness, and foot.	-0.3374	-0.0064	0.1840	**-0.1599**	-0.1489	-0.0069	0.1947	**0.0390**	-0.0428	-0.0074	0.2084	**0.1582**
S12	Manufacture of wood and of products of wood and cork, except furniture	-0.0548	0.0242	0.0369	**0.0063**	-0.0185	0.0401	0.0610	**0.0826**	0.0397	0.0203	0.0307	**0.0906**
S13	Manufacture of pulp, paper, and paper products	-0.1990	0.0070	0.1738	**-0.0181**	-0.0253	0.0064	0.1590	**0.1402**	0.0105	0.0022	0.0547	**0.0674**
S14	Publishing, printing, and reproduction of recorded media	-0.3878	0.0048	0.1900	**-0.1930**	-0.1819	0.0040	0.1586	**-0.0193**	-0.0208	0.0013	0.0525	**0.0330**
S15	Manufacture of coke, refined petroleum products, and nuclear fuel	-2.8718	0.9611	1.4678	**-0.4429**	-3.0143	0.5609	0.8592	**-1.5942**	-0.0142	0.0204	0.0311	**0.0372**
S16	Manufacture of chemicals and chemicals products	-2.9181	0.8224	1.5745	**-0.5212**	-0.8752	0.5541	1.0577	**0.7366**	-0.5702	0.4772	0.9106	**0.8176**
S17	Manufacture of rubber and plastic products	-0.4186	0.1792	0.2345	**-0.0049**	-0.1304	0.1267	0.1655	**0.1618**	-0.0215	0.0611	0.0798	**0.1194**
S18	Manufacture of other non-metallic mineral products	-0.7521	0.3294	0.5296	**0.1070**	-0.3070	0.3175	0.5094	**0.5199**	0.0137	0.0132	0.0211	**0.0479**
S19	Manufacture of basic metals	-0.8359	-0.1005	0.6453	**-0.2910**	-0.0293	-0.0790	0.5030	**0.3947**	0.0045	-0.0059	0.0373	**0.0359**
S20	Manufacture of fabricated metal products, except machinery and equipment	-0.5867	0.3322	0.4016	**0.1470**	-0.1435	0.2754	0.3326	**0.4645**	0.0161	0.0333	0.0401	**0.0895**
S21	Manufacture of machinery and equipment	-1.6324	0.8620	0.8126	**0.0421**	-0.5554	0.7349	0.6930	**0.8725**	0.0256	0.1123	0.1059	**0.2438**
S22	Manufacture of office machinery and computers	-0.3024	0.2656	0.2128	**0.1759**	-0.0818	0.2390	0.1918	**0.3491**	0.0056	0.0456	0.0366	**0.0878**
S23	Manufacture of electrical machinery and apparatus	-0.4948	0.2680	0.3139	**0.0872**	-0.1625	0.2428	0.2841	**0.3644**	0.0038	0.0320	0.0375	**0.0732**
S24	Manufacture of radio, television and communication equipment and apparatus	-0.5689	0.5971	0.3383	**0.3665**	-0.1823	0.4951	0.2818	**0.5946**	0.0056	0.0763	0.0436	**0.1256**
S25	Manufacture of medical, precision and optical instruments, watches and clocks	-0.2456	0.1448	0.1622	**0.0614**	-0.0945	0.1295	0.1449	**0.1799**	-0.0027	0.0218	0.0244	**0.0435**
S26	Manufacture of motor vehicles, trailers, and semi-trailers	-3.4840	2.3740	2.3950	**1.2851**	-0.6881	1.8501	1.8663	**3.0283**	-0.0501	0.3674	0.3706	**0.6880**
S27	Manufacture of other transport equipment	-0.3583	0.3397	0.2617	**0.2431**	-0.0477	0.2711	0.2093	**0.4327**	0.0033	0.0505	0.0390	**0.0928**
S28	Manufacture of furniture	-0.7259	-0.0017	0.4137	**-0.3139**	-0.2853	-0.0019	0.4773	**0.1900**	0.0502	-0.0006	0.1431	**0.1928**
S29	Recycling	*	*	*	*	*	*	*	*	*	*	*	*
S30	Electricity, gas, steam, and hot water supply	-5.5998	0.7614	3.3740	**-1.4644**	-1.5560	0.3646	1.6107	**0.4193**	0.0078	0.0035	0.0155	**0.0268**
S31	Collection, purification, and distribution of water	-0.1822	-0.0852	0.0961	**-0.1713**	-0.0538	-0.0462	0.0517	**-0.0484**	0.0012	-0.0050	0.0055	**0.0018**
S32	Construction	-3.8024	-0.5214	2.7053	**-1.6184**	-1.5617	-0.5656	2.9176	**0.7903**	0.3786	-0.1438	0.7365	**0.9713**
S33	Wholesale and retail trade; repair of motor vehicles, motorcy., and personal and hous. goods	-0.9212	-0.3207	1.4638	**0.2219**	0.4387	-0.3319	1.5051	**1.6119**	2.9694	-0.1488	0.6556	**3.4761**
S34	Hotels and restaurants	-2.0562	-0.9737	1.2728	**-1.7570**	-2.0503	-1.7150	2.2259	**-1.5394**	-1.7789	-3.2694	4.2218	**-0.8265**
S35	Land transport; transport via pipelines	-0.4239	0.0037	0.2476	**-0.1725**	-0.6697	0.0097	0.6404	**-0.0196**	0.0579	0.0005	0.0323	**0.0908**
S36	Water transport	-0.2443	-0.1565	0.1975	**-0.2033**	-0.2254	-0.4302	0.5381	**-0.1175**	-0.0156	-0.0096	0.0121	**-0.0131**
S37	Air transport	-0.2436	0.1306	0.1264	**0.0134**	-0.1299	0.2845	0.2754	**0.4301**	-0.0203	0.0202	0.0196	**0.0195**
S38	Supporting and auxiliary transport activities; activities of travel agencies	-0.1698	0.0197	0.1039	**-0.0462**	-0.1074	0.0306	0.1611	**0.0844**	-0.0147	0.0062	0.0324	**0.0238**
S39	Post and telecommunications	0.0757	0.1251	0.0990	**0.2999**	0.1259	0.0997	0.0790	**0.3045**	0.0517	0.0172	0.0137	**0.0825**
S40	Financial intermediation	-0.4413	0.1898	0.2114	**-0.0401**	-0.1835	0.1280	0.1426	**0.0871**	0.0008	0.0317	0.0353	**0.0678**
S41	Real estate, renting, and business activities	-0.6271	-0.0753	0.8730	**0.1706**	0.0865	-0.0631	0.7286	**0.7520**	0.4713	-0.0232	0.2646	**0.7128**
S42	Public administration and defence; compulsory social security	-0.7183	-0.4512	0.7743	**-0.3951**	-0.1158	-0.3044	0.5191	**0.0988**	0.1497	-0.0997	0.1682	**0.2182**
S43	Education	-0.3138	-0.1612	0.3285	**-0.1465**	-0.0548	-0.1060	0.2147	**0.0539**	0.1663	-0.0404	0.0802	**0.2061**
S44	Health and social work	-0.9353	-0.2670	0.6952	**-0.5071**	-0.3286	-0.1980	0.5126	**-0.0140**	-0.0542	-0.1387	0.3576	**0.1648**
S45	Other community, social, and personal service activities	-0.5041	-0.0201	0.3965	**-0.1277**	-0.1046	-0.0219	0.4295	**0.3030**	1.5571	-0.0594	1.1556	**2.6534**
S46	Private households with employed persons	0.0000	0.0000	0.0000	**0.0000**	0.0000	0.0000	0.0000	**0.0000**	0.0000	0.0000	0.0000	**0.0000**

Source: own elaboration from 1995 and 2000 Spanish NAMEA.

*: Information not available because in 1995 NAMEA there is not information about Recycling sector.

mainly due to eco-technological changes of (S30) ‘Electricity, gas, steam, and hot water supply’. The only exception to this trend is (S39) ‘Post and telecommunications’ whose eco-technological effect has provoked an increase of SO_2 emissions; however, the effect of this sector is practically negligible to the total eco-technological effect. On the other hand, the eco-technological effect causes an increase of synthetic greenhouse gas emissions. That is, there is an upward of emissions in all sectors with the exception of (S19) ‘Manufacture of basic metals’, (S20) ‘Manufacture of fabricated metal products, except machinery and equipment’, and (S21) ‘Manufacture of machinery and equipment’.

3.5. Final remarks

The purpose of this chapter was to analyse the driving forces of the evolution of atmospheric pollution in Spain from 1995 to 2000. In connection with the environmental Kuznets curve debate, we have decomposed the change in emissions into three main ‘sources’. First, the eco-technological effect that includes changes in technical coefficients and emission coefficients, i.e. shifts in total intensity of emissions matrix. Second, changes in the composition of final uses, i.e. the structure effect. And third, changes in the level of final uses, i.e. the level effect. We quantified the effects of these three determinants through performing a structural decomposition analysis (SDA) for nine different gases. On one hand, the six greenhouse gases CO_2, CH_4, N_2O, SF_6, HFCs, and PFCs; and on the other, three local gases SO_2, NO_x, and NH_3.

Since there are several methods for decomposing the total emission variation into its underlying factors, we executed the SDA applying the techniques proposed by Sun (1998) and Dietzenbacher and Los (1998), respectively. Both techniques are equivalent in the sense that they lead to the same decomposition and also fulfil the complete decomposition, the time reversal, and the zero value robust properties.

In order to avoid the influence of price variations when analysing changes between different input-output tables over time, it is necessary to deflate the 2000 Spanish input-output table. We carried out this deflation by applying the ‘heuristic’ approach proposed by Dietzenbacher and Hoen (1998). Thus, we got a symmetrical input-output table for the year 2000 in 1995 constant prices in which each cell of the transaction matrix has a specific price index.

The results of the environmental SDA for Spain show that from 1995 to 2000 all the gases increased their emissions with the only exception of SO_2. Certainly, the source that has more influence on the emission growth was the final use level. On the contrary, changes in the technological and emission coefficients had the opposite effect. So, it can be said that the technological change in Spain had a positive influence on the reduction of emissions in virtually all the gases. The only exceptions to the beneficial effect of technology were NH_3 and, particularly, the group of the three synthetic greenhouse gases. However, the eco-technological effect was only strong enough to counteract the level effect in the case of SO_2. Concerning the structure effect, we can conclude that shifts in the composition of the final uses led to increase emissions in almost all the gases. Nevertheless, we found that this effect provoked a modest reduction of the emissions of those gases connected with agriculture and food activities, i.e. CH_4, N_2O, and NH_3, mainly due to (S8) 'Manufacture of food products, beverages, and tobacco' and (S34) 'Hotels and restaurants', which are the sectors indirectly connected with agricultural activities.

When we performed the environmental structural decomposition analysis by sectors we found that (S33) 'Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and households goods' was, in general, a pollutant sector in all gases; whereas (S34) 'Hotels and restaurants' was the sector that contributed the more to reduce the emissions of almost all gases. On the whole, the level effect always was positive irrespectively the gas and the sector considered. The tendency of the structure effect in each sector was the same for all gases. Finally, the eco-technological effect was the only one that present different results through both sectors and gases.

One of the advantages of SDA stems from the fact that it is developed within input-output approach that allows assessment of direct and indirect emissions. Consequently, it could aid policy makers to design technology and/or demand policies directed towards more friendly environmental economy. From the results of this study we are drawn to the conclusion that Spain would need to implement urgently policies aimed at shifting the level and structure of final uses. However, the execution of measures to reduce the level of consumption does not seem to be very popular either in political or economical terms. The other alternative seems to be more feasible; hence, policy makers may direct their actions towards altering the composition of final uses. Nevertheless, the combination of technology and demand policies should probably be the best option to achieve the reduction of gas emissions. A good example of this is the case of SO_2 in which the policies that target technological developments manage to counteract the effect of the level of final uses.

In this chapter, however, we considered all the components of the final uses together; so, it is not possible to determine which of them had more influence. Since the final consumption expenditure by households is the most important component[95], it would be worth to analyse more in depth the emissions associated with household consumption. This topic will be consider in Chapter 4. Another interesting study would be to analyse the influence of shifting trade patterns on the evolution of emission. For doing so, we would need to perform a SDA broken down the total intersectorial transaction matrix into domestic and imported matrices. However, due to the Spanish data availability is not possible to get a satisfactory estimation of these matrices. Nevertheless, in Chapter 5 we will focus on this issue from another perspective.

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[95] It represents more than the 40% of total final uses in both years 1995 and 2000.

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Appendix

3.A. Description of the deflation process

Once the 2000 symmetrical input-output table has been estimated (see Chapter 2) the next step is to deflate each component of final uses as well as the sectorial value added and output vectors. In this appendix we describe the deflation process of each of these elements.

Value added vector ($\mathbf{v}$): The INE provides the value added of each sector of the year 2000 in current and 1995 constant prices. However, this information is referring to non-homogeneous sectors whereas in a symmetrical input-output table we have homogeneous sectors. Therefore, from the 2000 value added in current and constant prices we calculate the implicit price index of value added for each sector, including the FISIM sector, and we use this price index to estimate the value added in constant price of the homogeneous sectors of the 2000 symmetrical input-output table.

Output vector ($\mathbf{x}$): Since we do not have any information about the sectorial output in constant price, we estimated it applying the above implicit price index of the value added.

Final consumption expenditure by household vector ($\mathbf{c}$): In this case total purchases on the domestic territory by non-residents, total purchases abroad by residents, and total final consumption expenditure are in constant prices. We have also information about final consumption expenditure on 47 COICOP groups. However, this information refers to constant and purchasers' prices but what we need is the consumption expenditure on CPA categories valued at constant and basic prices. For obtaining this we apply the transformation matrix to the consumption expenditure COICOP groups[96].

Final consumption expenditure by non-profit institutions serving households vector ($\mathbf{npish}$): The only information we have in constant prices is the total of final consumption expenditure by NPISH. So, from the final consumption expenditure by

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[96] COICOP is the acronym for Classification of Individual Consumption by Purpose. The transformation matrix is a composition matrix of aggregated commodity consumption that relates 46 CPA categories with 47 COICOP groups. For a detailed description of this matrix and see Chapter 4.

household vector in current and constant prices estimated above, we calculate the implicit consumer price indices and we apply these price indices to the **npish** vector.

Final consumption expenditure by government vector ($\mathbf{g}$): We have the final consumption expenditure of government by components and the total of this consumption in current and constant prices. So, we calculate the implicit price indices of the components and we apply them to the $\mathbf{g}$ vector.

Gross capital formation vector ($\mathbf{gcf}$): As in the previous case we have the gross capital formation by components and the total of the gross capital formation in current and constant prices. So, we follow the same process: we calculate the implicit price indices of the components and apply them to the $\mathbf{gcf}$ vector.

Import ($\mathbf{m}$) and export ($\mathbf{e}$) vectors: From the Spanish national account framework we only have at our disposal the total of exports and imports at current and constant price. However, the INE publishes the import and export prices indices base 2000 from 1990 to 2007. From this information we estimate the import and export vectors at constant prices.

When all vectors have been deflate and adjusted we proceed to apply the RAS method in order to obtain the transaction matrix in constant prices $\widetilde{\mathbf{Z}}$. The RAS method is a biproportional iterative routine developed to adjust a given matrix to exogenously given row and column sums. The adjustment is iterative, first the rows are adjusted and then the columns, and under mild conditions it converges. This method was developed in other fields but it was introduced in input-output approach by Stone (1961) with the aim of updating the direct input coefficient matrix $\mathbf{A}$. One of the features of the simplest version of the RAS method is that zero are not adjusted and hence they remain zero; however, when additional information is available this can be introduced in order to adjust the zero cells. The RAS method can also be reformulated as an optimization problem with a specific objective function. In this work, however, we apply the simply version[97].

3.B. 2000 Spanish symmetrical input-output table at 1995 constant prices

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[97] For technical aspects see Bacharach (1970), Macgill (1977, 1979), or Golan *et al.* (1994).

Table 3.B.1: 2000 Spanish symmetrical input-output table in 1995 million of euros (continues ...)

		Homogeneous sectors											
		S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**
S1	Agriculture, hunting, and related services activities	4073.95	36.40	19.00	0.00	0.00	0.00	0.09	20575.77	471.37	43.36	13.32	0.62
S2	Forestry, logging, and related services activities	11.06	0.26	0.00	0.00	0.00	0.00	0.04	1.23	0.10	0.01	4.47	556.25
S3	Fishing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	771.54	0.04	0.01	0.02	0.01
S4	Mining of coal and lignite; extraction of peat	0.23	0.00	0.06	0.00	0.00	0.00	2.47	0.03	0.01	0.00	0.00	0.00
S5	Extraction of crude petroleum, natural gas; uranium and thorium ores	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S6	Mining of metal ores	0.00	0.00	0.00	0.00	0.00	0.00	5.98	0.07	0.04	0.00	0.00	0.01
S7	Other mining and quarrying	0.68	0.00	4.85	0.37	0.00	0.00	13.70	8.35	6.22	0.06	0.01	0.20
S8	Manufacture of food products, beverages, and tobacco	5454.81	37.72	143.17	0.00	0.00	0.00	0.32	11655.05	1.00	28.09	412.88	0.18
S9	Manufacture of textile	17.37	0.20	46.79	0.00	0.00	0.00	0.73	88.23	2548.84	2595.08	138.92	10.17
S10	Manufacture of wearing apparel; dressing, and dyeing of fur	26.36	0.50	9.11	1.81	0.81	0.00	0.37	50.53	6.63	735.68	3.22	0.28
S11	Tanning and dressing of leather; manufac. of luggage, handbags, saddler, harness, and...	0.13	0.08	9.75	2.39	0.24	0.00	0.01	2.96	2.05	194.67	2488.49	3.70
S12	Manufacture of wood and of products of wood and cork, except furniture	172.50	1.51	12.69	45.59	0.00	6.80	4.87	423.46	6.47	0.54	38.96	2958.38
S13	Manufacture of pulp, paper, and paper products	48.65	0.35	2.35	0.00	0.05	0.00	2.26	912.10	60.36	37.61	70.80	124.80
S14	Publishing, printing, and reproduction of recorded media	4.74	0.07	0.68	0.84	0.00	0.00	0.81	73.89	6.51	3.48	4.52	13.03
S15	Manufacture of coke, refined petroleum products, and nuclear fuel	290.07	4.68	74.03	17.67	1.90	2.17	55.54	138.69	22.05	18.72	11.98	15.76
S16	Manufacture of chemicals and chemicals products	1758.94	17.99	22.96	29.12	0.98	11.92	143.01	665.74	1139.24	101.68	103.37	183.46
S17	Manufacture of rubber and plastic products	260.77	3.13	31.20	6.78	0.89	0.00	18.91	1052.76	90.94	16.37	359.99	40.55
S18	Manufacture of other non-metallic mineral products	64.06	1.51	1.06	5.24	0.37	0.20	11.17	895.15	0.95	0.31	0.09	11.93
S19	Manufacture of basic metals	0.00	0.00	0.00	10.45	0.56	5.84	19.44	0.60	7.24	0.54	2.48	15.93
S20	Manufacture of fabricated metal products, except machinery and equipment	758.81	9.01	27.16	17.35	2.34	11.17	99.10	862.69	68.10	33.24	39.65	186.11
S21	Manufacture of machinery and equipment	329.67	6.28	1.62	40.61	2.23	21.38	100.67	109.61	161.22	92.10	48.75	228.76
S22	Manufacture of office machinery and computers	1.34	0.01	1.42	0.00	0.00	0.11	0.01	5.52	6.09	0.57	0.27	0.28
S23	Manufacture of electrical machinery and apparatus	7.67	0.21	1.33	0.88	0.00	0.00	3.67	18.56	8.44	0.50	0.12	3.35
S24	Manufacture of radio, television and communication equipment and apparatus	0.09	0.00	0.00	0.00	0.00	0.00	0.00	6.36	0.86	0.67	0.26	0.12
S25	Manufacture of medical, precision and optical instruments, watches and clocks	0.02	0.00	2.50	0.00	0.00	0.00	0.00	0.43	0.11	0.49	0.03	0.01
S26	Manufacture of motor vehicles, trailers, and semi-trailers	2.12	0.96	2.05	0.44	0.12	0.00	0.07	77.66	15.12	5.41	0.93	0.90
S27	Manufacture of other transport equipment	4.20	0.29	162.18	5.87	0.00	1.38	2.13	23.61	0.14	0.10	0.05	0.10
S28	Manufacture of furniture	0.93	0.09	0.78	0.00	0.00	0.37	0.67	2.16	2.54	2.85	0.31	5.67
S29	Recycling	0.02	0.00	0.00	0.00	0.00	0.00	1.89	0.00	0.01	0.00	0.00	0.01
S30	Electricity, gas, steam, and hot water supply	323.17	2.92	31.68	54.60	2.16	2.78	129.86	687.53	215.53	77.20	47.73	111.74
S31	Collection, purification, and distribution of water	332.08	2.66	4.64	0.13	0.00	0.07	7.66	141.95	11.26	5.60	1.30	2.62
S32	Construction	199.65	3.09	1.28	3.56	0.11	1.04	30.01	105.63	33.55	5.91	7.06	8.34
S33	Wholesale and retail trade; repair of motor vehicles, motorcycles, and personal and...	1391.98	25.08	96.15	4.55	1.61	1.58	83.36	1869.75	254.18	244.40	372.59	377.49
S34	Hotels and restaurants	24.31	0.65	1.74	0.33	0.31	0.00	1.47	45.81	4.33	2.92	8.55	7.04
S35	Land transport; transport via pipelines	591.22	7.72	25.79	36.90	0.37	6.04	205.24	2410.64	254.05	113.57	69.47	387.86
S36	Water transport	29.34	1.71	0.80	1.54	0.88	0.00	0.30	95.63	12.41	4.63	6.22	3.99
S37	Air transport	9.26	0.08	6.47	1.04	0.38	0.18	1.94	69.52	3.65	14.56	7.41	9.18
S38	Supporting and auxiliary transport activities; activities of travel agencies	217.86	2.01	141.48	13.89	0.13	1.47	124.97	512.26	54.41	35.20	15.68	77.93
S39	Post and telecommunications	49.90	1.48	32.57	13.20	0.24	2.19	20.02	392.13	59.69	95.81	30.63	47.18
S40	Financial intermediation	137.93	5.43	20.81	3.09	0.92	1.27	4.62	130.10	28.17	11.74	8.05	20.98
S41	Real estate, renting, and business activities	184.38	6.96	62.01	31.40	11.68	7.85	125.88	3197.80	382.58	305.47	294.59	225.06
S42	Public administration and defence; compulsory social security	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S43	Education	4.79	1.01	1.91	0.69	0.46	0.60	0.34	58.86	9.26	6.88	3.56	4.20
S44	Health and social work	181.10	4.55	7.41	1.45	0.05	0.16	2.48	116.26	8.27	12.89	8.99	10.53
S45	Other community, social, and personal service activities	51.21	0.49	2.92	0.37	0.00	0.08	0.49	71.48	4.78	1.53	3.71	0.65
S46	Private households with employed persons	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FISIM	Financial intermediation services indirectly measured	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R1	Net taxes on products	-321.67	3.58	11.04	12.98	1.59	2.23	42.18	-1567.71	-136.48	48.61	23.20	-21.20
R2	FOB/CIF adjustment												
R3	Purchases on the domestic territory by non-residents												
R4	Direct purchases abroad by residents												
R5	Total intermediate consumption at purchases prices	16,695.72	190.68	1,025.45	365.12	31.38	88.90	1,268.75	46,760.41	5,832.31	4,899.06	4,652.62	5,634.18
R6	Value added at basic prices	18,893.79	603.31	1,153.74	858.36	85.02	80.90	946.29	15,146.65	2,978.87	2,474.50	1,694.43	2,530.48
R7	Output at basic prices	35,589.52	793.99	2,179.18	1,223.49	116.40	169.79	2,215.04	61,907.06	8,811.18	7,373.56	6,347.04	8,164.66
R8	Total imports	5,418.19	387.79	860.27	363.91	85.09	1,212.24	434.15	10,610.79	3,442.21	3,604.86	1,662.13	1,752.91
R9	**Total supply**	**41,007.71**	**1,181.78**	**3,039.46**	**1,587.39**	**201.48**	**1,382.03**	**2,649.18**	**72,517.85**	**12,253.39**	**10,978.42**	**8,009.18**	**9,917.57**

Table 3.B.1: 2000 Spanish symmetrical input-output table in 1995 million of euros (... continues ...)

	Homogeneous sectors																
	S13	**S14**	**S15**	**S16**	**S17**	**S18**	**S19**	**S20**	**S21**	**S22**	**S23**	**S24**	**S25**	**S26**	**S27**	**S28**	**S29**
S1	25.96	1.08	1.12	44.72	3.83	0.96	0.16	5.71	12.31	1.29	0.65	1.39	0.04	0.07	0.06	14.86	0.00
S2	319.68	2.13	0.00	17.89	84.08	0.14	0.10	0.95	0.64	0.08	0.10	0.03	0.02	0.00	0.01	5.55	0.00
S3	0.04	0.06	0.00	1.23	0.03	0.02	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S4	0.00	0.05	23.06	9.56	0.09	5.42	70.90	0.81	0.14	0.00	1.92	0.07	0.01	0.00	0.00	0.01	0.00
S5	0.00	0.00	180.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
S6	0.08	0.02	0.00	50.60	1.19	0.09	1229.10	13.70	4.57	0.00	0.52	0.00	0.04	0.01	0.01	1.26	0.00
S7	14.39	0.15	0.00	210.19	3.13	1360.22	96.84	9.42	8.52	0.01	3.35	0.03	0.16	0.01	0.05	11.13	0.00
S8	35.80	1.91	0.00	161.47	0.95	0.53	0.03	0.46	4.25	0.10	0.10	0.11	0.09	0.00	0.02	0.20	0.00
S9	18.40	20.09	0.00	320.57	159.77	17.95	1.89	62.75	12.25	0.63	4.78	0.80	0.96	384.02	35.10	209.81	0.05
S10	6.07	5.12	3.17	22.59	8.77	29.57	40.69	53.63	61.82	13.28	20.75	0.37	0.64	50.90	1.29	3.24	0.77
S11	0.06	0.42	1.39	1.19	1.06	0.40	0.05	0.34	0.39	0.03	0.05	0.06	0.03	0.00	0.07	37.50	0.00
S12	77.59	30.23	1.39	29.76	25.44	256.60	22.47	194.47	88.34	0.38	22.62	7.15	3.56	44.03	30.36	1877.72	3.58
S13	2559.30	2763.87	25.95	725.27	167.40	207.13	7.96	73.26	65.40	30.24	65.43	5.37	4.50	47.23	10.35	154.79	4.02
S14	42.36	1664.42	87.29	316.37	24.80	46.14	19.39	36.24	31.76	14.18	27.80	10.38	12.90	42.29	6.64	24.22	0.00
S15	32.48	10.41	1605.14	850.22	39.47	252.68	77.17	50.60	43.95	3.32	20.71	5.99	4.64	37.10	26.16	12.96	3.70
S16	369.64	321.43	370.96	6955.39	2942.02	566.46	744.17	634.04	274.31	51.93	303.32	25.94	21.28	924.67	145.14	247.83	2.85
S17	82.89	25.13	24.91	656.73	2039.85	144.61	96.32	258.71	335.30	78.96	537.74	150.15	25.14	2948.05	422.51	229.35	3.52
S18	0.23	0.63	33.73	155.16	31.45	1807.43	215.92	117.93	69.32	24.11	69.32	16.79	20.00	347.91	50.28	75.73	2.03
S19	16.72	7.26	32.59	42.18	52.66	292.09	2593.56	6119.05	1680.14	107.80	1985.27	149.02	89.42	4301.39	647.27	709.64	29.09
S20	143.27	41.20	313.17	627.29	132.61	513.66	2610.05	2139.54	2008.55	67.97	513.12	63.72	28.06	1477.10	247.72	322.88	131.95
S21	323.58	58.46	422.98	1028.51	393.29	955.24	770.08	1755.97	1381.62	1.14	148.66	37.24	31.47	991.32	382.27	201.93	6.97
S22	0.30	1.12	4.29	8.50	0.41	0.70	0.26	2.53	2.40	972.98	5.17	0.96	1.05	23.06	3.14	0.58	3.66
S23	2.34	0.99	48.52	57.71	28.08	70.89	85.13	182.51	1742.79	189.26	1983.92	513.54	311.84	984.05	153.09	46.21	0.21
S24	0.36	0.51	0.00	4.49	3.45	0.54	0.84	6.78	27.98	147.61	38.22	2077.13	730.46	233.86	127.89	0.55	0.00
S25	0.01	2.09	1.47	0.11	0.49	0.73	0.11	0.70	7.13	0.29	3.40	1.03	108.12	23.68	15.93	0.06	0.00
S26	1.39	0.92	5.55	4.57	8.51	76.28	5.23	100.33	178.47	6.04	21.80	5.47	9.07	17328.69	171.08	3.45	8.90
S27	0.05	2.24	4.83	0.53	0.43	1.94	1.18	6.85	9.70	0.10	0.09	0.12	0.28	0.45	667.80	0.29	0.80
S28	0.25	3.15	4.85	3.72	0.98	9.65	9.97	37.88	8.76	5.77	1.32	1.18	1.34	235.86	1.82	856.69	1.91
S29	66.42	0.42	0.00	2.30	0.58	6.66	394.51	4.40	0.64	0.01	0.16	0.00	0.03	0.00	0.00	0.08	0.00
S30	456.42	158.16	1279.17	1005.13	330.85	1018.36	1013.86	616.03	126.91	23.78	127.55	44.40	22.52	457.51	55.16	66.63	13.01
S31	4.19	5.98	110.68	86.98	6.41	29.27	28.96	26.20	8.85	1.32	3.39	1.34	0.57	15.22	1.03	2.88	3.67
S32	118.02	18.78	114.90	125.03	20.67	124.42	92.27	73.07	52.21	5.90	45.84	5.62	11.05	67.63	17.65	21.73	7.37
S33	576.95	377.17	174.27	1026.20	448.12	583.51	693.20	917.53	558.23	23.59	234.43	63.55	107.00	563.79	101.15	839.85	53.71
S34	7.34	19.09	58.27	380.20	23.70	13.85	24.25	58.15	42.37	1.29	18.35	8.30	7.01	45.54	9.73	8.78	0.90
S35	482.55	220.81	1573.39	913.16	327.26	1667.57	728.10	686.54	383.84	19.95	188.87	36.10	18.61	481.27	57.95	296.13	26.86
S36	16.57	7.33	62.42	66.85	17.63	25.98	22.29	41.36	30.04	0.12	11.31	0.39	0.22	49.97	0.12	13.40	2.15
S37	19.18	15.33	112.51	152.63	33.04	27.60	31.16	57.37	65.49	9.12	40.49	16.12	13.99	51.51	17.52	14.71	0.90
S38	94.51	100.69	467.96	286.10	109.01	286.68	316.26	204.61	147.06	17.07	99.95	28.18	14.76	132.40	63.63	57.16	5.26
S39	100.13	255.74	246.90	350.16	76.30	133.85	172.20	181.08	215.46	51.11	89.66	28.07	28.34	107.04	39.98	81.86	0.86
S40	31.51	26.86	236.95	99.03	48.69	63.05	63.27	68.18	75.15	3.45	16.64	14.07	4.48	39.83	15.13	24.10	0.43
S41	381.71	535.71	2025.79	2909.58	389.87	1412.28	707.05	1128.41	1062.60	280.64	736.90	414.61	140.89	1354.00	378.50	538.13	15.53
S42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S43	7.18	30.11	118.61	84.54	25.43	25.62	25.81	19.16	19.99	9.14	9.36	14.18	4.28	38.88	13.08	5.21	0.04
S44	7.44	14.28	45.70	37.49	7.09	22.32	15.06	28.16	19.93	0.52	3.02	5.29	1.23	14.87	3.34	9.78	0.04
S45	1.76	192.38	132.44	66.02	1.23	6.58	6.44	10.94	4.56	0.55	0.35	1.26	0.89	27.36	2.27	4.90	0.04
S46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FISIM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R1	20.46	35.25	769.74	120.73	51.36	261.13	88.44	74.46	72.08	14.69	32.59	30.44	10.87	72.95	24.36	19.41	5.97
R2																	
R3																	
R4																	
R5	6,465.58	6,979.20	10,726.05	20,018.65	8,071.48	12,326.80	13,122.74	16,060.79	10,946.46	2,179.75	7,439.03	3,785.98	1,791.86	33,945.53	3,946.66	7,053.18	340.76
R6	3,139.80	4,465.81	2,129.70	7,828.81	4,590.16	7,508.25	4,088.16	8,445.54	6,974.10	723.75	3,737.43	1,346.71	1,253.42	8,537.40	1,851.50	3,965.02	189.09
R7	9,605.38	11,445.01	12,855.75	27,847.46	12,661.63	19,835.06	17,210.90	24,506.34	17,920.56	2,903.50	11,176.46	5,132.69	3,045.28	42,482.94	5,798.16	11,018.20	529.85
R8	3,480.77	778.30	3,417.95	16,531.64	4,370.86	1,996.40	8,301.47	3,666.38	15,822.67	6,047.71	5,274.33	10,303.72	4,557.79	28,706.42	2,978.34	3,061.60	0.00
R9	**13,086.15**	**12,223.31**	**16,273.70**	**44,379.10**	**17,032.50**	**21,831.46**	**25,512.37**	**28,172.72**	**33,743.23**	**8,951.21**	**16,450.79**	**15,436.41**	**7,603.07**	**71,189.35**	**8,776.50**	**14,079.80**	**529.85**

Table 3.B.1: 2000 Spanish symmetrical input-output table in 1995 million of euros (... continues ...)

	Homogeneous sectors																	
	S30	**S31**	**S32**	**S33**	**S34**	**S35**	**S36**	**S37**	**S38**	**S39**	**S40**	**S41**	**S42**	**S43**	**S44**	**S45**	**S46**	**FISIM**
S1	23.57	0.93	522.87	1334.22	611.65	0.16	0.26	0.00	0.45	5.54	1.14	90.70	69.41	31.03	61.91	194.57	0.00	0.00
S2	1.88	0.03	0.20	15.89	0.01	0.00	0.00	0.00	0.01	0.00	0.00	3.81	2.00	1.15	1.26	0.41	0.00	0.00
S3	0.77	0.06	0.51	22.01	500.27	0.00	0.00	0.00	0.04	1.10	0.07	2.83	4.44	2.46	34.04	8.95	0.00	0.00
S4	1439.69	0.11	6.54	0.95	0.11	2.03	0.00	0.00	0.03	0.00	1.47	7.74	8.14	0.40	0.15	1.31	0.00	0.00
S5	19.91	0.00	0.10	0.01	0.00	0.44	0.00	0.00	0.02	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00
S6	1.71	0.00	0.38	8.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.35	0.00	0.00	0.00	0.00	0.00	0.00
S7	4.34	0.00	466.82	45.78	0.39	0.00	0.00	0.00	0.00	1.68	0.24	16.46	0.36	0.16	0.10	11.47	0.00	0.00
S8	12.02	2.55	54.04	487.13	12375.18	0.07	31.76	0.90	1.66	27.30	1.64	64.08	191.06	136.94	431.79	336.80	0.00	0.00
S9	12.36	0.69	8.03	348.12	99.49	0.56	6.88	0.62	3.50	29.79	1.01	67.42	51.61	5.68	106.45	17.62	0.00	0.00
S10	2.14	7.03	39.97	123.42	35.62	10.02	0.21	24.57	2.33	84.71	0.86	151.43	72.99	15.78	179.20	130.81	0.00	0.00
S11	0.51	0.33	7.82	62.09	1.70	0.13	0.00	0.11	0.09	0.00	0.00	7.48	24.83	0.34	9.07	3.48	0.00	0.00
S12	5.32	0.05	1851.20	177.09	25.89	1.75	0.00	0.00	111.72	24.51	0.96	64.31	3.46	0.33	2.69	72.66	0.00	0.00
S13	42.12	5.56	44.08	408.23	44.24	14.97	0.10	0.10	74.72	73.71	147.45	888.08	205.63	115.29	94.31	76.22	0.00	0.00
S14	93.79	24.04	102.03	559.73	72.21	24.82	0.00	0.20	80.13	146.73	234.12	2557.49	416.76	286.16	245.26	299.42	0.00	0.00
S15	2123.40	23.46	203.39	345.78	111.83	1186.61	69.01	380.24	164.81	62.92	35.60	199.07	96.72	86.40	119.33	104.51	0.00	0.00
S16	58.84	97.56	983.87	1132.96	153.67	21.79	4.22	0.19	148.61	0.81	18.28	705.63	195.97	93.31	2360.99	265.59	0.00	0.00
S17	24.11	8.55	1182.30	702.06	14.76	51.35	0.00	0.00	206.27	9.06	9.80	183.05	18.12	4.31	39.35	86.71	0.00	0.00
S18	149.48	8.28	12159.91	313.59	94.24	8.41	0.00	0.00	59.28	376.61	1.50	174.06	12.25	5.87	117.47	29.14	0.00	0.00
S19	28.20	31.81	727.35	393.76	0.58	1.33	0.00	0.00	0.06	3.87	5.72	145.59	0.98	2.70	0.00	0.41	0.00	0.00
S20	645.12	48.86	5369.95	671.76	36.97	22.12	0.00	0.00	153.69	21.27	28.97	306.01	71.00	26.94	11.97	130.96	0.00	0.00
S21	495.98	64.10	835.42	508.23	67.31	85.49	0.00	0.21	41.04	84.66	10.13	263.44	596.29	37.41	22.83	134.30	0.00	0.00
S22	5.21	0.94	9.71	232.17	25.55	33.52	2.41	6.28	61.74	87.57	75.55	587.09	63.70	76.63	35.70	61.18	0.00	0.00
S23	454.08	3.47	2517.36	260.93	2.81	4.98	0.00	0.00	18.01	177.49	23.26	142.57	19.53	28.83	25.54	31.80	0.00	0.00
S24	2.60	0.31	564.37	444.31	0.99	0.16	0.00	0.00	57.10	499.05	10.69	292.17	23.07	57.43	16.39	53.06	0.00	0.00
S25	0.53	0.20	4.17	13.05	0.61	0.15	0.00	0.11	0.05	1.75	1.03	21.95	15.06	50.71	1660.99	23.78	0.00	0.00
S26	20.59	2.84	4.67	3755.07	1.45	875.30	0.00	0.00	91.04	1.42	0.02	309.11	86.37	0.26	0.49	12.54	0.00	0.00
S27	0.03	5.39	6.64	72.43	1.94	269.73	130.95	313.39	66.79	3.36	0.02	99.71	403.29	12.97	4.16	6.56	0.00	0.00
S28	18.16	7.49	200.91	88.45	25.77	0.50	0.11	0.81	100.84	16.53	67.77	566.88	140.79	189.58	37.82	171.38	0.00	0.00
S29	0.78	0.00	0.30	3.25	0.02	0.00	0.00	0.00	0.01	0.04	0.00	45.41	0.00	2.10	0.00	0.32	0.00	0.00
S30	5294.84	236.00	345.36	1680.56	717.64	242.21	7.98	12.08	107.04	268.58	297.56	852.56	861.43	342.87	404.05	315.58	0.00	0.00
S31	44.46	5.52	12.31	159.09	221.22	5.66	0.08	0.16	6.82	4.47	8.23	59.53	75.59	44.07	59.52	101.04	0.00	0.00
S32	296.94	89.32	12818.03	1279.71	318.94	227.72	9.26	21.17	105.83	175.45	453.81	7961.28	450.42	372.23	404.68	553.74	0.00	0.00
S33	169.23	31.46	4396.07	3205.41	2019.36	3369.71	21.40	11.53	217.69	195.71	88.91	953.08	221.24	155.64	319.87	343.01	0.00	0.00
S34	57.54	3.08	349.89	262.12	63.79	105.83	8.37	109.69	664.95	40.99	228.07	472.53	192.41	232.26	307.56	199.50	0.00	0.00
S35	152.57	7.94	1393.56	2329.64	137.24	129.40	84.37	10.44	727.53	402.51	55.15	451.00	300.61	123.14	87.37	134.55	0.00	0.00
S36	15.85	4.19	26.36	66.90	0.65	8.85	0.57	0.00	29.44	0.06	1.86	61.42	34.71	2.21	1.96	8.18	0.00	0.00
S37	29.18	2.61	102.09	197.93	7.32	5.17	38.37	317.89	400.39	140.63	206.82	383.04	195.37	5.78	17.02	50.97	0.00	0.00
S38	55.82	1.85	201.94	1141.20	200.11	1372.22	487.41	958.82	1547.60	71.05	55.71	216.35	23.55	9.88	37.57	19.41	0.00	0.00
S39	372.43	49.14	664.64	1165.59	256.43	105.16	13.03	41.95	282.32	4510.51	1097.85	2101.33	971.08	327.81	399.49	665.07	0.00	0.00
S40	211.15	13.51	528.92	892.81	387.77	214.79	17.24	60.02	115.23	98.31	5051.48	1033.62	70.51	45.43	68.08	198.59	0.00	17888.00
S41	1641.53	230.75	4433.55	7626.02	1993.78	847.07	46.79	589.80	826.79	2020.92	2635.12	8878.47	2332.78	942.00	1832.14	1980.59	0.00	0.00
S42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S43	65.90	7.95	38.14	69.22	36.58	12.65	0.00	0.41	4.88	77.00	11.28	67.61	26.68	77.58	30.54	3.07	0.00	0.00
S44	34.40	5.85	151.47	315.76	118.81	29.27	0.00	0.00	1.62	125.50	23.75	163.17	42.73	29.86	526.14	49.80	0.00	0.00
S45	17.74	9.32	39.98	134.27	276.75	28.44	0.19	13.84	3.97	4.08	101.26	1393.15	97.17	16.48	270.00	3329.09	0.00	0.00
S46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FISIM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R1	-623.55	44.65	421.00	578.08	646.33	1446.38	7.39	15.24	169.26	144.19	832.81	949.07	1059.19	509.41	1018.72	264.22	0.00	0.00
R2																		
R3																		
R4																		
R5	13,523.26	1,087.81	53,798.23	33,635.19	21,708.00	10,766.94	988.37	2,890.79	6,655.39	10,021.45	11,826.96	33,966.39	9,749.33	4,507.82	11,403.96	10,482.36	0.00	17,888.00
R6	13,550.93	1,668.04	40,312.47	57,567.45	34,410.26	17,713.14	866.49	2,592.24	6,434.54	13,245.61	24,499.27	72,501.68	27,230.14	22,881.86	26,173.25	15,567.61	5,083.00	-17,888.00
R7	27,074.20	2,755.85	94,110.70	91,202.64	56,118.27	28,480.08	1,854.85	5,483.02	13,089.93	23,267.07	36,326.23	106,468.07	36,979.47	27,389.68	37,577.21	26,049.97	5,083.00	0.00
R8	142.45	0.00	7.96	849.18	98.46	338.84	59.44	1,860.02	1,320.04	828.44	1,108.58	11,026.85	0.00	0.00	0.00	1,733.41	0.00	0.00
R9	**27,216.65**	**2,755.85**	**94,118.66**	**92,051.82**	**56,216.72**	**28,818.92**	**1,914.29**	**7,343.05**	**14,409.97**	**24,095.51**	**37,434.81**	**117,494.92**	**36,979.47**	**27,389.68**	**37,577.21**	**27,783.38**	**5,083.00**	**0.00**

Table 3.B.1: 2000 Spanish symmetrical input-output table in 1995 million of euros (...finished)

	Total intermediate demand	Final consumption expenditure by				Gross capital formation			Total Exports	Total final uses	Total uses
		Households	NPISH	Government	Total	Fixed	Inventories	Total			
S1	28,296.51	4,881.69	0.00	0.00	4,881.69	326.71	76.80	403.51	7,482.98	12,768.17	41,007.71
S2	1,031.48	37.11	0.00	0.00	37.11	0.00	0.00	0.00	115.27	152.38	1,181.78
S3	1,350.83	1,346.55	0.00	0.00	1,346.55	0.00	0.00	0.00	344.80	1,691.35	3,039.46
S4	1,583.54	12.00	0.00	0.00	12.00	0.00	-5.51	-5.51	0.56	7.04	1,587.39
S5	200.80	0.00	0.00	0.00	0.00	0.00	1.07	1.07	0.02	1.09	201.48
S6	1,323.14	0.00	0.00	0.00	0.00	0.00	-37.82	-37.82	99.38	61.56	1,382.03
S7	2,299.85	7.27	0.00	0.00	7.27	0.00	-50.86	-50.86	397.56	353.97	2,649.18
S8	32,094.18	32,116.17	0.00	0.00	32,116.17	0.00	-276.77	-276.77	8,648.90	40,488.30	72,517.85
S9	7,455.98	2,075.81	0.00	0.00	2,075.81	89.42	39.24	128.66	2,607.95	4,812.42	12,253.39
S10	2,039.08	7,042.10	0.00	0.00	7,042.10	0.00	69.82	69.82	1,831.51	8,943.44	10,978.42
S11	2,865.50	3,181.41	0.00	0.00	3,181.41	3.38	-74.13	-70.75	2,038.79	5,149.45	8,009.18
S12	8,729.40	254.02	0.00	0.00	254.02	42.24	45.66	87.90	863.82	1,205.75	9,917.57
S13	10,411.63	807.76	0.00	0.00	807.76	0.00	-36.23	-36.23	1,923.96	2,695.48	13,086.15
S14	7,658.64	3,441.39	0.00	0.00	3,441.39	0.00	97.25	97.25	1,041.45	4,580.09	12,223.31
S15	9,043.07	3,315.43	0.00	0.00	3,315.43	0.00	161.98	161.98	3,771.42	7,248.84	16,273.70
S16	25,322.14	4,958.77	0.00	4,076.83	9,035.61	0.00	294.47	294.47	9,777.88	19,107.95	44,379.10
S17	12,481.97	589.35	0.00	0.00	589.35	45.72	62.25	107.97	3,878.34	4,575.67	17,032.50
S18	17,540.10	453.47	0.00	0.00	453.47	33.23	179.21	212.44	3,660.77	4,326.68	21,831.46
S19	20,260.58	4.13	0.00	0.00	4.13	0.00	115.10	115.10	5,173.35	5,292.58	25,512.37
S20	21,042.18	688.39	0.00	0.00	688.39	3,080.66	231.71	3,312.38	3,172.15	7,172.91	28,172.72
S21	13,280.47	1,984.14	0.00	0.00	1,984.14	10,089.57	187.53	10,277.10	8,228.27	20,489.50	33,743.23
S22	2,411.70	692.16	0.00	0.00	692.16	3,672.93	60.49	3,733.41	2,118.80	6,544.37	8,951.21
S23	10,156.44	211.71	0.00	0.00	211.71	2,215.59	114.90	2,330.50	3,772.59	6,314.80	16,450.79
S24	5,430.73	1,612.23	0.00	0.00	1,612.23	4,604.84	60.40	4,665.24	3,739.14	10,016.61	15,436.41
S25	1,963.08	861.77	0.00	96.98	958.75	3,214.16	44.61	3,258.77	1,426.43	5,643.94	7,603.07
S26	23,202.68	13,329.75	0.00	0.00	13,329.75	7,078.03	329.55	7,407.58	27,296.06	48,033.39	71,189.35
S27	2,295.10	843.56	0.00	26.97	870.53	2,109.02	-16.97	2,092.05	3,523.45	6,486.03	8,776.50
S28	2,835.26	5,906.60	0.00	0.00	5,906.60	2,766.04	206.05	2,972.09	2,371.55	11,250.25	14,079.80
S29	530.36	0.00	0.00	0.00	0.00	0.00	0.56	0.56	0.00	0.56	529.85
S30	20,488.68	6,520.21	0.00	0.00	6,520.21	0.00	105.40	105.40	143.61	6,769.23	27,216.65
S31	1,654.67	1,103.29	0.00	0.00	1,103.29	0.00	1.22	1.22	0.00	1,104.51	2,755.85
S32	26,859.92	2,461.75	0.00	0.00	2,461.75	64,844.29	0.00	64,844.29	6.79	67,312.83	94,118.66
S33	27,784.28	52,394.77	0.00	2,423.38	54,818.15	2,086.44	0.00	2,086.44	7,418.89	64,323.49	92,051.82
S34	4,123.17	52,101.85	0.00	0.00	52,101.85	0.00	0.00	0.00	0.00	52,101.85	56,216.72
S35	18,744.86	6,499.01	0.00	392.19	6,891.20	248.51	0.00	248.51	2,972.10	10,111.81	28,818.92
S36	788.77	188.09	0.00	22.16	210.25	13.65	0.00	13.65	903.21	1,127.11	1,914.29
S37	2,902.92	1,389.13	0.00	127.85	1,516.98	0.00	0.00	0.00	2,928.99	4,445.98	7,343.05
S38	10,029.09	2,595.55	0.00	87.92	2,683.48	0.00	0.00	0.00	1,717.60	4,401.08	14,409.97
S39	15,927.62	7,478.16	0.00	0.00	7,478.16	0.00	0.00	0.00	721.80	8,199.97	24,095.51
S40	28,099.38	7,845.63	0.00	0.00	7,845.63	0.00	0.00	0.00	1,546.39	9,392.02	37,434.81
S41	58,105.98	34,927.34	0.00	1,181.91	36,109.25	15,064.08	0.00	15,064.08	8,332.61	59,505.95	117,494.92
S42	0.00	0.00	0.00	36,979.47	36,979.47	0.00	0.00	0.00	0.00	36,979.47	36,979.47
S43	1,072.69	5,970.74	3.67	20,344.74	26,319.15	0.00	0.00	0.00	0.00	26,319.15	27,389.68
S44	2,207.82	8,875.00	3,127.71	23,371.13	35,373.84	0.00	0.00	0.00	0.00	35,373.84	37,577.21
S45	6,333.41	15,059.33	628.62	4,534.66	20,222.61	611.09	0.00	611.09	629.02	21,462.72	27,783.38
S46	0.00	5,083.00	0.00	0.00	5,083.00	0.00	0.00	0.00	0.00	5,083.00	5,083.00
FISIM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R1	7,285.69	30,416.36	0.00	260.80	30,677.15	8,266.37	0.00	8,266.37	-176.54	38,766.99	46,038.00
R2		0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1,287.87	-1,656.00	-1,656.00
R3		-26,436.25	0.00	0.00	-26,436.25	0.00	0.00	0.00	26,436.25	0.00	0.00
R4		4,780.29	0.00	0.00	4,780.29	0.00	0.00	0.00	0.00	5,961.00	5,961.00
R5	507,545.33	309,908.0	3,760.0	93,927.0	407,595.0	130,506.0	1,987.0	132,493.0	161,600.0	702,500.6	1,204,718.9
R6	482,630.98										
R7	990,176.31										
R8	168,504.58										
R9	**1,158,680.89**										

4. Atmospheric pollution and household consumption patterns in Spain

4.1. Introduction

Worldwide deterioration of environmental quality has been of growing interest amongst academics and politicians over the recent past. As mentioned in Chapter 1, the debate on the environmental effects of economic growth has been strongly influenced by the Environmental Kuznets Curve (EKC) hypothesis (Grossman and Krueger, 1991; Shafik and Bandyopadhyay, 1992), which is founded on the fact that per-capita income growth may involve changes in production processes and/or final demand towards less pollutant production and consumption patterns[98]. That is, economic growth may stimulate not only technological changes but also changes in consumption structure and/or in individual preferences. On one hand, it seems that consumption patterns move away from more pollutant goods and services towards less environmental deteriorating commodities; and, on the other hand, once a certain income level is achieved, consumers may shift the consumption of certain goods and services to consume more environmental quality[99]. Therefore, it seems important to focus the research not only on the supply-side such as the production process but

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[98] In an open economy, besides, the 'delinking' could also be due to the importation of pollutant intensive commodities. In this case, however, it was no a genuine delinking but only a displacement of environmental costs (Arrow *et al.*, 1995; Suri and Chapman, 1998; Muradian and Martínez-Alier, 2001) (see Chapter 5).

[99] As Roca (2003) pointed out 'environmental quality' is in most cases a public good that cannot be bought in the market and, hence, some environmental policies or any kind of regulation will be needed to solve some environmental problems.

also on the demand-side where consumers should play an active role in the process of reducing environmental pressures (United Nations, 2007).

The aim of this chapter is not to test the existence of an EKC in Spain but to study one of the elements that determine the relationship between income growth and environmental pressures. In particular, this chapter analyses the emissions associated with different levels of private consumption taking into account that when households reach a higher 'economic position' and their consumption increases, this increase is not homothetic; that is, consumption structure changes whereas consumption level increases. Although this approach is not usually applied to study the EKC hypothesis, we consider that this kind of comparative static analysis is pertinent to the EKC debate as it includes significant elements for estimating the dimension of some key factors in such hypothesis.

For doing so we use the environmentally extended input-output model described in Chapter 2 to evaluate the impact of different Spanish household's consumption on atmospheric pollution in 2000, classifying households by quintiles of expenditure. We combine statistic information from different databases and we examine the emissions of nine gases: the six greenhouse gases (CO_2, CH_4, N_2O, SF_6, HFCs, and PFCs) and three gases associated with local and regional environmental problems (SO_2, NO_x, and NH_3). We find that the more a household spends the more emissions it generates; however, the atmospheric pollution emitted per unit of household consumption generally decrease with the expenditure level. These outcomes are confirmed by the values of expenditure elasticity of emissions we estimate for all the gases performing a multivariate regression. We find that the expenditure elasticity is always positive and lower than unit for almost all gases. The only exception to this is the synthetic greenhouse gases whose elasticity is higher than unit.

Traditionally, input-output methodology has been used to measure total factor requirements of commodities regarding two primary factors, i.e. labour and capital. One example of this is the well-known work of Leontief (1953). However, the oil embargo and rising prices in the middle of 1970's oriented the interest towards an input frequently situated in the intermediate part of the input-output tables, i.e. the measurement of total energy requirements. These first studies were focused on evaluation the energy requirement of different economic sectors or on analysing the effects of a fuel price rise on the cost structure of sectors (Flaschel, 1982). More recently, however, the concern for environmental deterioration has motivated the interest of this kind of analysis considering the energy requirement as an indicator of environmental pressure.

Nevertheless, little attention was directed to household consumption; that is, how much energy a household requires to maintain its standard of living. The technique of linking energy requirements based on input-output analysis and household expenditure data was developed by Robert Herendeen, who applied this seminal work to the USA economy (Herendeen and Tanaka, 1976; Herendeen *et al.*, 1981) and to Norway (Herendeen, 1978). These studies examined the total energy cost of living for different types of households considering not only the direct demand for energy products, but also the indirect energy required to produce and distribute the commodities demanded by households. This methodology has been also applied in other countries such as the Federal Republic of Germany (Denton, 1975), New Zealand (Peet *et al.*, 1985), and the Netherlands (Vringer and Blok, 1995). Reinders *et al.* (2003) evaluated the average energy requirement of households in 11 member states of the European Union (EU), and Lenzen *et al.* (2006) analysed the relationship between income level and energy requirement for five countries, i.e. Australia, Brazil, Denmark, India and Japan.

Nevertheless, no research was undertaken on analysing the CO_2 emissions associated with the household energy requirements until the validation of the Kyoto protocol in 1997, from which various countries are concerning in limiting their emissions of greenhouse gases. According to our knowledge, the first study in analysing both energy requirements and CO_2 emissions was carried out by Lenzen (1998a) for Australia, which was followed by Weber and Perrels (2000) for West Germany, France, and the Netherlands; Munksgaard *et al.* (2000) and Wier *et al.* (2001) for Denmark; and Peters *et al.* (2004) for Norway. All these studies are based on energy input-output models combining energy and household expenditure data and none of them offers results for other emissions apart from CO_2[100]. So, according to our knowledge this is the first work in considering other gas emissions generated by the consumption of different households[101].

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[100] A good review about different input-output methods is Kok *et al.* (2006).

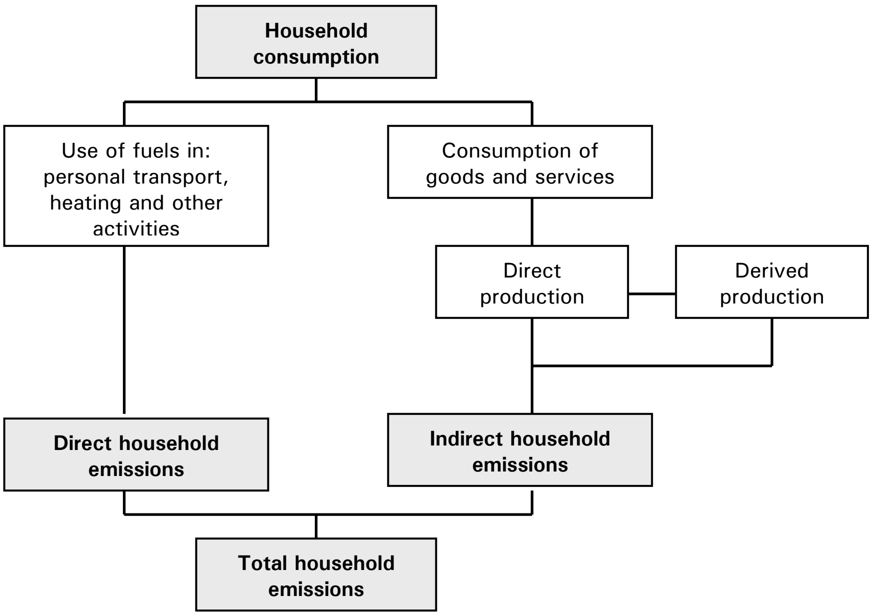
[101] It should be mentioned that Lenzen (1998b), Peters and Hertwich (2006), and Sánchez-Chóliz *et al.* (2007) take other gas emissions into account. On the other hand, Nijdam *et al.* (2005) and Huppes *et al.* (2006) also analyse other environmental impacts of private consumption such as acidification or eutrophication. However, the level of analysis of these studies is quite aggregate since they evaluate the emissions embodied in total private consumption of the average household without differentiating different types of households.

The rest of the chapter is as follows. In Section 4.2, we develop an environmentally extended input-output model for evaluating total emissions embodied in household consumption. In Section 4.3, we describe the characteristics of Spanish data and the modifications that have been necessary to make in order to correlate data from different sources. In Section 4.4, we present the results for Spanish households in 2000. In Section 4.5 some conclusions are given. Finally, the Appendix of this chapter is devoted to present some detailed results and/or procedures.

4.2. Theoretical approach

As Figure 4.1 illustrates, in analysing total emissions generated by household consumption we consider both direct and indirect household emissions. The former are emissions generated directly by some activities carried out by households such as using fuels for personal transport or heating; whereas the latter are emissions associated with production of goods and services purchased by households, i.e. food, clothes, furniture, electricity, etc. Thus, indirect household emissions also include direct and indirect emissions generated by different economic sectors.

Figure 4.1: Direct and indirect emissions from household consumption



Source: own elaboration from Munksgaard *et al.* (2000).

4.2.1. Direct emissions from households

Let k be the number of atmospheric pollutants, h the number of households, and s the number of consumption purposes, direct emissions generated by households are expressed by matrix $\mathbf{R}^{\mathbf{direct}}$ of dimension (kxh):

$$\mathbf{R}^{\mathbf{direct}} = \mathbf{D}^{\mathbf{direct}}\mathbf{C} \tag{4.1}$$

Where $\mathbf{D}^{\mathbf{direct}}$ is the intensity matrix of dimension (kxs) of direct household emissions, whose elements d_{lp}^{direct} represent the direct emissions of pollutant l measured in physical units associated with each monetary unit spent on a consumption purpose p. And $\mathbf{C}$ is a matrix of dimension (sxh) that indicates expenditure on different goods and services grouped according to consumption purposes carried out by each household.

4.2.2. Indirect emissions from households

On the other hand, indirect emissions from household consumption can be estimated using the environmentally extended input-output model described in Chapter 2. In this section, however, we adapt the general solution of this model to consider only private consumption and not all final demand or final uses. Specifically, being n the number of sectors of the economy, the indirect household emissions are given by matrix $\mathbf{R}^{\mathbf{indirect}}$ of dimension (kxh):

$$\mathbf{R}^{\mathbf{indirect}} = \mathbf{JUC} \tag{4.2}$$

Where $\mathbf{J}$ is the matrix of total emission intensity of dimension (kxn), $\mathbf{U}$ is a coefficient matrix of dimension (nxs) that transforms household expenditure classified by consumption purposes into equivalent expenditure on products, and $\mathbf{C}$ is the matrix of household expenditures defined above.

As mentioned in Chapter 2, matrix $\mathbf{J}$ is defined from the emission coefficient matrix $\mathbf{W}$ and Leontief inverse, i.e. $\mathbf{J} = \mathbf{W}(\mathbf{I} - \mathbf{A})^{-1}$, and it corresponds to the intensity matrix of total emissions from economic sectors. This matrix enables us to calculate total emissions, i.e. direct and indirect emissions, generated by economic sectors to satisfy one monetary unit of final demand or final uses of each sector. In the particular case of private consumption of households, it would express the atmospheric impact of one unit spent on economic sectors' products. However, if household consumption is classified by consumption purposes, the intensity matrix should be represented by:

$$\mathbf{D}^{\mathbf{indirect}} = \mathbf{W}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{U} \qquad (4.3)$$

Where $\mathbf{D}^{\mathbf{indirect}}$ is the intensity matrix of indirect household emissions that enables us to calculate total emissions to satisfy one unit of household expenditure on commodities organised according to the consumption purpose classification. Thus, expression (4.2) can be rewritten as:

$$\mathbf{R}^{\mathbf{indirect}} = \mathbf{D}^{\mathbf{indirect}}\mathbf{C} \qquad (4.4)$$

As pointed out in Chapter 2, this expression implies that we consider not only emissions domestically produced by this economy to satisfy private consumption, but also those associated with the production of imports. Analysing the problem in this way involves that households are responsible for the global environmental consequences of their consumption regarding where they have been produced (see Section 2.4).

4.2.3. Total emissions from households

Finally, adding direct and indirect household emissions we obtain total emissions associated with household consumption $\mathbf{R}^{\mathbf{household}}$. Formally, from expressions (4.1) and (4.4) we get:

$$\mathbf{R}^{\mathbf{household}} = \mathbf{DC} \qquad (4.5)$$

Where $\mathbf{D}$ is now the intensity matrix of total household emissions, whose elements d_{lp} are the total emission impact generated per one monetary unit of household consumption classified by consumption purposes including both direct and indirect household emissions coefficients, i.e. $\mathbf{D} = \mathbf{D}^{\mathbf{direct}} + \mathbf{D}^{\mathbf{indirect}}$.

4.3. Data set description

The model presented in previous section requires combining data from different statistical sources and with different classifications. In this section, first, we describe the databases used in this chapter. Then, we explain the data preparation necessary to compute the model. Finally, we make some considerations about household classification.

4.3.1. Data sources

Four main data sources were employed for setting up the model: the 2000 supply and use tables from the Spanish input-output framework base 1995 (INE, 2005); the 2000 Spanish environmental accounts for air emissions base 1995, usually referred as NAMEA framework (INE, 2006); Spanish household budget continuous survey for 2000 base 1997 (INE, 2004); and Spanish matrix that relates products classified according to CPA and according to COICOP[102] for the year 1995 supplied by INE.

From the supply and use framework and environmental accounts for air emissions we estimated the Spanish environmentally extended input-output table for 2000 as we described in Section 2.6 of Chapter 2. However, due to the aim of this chapter we only consider direct and indirect emissions associated with household consumption, neglecting those generated by other final uses (government expenditures, investment, exports, etc.) and the CH_4 associated to waste management.

The Household Budget Continuous Survey (HBCS) mainly informs about the amount and structure of household expenditures. It also collects information on household incomes and other socio-economic characteristics regarding living standards such as household equipment, number of members, and level of studies and/or professional activity of breadwinner. The main objective of HBCS is to update the weights for the basket of goods and services used in consumer price indices; however, the socio-economic variables gathered in the HBCS also allows for analysing consumption patterns of different sort of households. The sample size of the 2000 Spanish HBCS is 9,631 representative households[103] and for each household the survey records expenditure on goods and services for final consumption classified by COICOP[104]. These goods and services are arranged in 47 groups grouped into 12

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[102] CPA and COICOP stand for *Classification of Product by Activity* and *Classification of Individual Consumption by Purpose*, respectively.

[103] In fact we compute the model with 9,628 because in the original database there are three households whose income register was zero. Since it does not have sense to work with expenditures of non-income households we decided to eliminate them.

[104] The COICOP classifies the purpose of individual consumption expenditure incurred by three institutional sectors: households, non-profit institutions serving households, and government. Division

main divisions[105]. The expenditures are evaluated using the purchase criterion, i.e. they are recorded at the moment of availability of commodity by household regardless whether it has been paid in cash or not. This criterion has important consequences for durable goods because following it total amount of expenditure on goods, such as cars or appliances, is registered completely in the current year, although they are going to be consumed for more than one year.

Finally, we have used the matrix that relates products and consumption purposes. This matrix is essential to apply the model since the data sources described above use different criteria to classify products. That is, input-output framework classifies goods and services by CPA whereas HBCS classified them by COICOP. Concretely, the 1995 Spanish transformation matrix is a coefficient matrix that converts household expenditures on 61 products classified by CPA into equivalent expenditure on 47 products classified by COICOP.

4.3.2. From data to model: procedures to compute the variables of the model

In order to estimate direct and indirect household emissions, classifications and dimensions of all matrices have to be compatible. Thus, we need to presuppose some assumptions and prepare the data before computing the theoretical model proposed. We compute the model in terms of nine atmospheric gases; 9,628 households; 46 NACE sectors or CPA products; and 47 consumption purposes, i.e. goods and services classified by COICOP groups.

a) Direct household emissions

The Spanish NAMEA framework supplies aggregated data on total direct emissions generated by all households of Spanish economy for the nine gases considered in this study. However, our aim is to calculate direct emissions of individual household consumption, $\mathbf{R}^{\mathbf{direct}}$. For doing so, we need to estimate the intensity matrix of direct

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13 of COICOP corresponds to COPNI (*Classification of the Purpose of Non-Profit Institutions Serving Household*) and division 14 to COFOG (*Classification of the Functions of Government*). Therefore, divisions 1 to 12 collect expenditures of households. Accurately, the latter uses the COICOP/HBS (*Classification of Individual Consumption by Purpose/Household Budget Survey*) abbreviation to avoid confusions. In this work, however, we use the COICOP abbreviation to refer to divisions 1 to 12 of household consumption expenditures.

[105] Divisions and groups correspond to two-digit and three-digit levels, respectively. In this study we only use data until the four-digit level named classes, although the detail of the data collected in the Spanish HBCS reaches the five-digit level.

household emissions $\mathbf{D}^{\text{direct}}$ and the household expenditure matrix $\mathbf{C}$. The procedure and assumptions adopted to estimate the $\mathbf{D}^{\text{direct}}$ matrix are as follows:

- Since direct emissions are only relatively important for CO_2 and NO_x, we only consider direct household emissions of these two gases[106].
- Taking into account that CO_2 and NO_x emissions are closely linked to energy goods, we share their emissions between 4.5 and 7.2 COICOP groups according to an expenditure criterion, i.e. we calculate the ratio expenditure on each energy group to total expenditure on energy goods[107]. Notice that this criterion implies the restrictive assumption that one monetary unit spent on any energy good of any of these two groups generates the same direct emissions.
- Finally, we calculate the emission intensity of these COICOP groups dividing total direct emissions of CO_2 and NO_x by total expenditure on 4.5 and 7.2, respectively[108]. So, we obtain a matrix $\mathbf{D}^{\text{direct}}$ where the elements for the remainder seven gases not considered and also for those activities that do not used energy goods are zero (see Appendix 4.A).

Lastly, we derive matrix $\mathbf{C}$ directly from the 2000 Spanish HBCS, aggregating expenditures of 9,628 households on five-digit level products into 47 COICOP groups.

b) Indirect household emissions

Indirect household emissions $\mathbf{R}^{\text{indirect}}$ are determined by the intensity matrix of indirect household emissions $\mathbf{D}^{\text{indirect}}$ and the household expenditure matrix $\mathbf{C}$. The latter has been previously calculated, and the former is the product of two matrices: the matrix of total emission intensity from the economy ($\mathbf{J}$), and the coefficient matrix that transforms household expenditure on consumption purposes into equivalent expenditure on products ($\mathbf{U}$).

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[106] According to 2000 Spanish NAMEA framework, the percentage of direct household emissions to total economy emissions represents 19.1% for CO_2, 1.8% for CH_4, 6.9% for N_2O, 0.7% for synthetic greenhouse gases, 1.7% for SO_2, 20.7% for NO_x, and 1.2% for NH_3 (INE, 2006).

[107] We consider total expenditure on 4521 (natural gas), 4522 (liquefied gas), 4531 (liquid fuels), 4541 (solid fuels), and 7221 (fuels and lubricants).

[108] The total expenditure of the economy is the mean expenditure of the HBCS sample by the number of official households in Spain in the year 2000. According to Spanish HBCS the number of households in Spain was 13,086,197 and the effective size of the sample is 9,628. This information is available at http://www.ine.es.

However, the estimation of matrix **U** is not straightforward since the original matrix provided by INE is not exactly the matrix we need. First, the matrix supplied by INE refers to 1995 when we need the year 2000 as a reference. Second, it converts household expenditures classified by 61 CPA into 47 COICOP, i.e. it is a matrix of row coefficients, when we need a matrix of column coefficients that converts 47 COICOP expenditures into 46 CPA. Finally, the most important feature concerns the valuation discrepancy between CPA and COICOP classifications. As mentioned in Chapter 2 CPA products in Spanish input-output table are valued and at basic prices; however, in the transformation matrix provided by INE total amount of household expenditures calculated according to CPA or COICOP classifications are valued at purchases' prices. This is so because in the transformation matrix net taxes on products are included in one row together with trade and transport products. Thus, bearing in mind all this characteristics we estimated matrix **U** following the procedure detailed in Appendix 4.B.

4.3.3. Some considerations about household classification

Once we have estimated direct and indirect household emissions, the calculation of total emissions from household consumption is quite straightforward. However, we are not concerned about the magnitude of these emissions but in analysing how do these emissions change as households reach a higher 'economic position'. Households should be, therefore, classified according to their 'economic position'. Nonetheless, when classifying household data from the HBCS, there are some factors to be considered. In this section, we point out two of them: first, the variable that would be used to classify households, and second, the approach that would be applied to consider household differences in size and composition.

a) The classifying variable: income versus expenditure

Generally, income is considered as the natural indicator of consumers' financial ability to purchase goods and services and, hence, the best variable to measure the 'economic position' of consumers. Although income has been the standard criterion to classify household expenditure data, it presents some disadvantages that may limit its usefulness as a classifying variable. The first drawback, and probably the most important for this study, is the incomplete reporting and underreporting of income in HBCS. One of the reasons is that some of the interviewed households are reluctant to report some or all of their income or even when they do, they do not know the exact amount of it. Consequently, household expenditure surveys provide more complete and reliable data on expenditures than on income. Generally, questions about expenditures on goods and services are answered by almost all household of the sample, whereas answers about monthly net revenues have often to be estimated from income intervals and other variables (INE, 2004).

The second drawback is that income levels are more variable over time than expenditure levels are. According to the permanent income hypothesis proposed by Friedman (1957), the choices consumers make regarding their consumption patterns are determined not by their current income but by their longer-term income expectations. So, consumers attempt to maintain their standard of living fairly constant even though their incomes may vary over time, taking into account whether increases and decreases in income are a temporary or a permanent variation. This would imply that gains and losses in income that people see as temporary had little effect on their consumption spending, and only when they become convinced that the variation in income is permanent, they will change their consumption patterns. As a consequence of classifying households by income, the average expenditure of both lower and higher income classes would be affected. On one hand, low-income classes would include those households with temporary decreases that have typical consumption patterns of higher income groups. On the other hand, high-income classes would include those households with temporary increases that have a consumption pattern more characteristic of lower income households.

Moreover, if we analyse emissions associated with different consumption patterns classifying households by income, it could be interpreted as savings do not generate emissions when in fact investment can be as environmentally problematic as consumption, or even more so.

It is because of all these disadvantages that other variables to classify household data should be considered. Probably, the most suitable alternative may be the expenditure variable. Rogers and Gray (1994), in a study of the Bureau of Labor Statistics on consumer expenditure survey data, argued that the problems mentioned above can be overcame by classifying households according to expenditure levels[109].

Taking all of this into account, in this study we classify households according to their expenditure level. However, this approach also has some limitations. One significant problem results from the criterion used to evaluate expenditures in the HBCS. As mentioned above, by the purchase criterion total prices of durable goods are included in current consumption expenditures when, from an economic viewpoint, it should be only included the economic value of the service flows provided by durable goods. Therefore, the way in which expenditures of durable goods are treated in the HBCS causes that those households who have bought durable goods in the current year may be classified in highest percentiles. From a technical point of view, total expenditures on durable goods should be distributed amongst different years according to their shelf life. This method is very data demanding and implies to have information not only about the shelf life of each durable good, but also the year in which they have been purchased. In this study, however, we are not able to measure the consumption of durable goods in economic terms since we do not have at our disposal all the required data[110].

b) Consumer units: total expenditure versus equivalent expenditure

Once it has been chosen the variable to classify households according to their 'economic position', we need to face the issue of comparing them. If all households were identical in demographical terms the same expenditure level would indicate the same 'economic position'; however, because of the size and/or composition, households with the same expenditure level could have different 'economic positions'. Therefore, we need to adopt some method in order to compare them.

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[109] However, income and expenditure levels are not the only variables to classify household. In order to consider other factors influencing lifestyles, alternative perspectives have been adopted such as multivariate econometric approach (Lenzen *et al.*, 2006), and/or household classifications compiled on the basis of several characteristics, e.g. Duchin (1998) classifies United States households using 40 "geo-demographic lifestyle clusters".

[110] Rogers and Gray (1994), considering that the most important expenditure of durable goods is on vehicles, propose a different approach to correct the measure only for financed vehicles. Concretely, they exclude purchase price of financed vehicles and include principal payments of financed vehicles. However, in our opinion, this method should be applied for all purchased vehicles and not only for the financed ones.

One approach is to consider per-capita expenditures, i.e. dividing total expenditure of a household by the number of members. Although it is the most usual approach to analyse energy or emission requirements of household consumption (Herendeen and Tanaka, 1976; Herendeen, 1978; Herendeen *et al.*, 1981; Vringer and Blok, 1995; Lenzen, 1998b; and Lenzen *et al.*, 2006), it only handles the household size issue but it considers neither the composition nor the economies of scale in consumption of households[111].

Another possibility is to construct equivalent consumer units weighing each household according to the number of members and the age of them. By doing this we consider not only the economies of scale but also different monetary necessities that children and adults could have. These equivalent consumer units can be calculated by applying different equivalence scales, which have been extensively discussed in the welfare literature. Amongst all, the most generally applied are the parametric equivalence scales because they are quite understandable and quite easy to compute (Mancero, 2001). Two examples of them are the OECD scale and the modified OECD scale. EUROSTAT recommends the latter because it considers that the OECD scale underestimates the economies of scale in consumption since additional members are over-weighted (Moreno, 2004). Thus, the equivalent expenditure for each household is calculated dividing total household expenditure by the factor resulting of the following expression:

$$EQ(n_1, n_2) = 1 + 0.5(n_1 - 1) + 0.3n_2 \qquad (4.6)$$

Where n_1 is the number of adults and n_2 the number of children under 14 years in each household. According to the modified OECD scale, the first person counts 1, additional adults count less than the first (0.5), and children count less than adults (0.3). That is, they take into account both differences in size and/or composition and the economies of scale in consumption, presupposing that necessities of monetary expenditures to meet consumption necessities of children are lower than the consumption necessities of adults[112].

From the latter it can be argued that the choice of the parameters may be arbitrary unless they were supported by some empirical evidence, since they may

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[111] Households may present economies of scale in consumption of some goods and services, since larger families share some commodities.

[112] In contrast, the OECD scale weights the first person by 1, other persons by 0.7, and children under 14 years by 0.5.

vary in different countries and over time. For instance, a parameter of 0.3 for children or even the limit age of 14 may be too restrictive in some societies. That is, even though it is commonly considered that expenditures on children are lower than on adults, it is not true for all commodities. Take, for example, the case of those goods and services that are exclusively for children such as nappies; or those of which children use more intensively such as scholar books, games, etc. Moreover, other goods, as clothes, need to be replaced more often for children than for adults; and others, as food, may be more expensive when considering children, since we usually purchase higher quality food for them. These examples suggest that equivalent expenditures calculated by applying these parametric equivalence scales may overestimate the expenditure of larger households just as of households with more children.

Thus, in this chapter we classify households by quintiles of expenditures adopting both methods described above. That is, on one hand, we estimate the per-capita emissions and, on the other hand, the emissions associated with the expenditure of equivalent consumer units; in this last method we apply the modified OECD scale.

4.4. Empirical results

This section analyses total emissions generated in 2000 by Spanish households classified according to expenditure level. As pointed above, we have considered nine different gases: the six greenhouse gases (CO_2, CH_4, N_2O, SF_6, HFCs, and PFCs) and three other gases (SO_2, NO_x, and NH_3)[113]. In Section 4.4.1 we present a general overview of the more pollutant consumption purposes, i.e. COICOP categories; whereas in Section 4.4.2 we analyse total emissions from different households classified by expenditure level.

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[113] As mentioned in Chapter 2, the so-called 'greenhouse synthetic gases' SF_6, HFCs, and PFCs have been grouped and the six greenhouse gases have been unified measuring their emissions in CO_2 equivalent units according with the global warming potentials established by the Intergovernmental Panel of Climate Change (IPCC, 1997). It should be also mentioned, that in this chapter we only consider total emissions from household consumption.

4.4.1. Emission intensities for goods and services classified by COICOP

Let us start our analysis by presenting total emission intensities for different COICOP commodities, i.e. direct and indirect emissions generated by one monetary unit of household expenditure classified by consumption purposes. We have estimated pollutant intensities for 47 COICOP groups and the outcomes are presented in Appendix 4.C. Generally, these groups are aggregated into 12 COICOP divisions; however, for the sake of clarity and in order to highlight the more pollutant commodities, in this study we prefer to aggregate them into 14 categories or 'pseudo-divisions'. These 14 categories are the same 12 standard division but splitting up divisions 0.4 'Housing, water, electricity, gas and other fuels' and 0.7 'Transport' as Figure 4.2 shows[114].

Figure 4.2: Correspondence between COICOP pseudo-divisions and COICOP divisions

COICOP pseudo division codes	COICOP pseudo divisions	COICOP division codes
I.	Food and non-alcoholic beverages	01
II.	Alcoholic beverages, tobacco, and narcotics	02
III.	Clothing and footwear	03
IV.a.	Housing and water	04.1 – 04.4.
IV.b.	Electricity, gas, and other fuels	04.5.
V.	Furnishings, households equipment, and routine household maintenance	05
VI.	Health	06
VII.a.	Personal transport	07.1. – 07.2.
VII.b.	Transport services	07.3.
VIII.	Communication	08
IX.	Recreation and culture	09
X.	Education	10
XI.	Restaurants and hotels	11
XII.	Miscellaneous goods and services	12

Source: own elaboration from 2000 Spanish HBCS (INE, 2004).

Figures 4.3 and 4.4 present total emission intensities for the six greenhouse gases and the three other gases, respectively. These figures show how the

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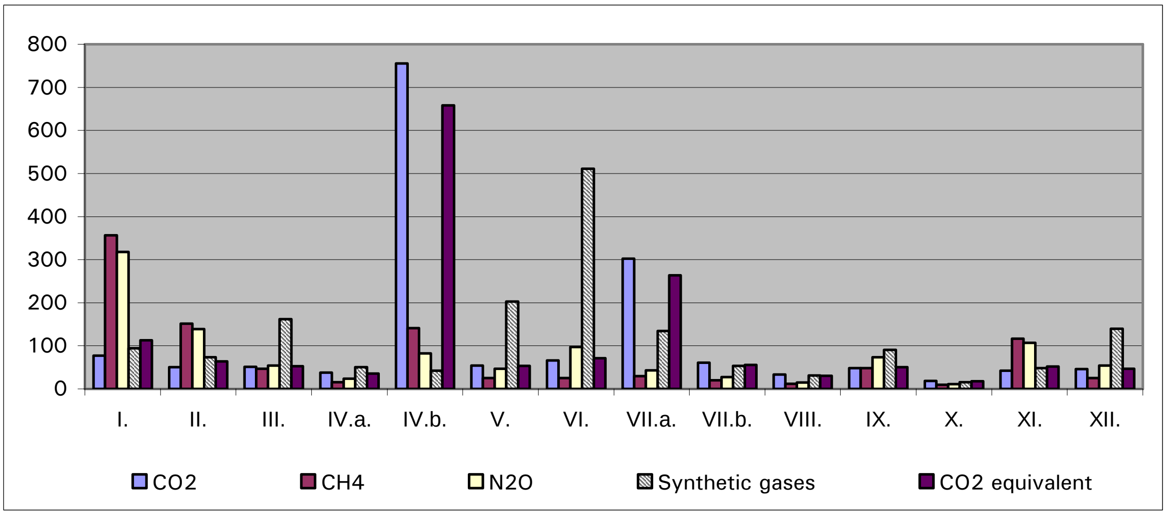
[114] On one hand, the pseudo-division IV.a 'Housing and water' includes all expenditures related with housing maintenance and water supply. Specifically, it includes: group 04.1 'Actual rentals for housing', group 04.2 'Imputing rentals for housing', group 04.3 'Maintenance and repair of the dwelling', and group 04.4 'Water supply and miscellaneous services relating to the dwelling'. The pseudo-division IV.b 'Electricity, gas, and other fuels' corresponds to the COICOP group 04.5 On the other hand, the pseudo-division VII.a 'Personal transport' includes purchases of vehicles, i.e. group 07.1 'Purchase of vehicles', and all expenses associated with the use of private vehicle such as purchases of fuels and lubricants, i.e. group 07.2 'Operation of personal transport equipment'. The pseudo-division VII.b 'Transport services' is the group 07.3, which corresponds to non-private transport of persons and luggage by railway, road, air, and sea.

expenditure of one monetary unit in the purchase of a range of different goods and services may have very different implications in terms of quantity and type of emissions.

Figure 4.3: Total emission intensities of greenhouse gases of COICOP pseudo-divisions, Spain 2000

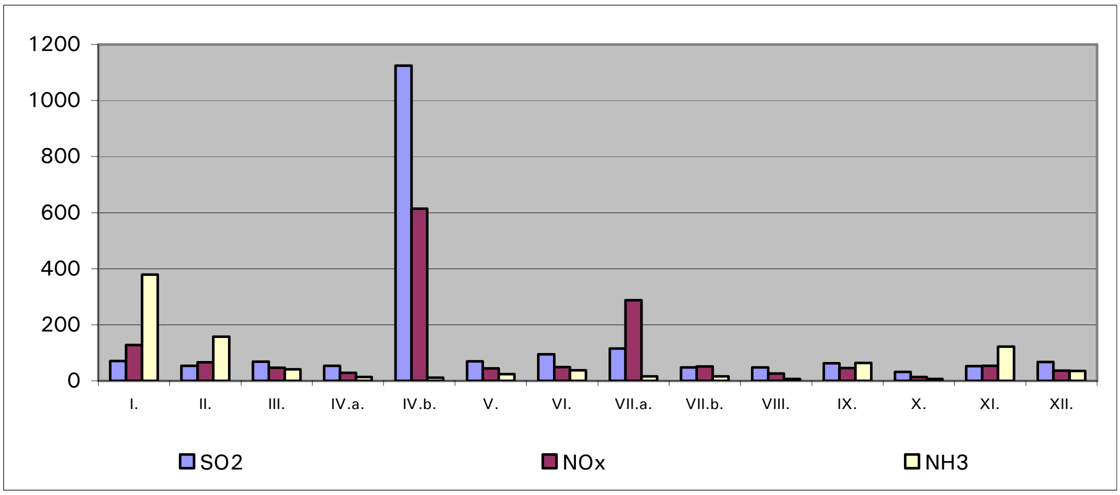
Units: index numbers, mean emissions of total expenditure of households 2000 base = 100.



Source: own elaboration.

Figure 4.4: Total emission intensities of other gases of COICOP pseudo-divisions, Spain 2000

Units: index numbers, mean emissions of total expenditure of households 2000 base = 100.



Source: own elaboration.

As these tables show, one euro spent in IV.b ‘Electricity, gas, and other fuels’ generates more than eleven times emissions of SO_2 than one euro spent on the average household consumption. The expenditure on this pseudo-division is also the most pollutant in terms of CO_2 and NO_x. Regarding CO_2, SO_2, and NO_x VII.a 'Personal transport' stands out as the second pollutant pseudo-division[115]. In contrast, the most polluting goods in terms of CH_4, N_2O, and NH_3 are those included in pseudo-divisions I 'Food and non-alcoholic beverages', II 'Alcoholic beverages, tobacco, and narcotics', and XI 'Restaurants and hotels'. This result is not unexpected because these categories are connected with agriculture and cattle raising CPA groups, which had also the highest emission intensities (see Table 2.7 in Chapter 2). In fact, the emission intensity of 'Food and non-alcoholic beverages' is more than three times higher than the emission intensity of the average expenditure for these three gases. Finally, the synthetic greenhouse gases are relevant in pseudo-divisions VI 'Health' and V 'Furnishings, household equipment, and routine household maintenance'. The former mainly caused by group 6.1 'Medical products, appliances, and equipment'[116].

So, we are therefore drawn to the conclusion that not only the amount of expenditures but also its distribution over expenditure categories is relevant to explain emissions generated by different households.

4.4.2. Total emissions of different household classified by expenditure level

As mentioned in Section 4.3, we adopt two different methodologies to compare households with different size and/or composition. First, we calculate per-capita emissions and classify households by quintiles of per-capita expenditure. The second approach is based on the construction of equivalent consumer units applying the modified OECD scale. We calculate emissions associated with equivalent expenditure of each household and we classify them by quintiles of equivalent expenditure. Both approaches are different ways to compare households and entail different hypothesis on economies of scale in consumption and on necessities of monetary expenditures to meet consumption necessities of children and adults[117].

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[115] Notice that CO_2 and NO_x emission includes both direct and indirect household emissions, whereas the remainder gases only include indirect ones.

[116] It should be stressed that HBCS only refers to private expenditures on health; neither the consumption of public health nor subsidised medicines, which are usually consumed by lower expenditure quintiles, are considered. As a consequence, it should be expected that relative expenditure on the pseudo-division VI 'Health' will be higher in highest expenditure quintiles than in lower quintiles. The same would be also applied for expenditures on education.

[117] We also perform a third approach applied by Herendeen and Tanaka (1976), Herendeen (1978), Herendeen *et al.* (1981), and Vringer and Blok (1995) in which households are grouped into five groups according to their size, i.e. households composed by one, two, three, four, and five or more members.

In this section, three kinds of results will be presented. First, we graphically illustrate average emissions and average emission intensities of households classified by per-capita expenditure quintiles and equivalent expenditure quintiles. Second, in order to complement the graphical analysis we perform a multivariate regression. And third, we analyse and discuss how the composition of different households' consumption baskets would explain different emission patterns.

a) Graphical analysis: average emissions and average emission intensities

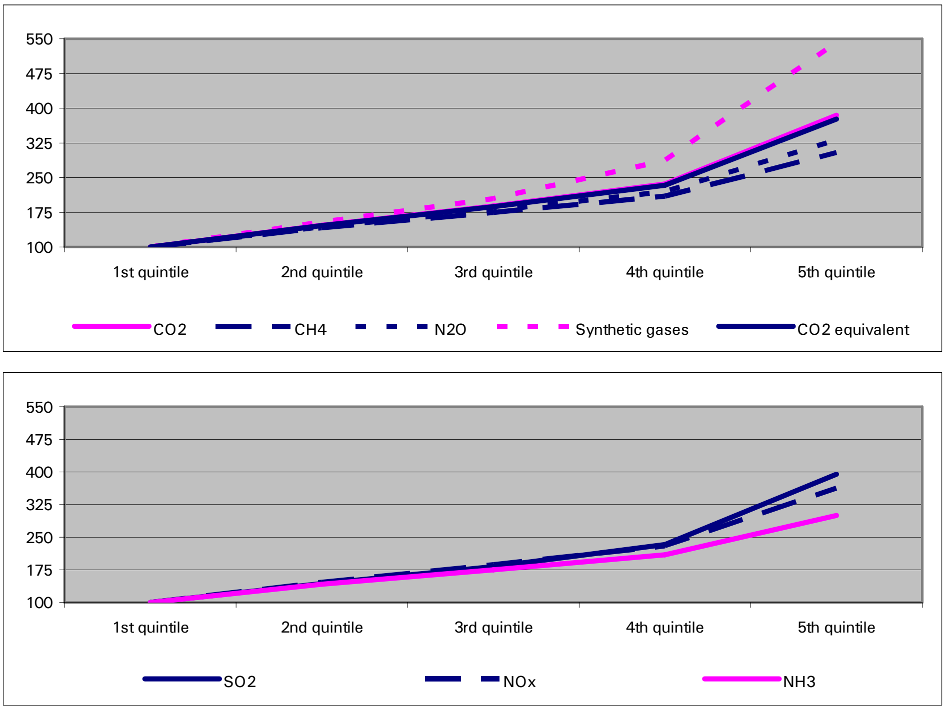
Figures 4.5 and 4.6 show the mean emissions of the greenhouse and the three other gases by per-capita expenditure quintiles and equivalent expenditure quintiles. As these figures illustrate, emissions increased monotonically with household expenditure for all pollutants confirming that the more households spent, the more emissions they generated. In the transition from the forth to the fifth quintile, there was a strong increase of all emissions but particularly for the synthetic greenhouse gases. The latter may due to the limitations of choosing the expenditure as a classifying variable, i.e. the treatment of durable goods and the unreported consumption of subsidised goods and services such as public health.

However, when analysing the evolution in emission intensity terms (Figures 4.7 and 4.8), we observe that the amount of pollutants emitted per unit of household consumption generally decreased with the expenditure level. That is, the consumption patterns of higher quintiles were less pollutant that those of lower quintiles. The exception to this was the synthetic greenhouse gases. The most significant albeit also moderate decrease was reported for those pollutants closely associated directly with food and indirectly with agriculture and cattle raising, i.e. CH_4, N_2O, and NH_3. This is an unsurprising result since generally the proportion of money spent on food decreases with the level of expenditure (see Section c below).

For every group we calculate the emissions associated with household expenditures and we classify them by quintiles. Notice that this approach only considers the size of the households but not the different composition between adults and children. However, for the sake of clarity we decide to present the graphical results in Appendix 4.D.

Figure 4.5: Per-capita mean emissions of greenhouse gases and other gases by quintiles of expenditure, Spain 2000

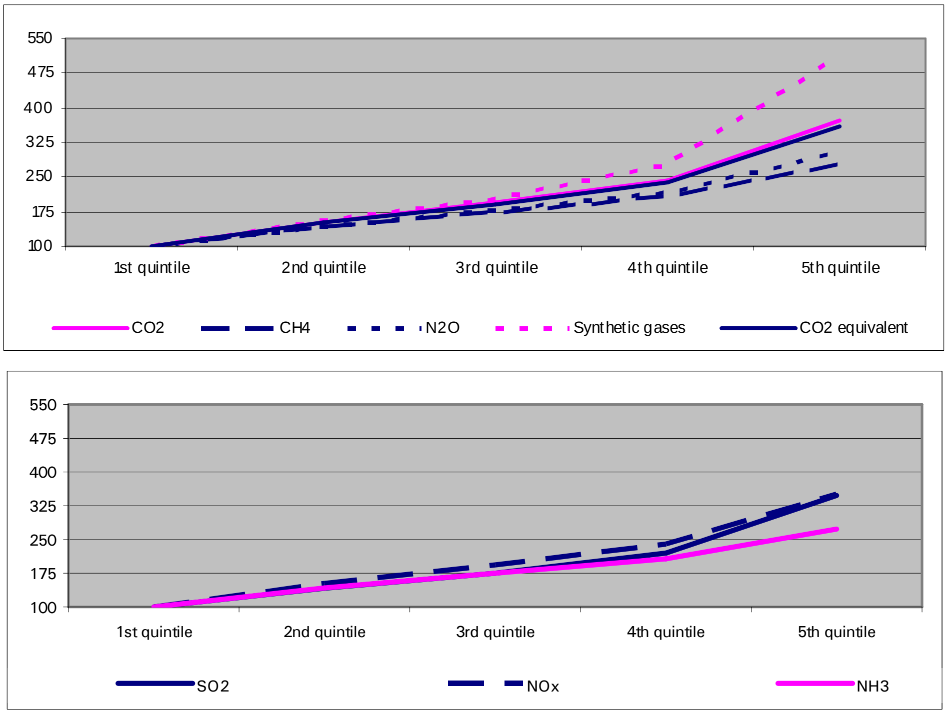
Units: first quintile base = 100.



Source: own elaboration.

Figure 4.6: Equivalent mean emissions of greenhouse gases and other gases by quintiles of equivalent expenditure, Spain 2000

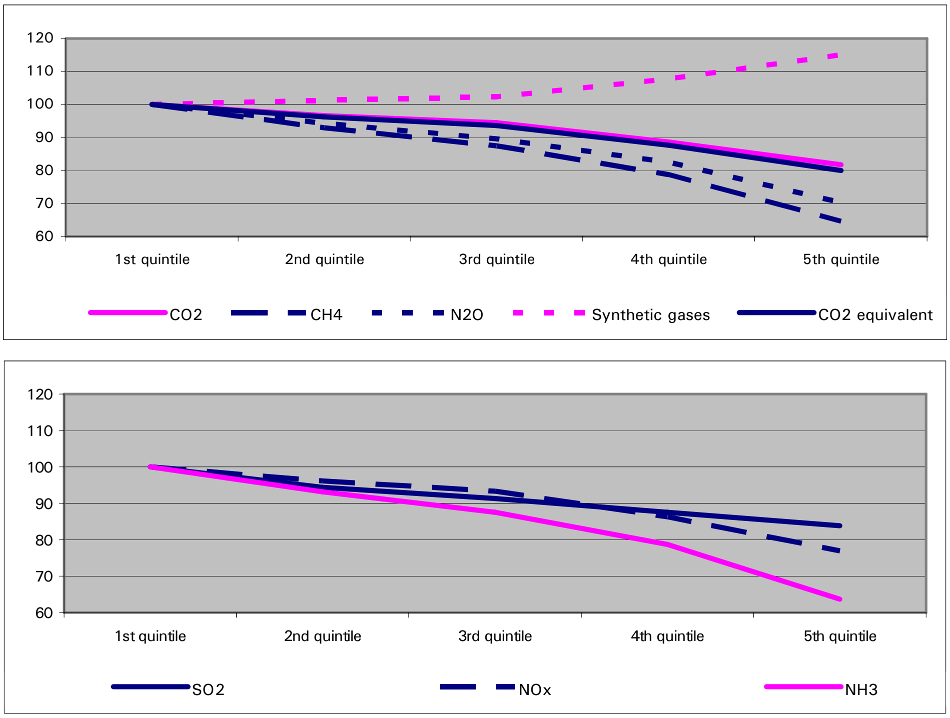
Units: first quintile base = 100.



Source: own elaboration.

Figure 4.7: Per-capita mean intensities of greenhouse gases and other gases by quintiles of expenditure, Spain 2000

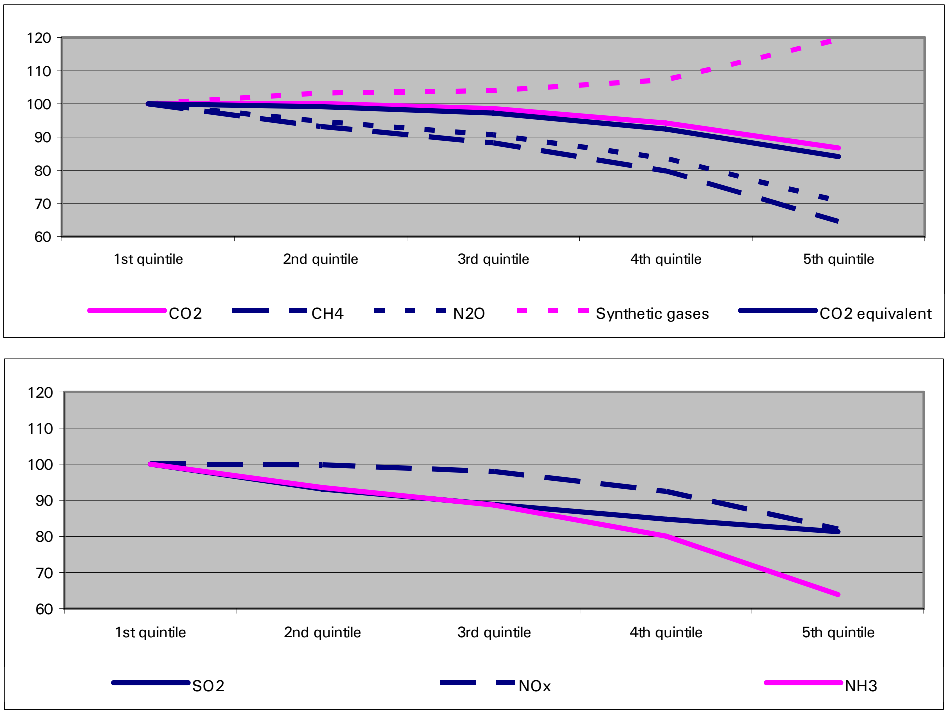
Units: first quintile base = 100.



Source: own elaboration.

Figure 4.8: Equivalent mean intensities of greenhouse gases and other gases by quintiles of equivalent expenditure, Spain 2000

Units: first quintile base = 100.



Source: own elaboration.

Regarding the EKC debate, it can be stated that in general terms as the expenditure level increases it could be expected a change in the consumption structure that may show a relative delinking between increasing expenditure and emissions. However, there was not any decrease in absolute terms neither any turning point was recorded for any gas; thus, we cannot state the existence of an absolute delinking (de Bruyn and Opschoor's, 1997). The latter only could happen if the more pollutant commodities were 'inferior goods', which should be supported by negative expenditure elasticity. Obviously, the aim of this chapter is not to test the existence of the EKC but to introduce some elements for its analysis. In fact, there could be other factors, such as technological improvements, which may explain an absolute delinking for some gases over the time (see Chapter 3).

b) Statistical analysis: expenditure and size elasticity of emissions

Although the graphical approach is suggestive and easy to interpret, its outcomes can benefit from a parallel statistical analysis. In this section, we carry out a multivariate regression to analyse the relation between emissions and expenditure corrected by the effect of household size. We have decided to apply the same functional form used by Wier *et al.* (2001) and Lenzen *et al.* (2006) to analyse household energy requirements and/or the embodied emissions in other countries[118]:

$$R^{household} = \alpha C^{\beta_1} * \exp(\beta_2 N) \qquad (4.7)$$

Where α is a constant, $R^{household}$ are per-capita household emissions, C are per-capita household expenditure, and N the number of household members. This expression lends itself easily to linear regression analysis by taking logarithm of both sides. Thus, we estimate the expenditure elasticity of emissions β_1 and the relationship between the variation of household size and emissions β_2 by performing a regression considering 9,628 different households. We apply the ordinary least-squares method to:

$$\ln R^{household} = z + \beta_1 \ln C + \beta_2 N \qquad (4.8)$$

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[118] Wier *et al.* (2001) showed that this functional form yields a better correlation than power, logarithmic, or polynomial functions.

On one hand, the expenditure elasticity of emissions β_1 describes the relative change in household emissions $R^{household}$ for a given relative change in household expenditure C:

$$\beta_1 = \frac{\frac{\partial R^{household}}{\partial C}}{\frac{R^{household}}{C}} \tag{4.9}$$

On the other hand, the dependence of emissions on the number of household members N can be characterised by the relative change β_2:

$$\beta_2 = \frac{\partial R^{household}}{R^{household} \partial N} \tag{4.10}$$

If $\beta_1 > 1$, it means that emissions increase more proportionally than household expenditure increase for a given household size. Whereas values between 0 and 1, i.e. $0 < \beta_1 < 1$, would indicate that emissions increase less proportionally than household expenditure increase, showing a relative delinking between increasing expenditure and emissions. For instance, $\beta_1 = 0.6$ means that for a 10% increase in household expenditure, the emissions increase approximately 6%. In fact, the graphics described in Section a and the expenditure elasticity of emissions β_1 are directly linked. Given that the elasticity β_1 measures the deviation from proportionality of emissions with regard to expenditures, an increasing function of average emissions means a positive elasticity β_1; besides, if function of average emission intensity is increasing (decreasing) the elasticity β_1 will be higher (lower) than one. On the contrary, a negative elasticity β_1 should be followed by a decreasing function of average emissions, which would be the result we would expect if it were an absolute delinking between increasing expenditure and emissions. Thus, β_1 could also be interpreted as a synthetic quantitative indicator for analysing the effect of the expenditure level upon the emissions[119].

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[119] Similarly, positive values for β_2, for instance $\beta_2 = 0.3$, it would mean that for each additional household member the per-capita emissions increase approximately by 30%. On the contrary a negative value of $\beta_2 = -0.2$, it would indicate that each additional household member decreases per-capita emissions by approximately 20% (Wier *et al.*, 2001).

The results of the multivariate regression are shown in Table 4.1. We find that the expenditure variable was significant for all gases, whereas size it was only for CO_2, synthetic greenhouse gases, SO_2, and NO_x but not for CH_4, N_2O, and NH_3[120].

Table 4.1: Expenditure elasticity and size elasticity of per-capita emissions of nine gases, Spain 2000

	Expenditure			Size			
	β_1		|t|	β_2		|t|	R^2
CO_2	0.91	±0.005	175.028*	0.03	±0.002	16.551*	0.77
CH_4	0.72	±0.006	122.333*	0.00	±0.002	0.966	0.64
N_2O	0.78	±0.005	155.364*	0.00	±0.002	1.031	0.74
Synthetic gases*	1.11	±0.004	258.771*	0.03	±0.002	17.506*	0.88
Total in CO_2 equivalent	0.89	±0.005	194.363*	0.03	±0.002	15.336*	0.81
SO_2	0.86	±0.003	247.921*	-0.03	±0.001	25.061*	0.89
NO_x	0.87	±0.005	168.676*	0.04	±0.002	18.298*	0.76
NH_3	0.71	±0.006	109.721*	0.00	±0.003	0.907	0.58
Correlation coefficient							0.33
Variance Inflation Factor							1.13

* Significant variables at the 95% confidence level.
** Synthetic gases are total SF_6, HFCs and PFCs emissions measured in CO_2 equivalent units.
Source: own elaboration.

As expected, all gas emissions had positive expenditure elasticity β_1 and for the synthetic greenhouse gases it was higher than unit. The elasticity values oscillated from 0.71 to 1.11. The energy gases, i.e. CO_2, SO_2, and NO_x, had high elasticity values but inferior to unit. The lowest values corresponded to those gases linked with food consumption, i.e. CH_4, N_2O, and NH_3. These results indicate that increase of household expenditure generates an increase of emissions less than proportional. In the case of CH_4, N_2O, and NH_3 it could be explained because 'wealthier' households spend less percentage of their budget on food. In both cases, these values indicate that the emission intensity diminishes with the expenditure level as Figures 4.7 and 4.8 showed, which could be explained if households of higher quintiles purchase more commodities with low energy intensities. In contrast, the highest value ($\beta_1 = 1.11$) corresponded to synthetic greenhouse gases, i.e. when household expenditures increase by 10% synthetic greenhouse gas emissions increase more than proportionally 11.1%. In this case, it may be due to the higher expenditure of 'wealthier' households on those COICOP categories with high

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[120] Given the purpose of this chapter, we are not particularly interested in analysing the values of 'size elasticity' β_2 but those related to the 'expenditure elasticity' β_1. For this reason we only analyse the outcomes of the latter. Moreover, it should be mentioned that the values of β_2 are really small and in some cases not statistically significant.

emission intensity such as medical products and/or on furniture and other household equipment as air conditioning.

It should be mentioned that due to the aggregation level of the data, this approach does not allow for specific consumer choices between different types of goods and services of the same category such as high-quality versus low-quality products or hand-made versus manufactured goods. High-quality and hand-made commodities usually have a higher price; whereas total emissions embodied in them do not need to increase in the same magnitude or even can decrease. Thus, for high-quality and hand-made goods it should be expected lower emission intensities (Weber and Perrels, 2000). However, due to input-output aggregation, we are assuming that one euro spent either on a high-quality good or on a low-quality good will result in the same amount and type of pollutant. Consequently, the actual expenditure elasticity of emissions may be smaller than those reported in this study (Vringer and Blok, 1995).

As discussed above, most of the studies examined direct and indirect energy requirement for household consumption and only few of them estimated emissions embodied in it (mainly CO_2 emissions). Moreover, according to our knowledge, no research has been undertaken on other types of atmospheric pollutants. However, given the strong relationship between energy requirements and associated CO_2 emissions we can compare our per-capita expenditure elasticity for CO_2 emissions with per-capita expenditure elasticity of energy requirements of others works. Thus, our result of a high elasticity less than one agrees with other works. Specifically, Lenzen *et al.* (2006) calculated the per-capita expenditure elasticity of energy requirements for five countries. They report values that range from 0.64 of Japan to 1 of Brazil, with values of 0.78 for Australia, and 0.86 for Denmark and India. Although we cannot strictly compare these results with our per-capita expenditure elasticity for CO_2 emissions, our outcome $(\beta_1 = 0.91)$ lies within those values[121].

c) Analysis of the composition of households' consumption baskets

From the above results, it appears that as expenditure increases consumption patterns tend to move away from goods and services with high emission intensities

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[121] Lenzen *et al.* (2006) carried out a multivariate regression considering seven variables and only evaluate the per-capita energy requirement but not associated emissions.

towards less emission intensive commodities. This is so for all gases but for synthetic greenhouse gases that present an opposite tendency.

Figure 4.9: Distribution of equivalent expenditure per quintiles of expenditure, Spain 2000

Source: own elaboration.

Figure 4.9 breaks down household equivalent expenditure into the 14 COICOP pseudo-divisions. It confirms the previous statement. That is, on one hand, higher quintiles spent a higher proportion of their budgets on those categories with lower emission intensities such as X 'Education'. And, on the other hand, their expenditure percentages on more polluting categories were lower. This was so in I 'Food and non-alcoholic beverages', II 'Alcoholic beverages, tobacco, and narcotics', and IV.b 'Electricity, gas, and other fuels'. However, the previous hypothesis seems not to have been supported in two categories with relatively high emission intensities, i.e. VII.a 'Personal transport' and XI 'Restaurants and hotels'. Regarding the synthetic greenhouse gases the results are as expected: higher quintiles spent relatively more income on V 'Furnishings, household equipment, and routine household maintenance' and VI 'Health'.

Nevertheless, pseudo-divisions represented in Figure 4.9 group different goods and services, which can present different behaviour. For instance VII.a 'Personal transport' includes the purchase of vehicles (group 7.1) but also expenditures on fuels and lubricants for vehicles (group 7.2). In Table 4.2, we display the expenditure percentages of total household expenditure on 47 COIOCP groups. The criteria to select those commodities were two: first, the level of pollutant intensity and, second, the relative weight of each COICOP group of total expenditure.

Table 4.2: Equivalent expenditure in key commodities for emissions as percentage of total equivalent expenditure of each quintile, Spain 2000

Units: percentage of total expenditure.

	First quintile	Second quintile	Third quintile	Forth quintile	Fifth quintile
CO_2, NO_x, and SO_2					
04.5. Electricity, gas, and other fuels	5.00	4.10	3.56	3.04	2.31
07.2. Operation of personal transport equipment	4.05	5.46	5.93	5.73	4.75
CH_4, N_2O, and NH_3					
01.1. Food	24.69	21.78	19.83	16.89	11.94
11.1. Catering services	5.51	6.79	7.81	8.39	7.94
Synthetic greenhouse gases					
06.1. Medical products, appliances, and equipment	1.35	1.38	1.25	1.22	1.05
12.1. Personal care	2.06	2.09	2.04	1.96	1.69
05.6. Goods and services for household maintenance	1.57	1.68	1.66	1.77	2.26
07.1. Purchase of vehicles	0.20	0.44	0.93	2.81	10.89
03.1. Clothing	4.74	5.98	6.41	6.59	6.04

Source: own elaboration.

As expected, this table confirms previous results but it also helps us to understand better some of them. For instance, from Table 4.2 we can see that the behaviour of VII.a 'Personal transport' is mainly due to the group 7.1 'Purchase of vehicles'. As mentioned in Section 4.3.3, purchases of durable goods such vehicles are concentrated in the highest quintile. Probably, the 10.89% of the fifth quintile would also explain the evolution of synthetic greenhouse gases. Regarding the COICOP groups linked with CH_4, N_2O, and NH_3 emissions, we see that expenditures on 01.1 'Food' decreased as expenditure level increased; whereas 11.1 'Catering services', which gathers expenditures on restaurants and analogous, increased until the forth quintile and then decreased smoothly. However, if we consider the global expenditure on both groups, i.e. 01.1 and 11.1 together, we see that it decreased as the level of expenditure increased.

4.5. Final remarks

In this chapter we applied the input-output approach to analyse a specific topic related to the EKC hypothesis. The purpose of this chapter was not to test the existence of an EKC in Spain but to study whether the structure of consumption of 'wealthier' household could have a positive effect for reducing environmental pressures. With this aim in mind, we applied the environmentally extended input-output model to analyse the impact on atmospheric pollution of the consumption of different Spanish households in 2000. Combining information from different databases we estimated total emissions from household consumption of nine gases, i.e. the six greenhouse gases (CO_2, CH_4, N_2O, SF_6, HFCs, and PFCs) and three local gases (SO_2, NO_x, and NH_3). Households were classified by quintiles of expenditure and we applied two approaches: on one hand, we estimated the per-capita emissions and, on the other hand, the emissions associated with the expenditure of equivalent consumer units applying the modified OECD scale.

In connection with the EKC debate, we can say that the more a household spends the more emissions it generates; however, the atmospheric pollution emitted per unit of household consumption decreases with the expenditure level. In fact, in 2000 Spanish households with higher 'economic position' spent a lower proportion of their budgets on those categories more pollutant, i.e. on 'Electricity, gas, and other fuels' (CO_2, NO_x, and SO_2) and on 'Food' (CH_4, N_2O, and NH_3). On the contrary, the expenditure percentage on 'Furnishing, household equipment, and routine household maintenance' was higher, which could explain the opposite trend of the synthetic greenhouse gases.

These outcomes were confirmed by the values of expenditure elasticity of emissions that we estimated for all the gases performing a multivariate regression. We found a positive elasticity significantly lower than unit for almost all gases. The only exception to this was the synthetic greenhouse gases, which presented a positive elasticity higher than unit in keeping with the graphical analysis. These results could be arguments to justify a relative delinking between increasing consumption and emissions but it would not be sufficient to expect an absolute one.

The latter should be supported by negative expenditure elasticity, which only could happen if the more pollutant commodities were ‘inferior goods’. Obviously, it could be other factors that have not been considered in this chapter that may explain an absolute delinking for some gases along the time. One of these factors is technological changes, which induced by environmental policy or by themselves could act in the opposite direction.

Although input-output analysis is a suitable methodology to analyse this topic there are some limitations related to, especially when analysing emissions embodied in individual or particular kind of goods or services, which should be pointed out. For instance, in a conventional environmentally extended input-output model a 100€ pair of shoes is assumed to emitted four times as much gases as a 25€ pair of shoes. This is so, even though they were produced with the same technology or they were the same pair of shoes with different price, e.g. before and after sale price. Another limitation is regarding the aggregation level of available input-output tables, which could imply in some cases that similar products were assumed to be produced with the same technology and hence to generate the same emissions per unit of monetary unit worth, although they had been produced following different production processes such a wooden hand made chair and a manufactured one. However, despite the aim of this study is not to make this kind of detailed analysis these drawbacks could be overcome by using input-output tables in physical units or applying more detailed data as life cycle analysis.

On the other hand, it also deserves to be mentioned some particularities of the environmentally extended input-output model applied in this chapter. First, as already stated, we considered both domestic and imported emissions assuming in order to consider the global emissions households are responsible for, regardless where they have been generated.

Second, it is important to remark that in this chapter we did not consider actual final consumption of households but their final consumption expenditure. The difference between these concepts lies in the treatment of certain goods and services financed by the government or non-profit institutions serving households that are supplied to households as social transfers in kind (European Commission, 1996). Thus, demand on public services and/or infrastructure as well as non-monetary transactions are excluding from this study because the difficulty to allocate collective consumption to individual households.

Third, we classified households by quintiles since we carried out a static analysis. However, if the purpose of the study were to analyse the effects of growth population or income distribution it should be considered to classify them using intervals. Regarding household classification we used expenditure as classifying variable instead of income. By doing so we avoided the problem of estimating emissions related to savings, since a monetary unit lent to a bank or spent for stock soon finds its way into a construction project, a new business, or new machines, which can generate as much emission or more as private consumption. Although it was not the aim of this chapter it would be worth to consider it on future research.

Finally, this study may provide a basis for planning future environmental policy. Since we have information about which are the more pollutant products some environmental policies aimed at reducing the emissions can be applied on consumers. The most common and well known instrument is environmental tax that imposes highest levies on the most polluting commodities. Environmental taxes on consumers are traditionally applied to some energy goods such as fuels or other energy goods in order to tax direct emissions; however, we do not have any evidence that this instrument had been applied to tax indirect household emissions through levies to other goods and services. In some countries, however, there are taxes on emissions produced by economic sectors, which transfer part of the levy to consumers. Somehow it is a way to tax indirect household emissions indirectly. The impact of such policies, however, will depend on the demand price elasticity of each product. Besides it, other ways to reduce emissions will be those directly addressed to consumers such as environmental information campaigns or green label programmes.

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Appendix

4.A. Intensity matrix of total household emissions $\mathbf{D}$

Table 4.A.1 presents the intensity matrix of total household emissions $\mathbf{D}$, whose elements represent emission coefficients from direct and indirect household emissions, i.e. $\mathbf{D} = \mathbf{D}^{\mathbf{direct}} + \mathbf{D}^{\mathbf{indirect}}$. However, as mentioned in Section 4.3.2 we only considered CO_2 and NO_x direct emissions of 04.5 ‘Electricity, gas, and other fuels’ and 07.2 ‘Operation of personal transport equipment’ COICOP groups. Therefore, the cell 04.5-CO_2 is the sum of direct and indirect coefficient, i.e. 5.25=1.78+3.47. Similarly, cell 04.5-NO_x is 22.79=9.41+13.38, cell 07.2-CO_2 is 3.56=2.93+0.63, and cell 07.2-NO_x is 18.67=15.45+3.22. For the remainder cells all the coefficients represent only indirect emissions. Notice that for printing reasons we show the transpose of matrix $\mathbf{D}$.

Table 4.A.1: Intensity matrix of total household emissions, Spain 2000

Units: tonnes of gas (except CO_2 in thousand of tonnes and SF_6, HPCs, and PFCs in kilograms) per million of euro.

	Greenhouse gases						Other gases		
	CO_2	CH_4	N_2O	SF_6	HFCs	PFCs	SO_2	NO_x	NH_3
01.1. Food	0.54	10.26	0.53	0.01	1.56	0.06	2.12	4.76	3.17
01.2. Non-alcoholic beverages	0.52	9.27	0.48	0.01	1.58	0.06	2.17	4.16	2.85
02.1. Alcoholic beverages	0.43	6.52	0.34	0.01	1.37	0.06	1.87	3.22	1.99
02.2. Tobacco	0.32	3.43	0.18	0.01	1.13	0.05	1.53	2.15	1.03
02.3. Narcotics	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
03.1. Clothing	0.36	1.25	0.09	0.01	2.87	0.05	2.12	1.73	0.33
03.2. Footwear	0.34	1.76	0.09	0.01	2.16	0.05	1.93	1.71	0.39
04.1. Actual rentals for housing	0.19	0.32	0.03	0.01	0.63	0.04	1.23	0.81	0.09
04.2. Imputed rentals for housing	0.19	0.32	0.03	0.01	0.63	0.04	1.22	0.81	0.09
04.3. Maintenance and repair of the dwelling	0.62	0.84	0.07	0.03	1.91	0.18	2.98	2.44	0.19
04.4. Water supply and miscellaneous services relating to the dwelling	0.56	1.31	0.10	0.01	0.97	0.09	4.29	2.24	0.40
04.5. Electricity, gas and other fuels	5.25	4.04	0.14	0.01	0.64	0.06	33.88	22.79	0.10
05.1. Furniture and furnishings, carpets and other floor coverings	0.41	0.83	0.07	0.02	1.85	0.21	2.14	1.97	0.20
05.2. Household textiles	0.45	1.95	0.13	0.01	4.78	0.06	2.71	2.20	0.52
05.3. Household appliances	0.39	0.62	0.05	0.05	1.35	0.32	2.22	1.71	0.12
05.4. Glassware, tableware and household utensils	0.98	0.81	0.08	0.01	1.88	0.35	4.67	3.38	0.13
05.5. Tools and equipment for house and garden	0.47	0.73	0.06	0.20	1.73	0.43	2.71	2.05	0.14
05.6. Goods and services for routine household maintenance	0.25	0.39	0.09	0.00	5.28	0.03	1.49	0.98	0.18
06.1. Medical products, appliances and equipment	0.66	0.93	0.22	0.02	14.12	0.12	3.98	2.57	0.44
06.2. Outpatient services	0.21	0.48	0.08	0.01	1.99	0.03	1.44	0.86	0.15
06.3. Hospital services	0.21	0.48	0.08	0.01	1.99	0.03	1.44	0.86	0.15
07.1. Purchase of vehicles	0.55	0.77	0.07	0.03	3.07	0.53	3.37	2.22	0.14
07.2. Operation of personal transport equipment	3.56	0.93	0.07	0.01	0.97	0.05	3.61	18.67	0.13
07.3. Transport services	0.42	0.58	0.05	0.01	0.86	0.05	1.45	1.91	0.13
08.1. Postal services	0.23	0.27	0.02	0.01	0.30	0.04	1.46	0.88	0.04
08.2. Telephone and telefax equipment	0.42	0.57	0.05	0.10	1.40	0.25	2.44	1.73	0.11
08.3. Telephone and telefax services	0.23	0.33	0.02	0.01	0.42	0.04	1.41	0.94	0.06
09.1. Audio-visual, photographic and information processing equipment	0.37	0.69	0.07	0.06	1.81	0.17	2.20	1.64	0.21
09.2. Other major durables for recreation and culture	0.39	1.05	0.07	0.02	1.90	0.25	2.20	1.79	0.25
09.3. Other recreational items and equipment, gardens and pets	0.40	4.68	0.27	0.01	2.61	0.12	2.01	2.52	1.43
09.4. Recreational and cultural services	0.24	1.25	0.17	0.01	0.71	0.03	1.40	1.20	0.79
09.5. Newspapers, books and stationery	0.40	0.78	0.06	0.01	1.81	0.06	2.46	1.77	0.18
09.6. Package holidays	0.36	0.68	0.05	0.01	1.16	0.05	1.71	2.07	0.12
10.1. Pre-primary and primary education	0.13	0.27	0.02	0.00	0.25	0.02	0.96	0.52	0.06
10.2. Secondary education	0.13	0.27	0.02	0.00	0.25	0.02	0.96	0.52	0.06
10.3. Post-secondary non-tertiary education	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.4. Tertiary education	0.13	0.27	0.02	0.00	0.25	0.02	0.96	0.52	0.06
10.5. Education not definable by level	0.13	0.27	0.02	0.00	0.25	0.02	0.96	0.52	0.06
11.1. Catering services	0.29	3.34	0.18	0.00	0.80	0.03	1.58	2.00	1.01
11.2. Accommodation services	0.29	3.30	0.17	0.00	0.80	0.03	1.58	1.99	1.00
12.1. Personal care	0.44	1.21	0.19	0.01	5.63	0.08	2.65	1.93	0.64
12.2. Prostitution	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12.3. Personal effects n.e.c.	0.38	0.86	0.06	0.02	1.67	0.17	1.99	1.82	0.19
12.4. Social protection	0.21	0.48	0.08	0.01	1.99	0.03	1.44	0.86	0.15
12.5. Insurance	0.25	0.38	0.03	0.01	0.39	0.03	1.75	0.97	0.07
12.6. Financial services n.e.c.	0.24	0.41	0.03	0.01	0.45	0.03	1.69	0.99	0.08
12.7. Other services n.e.c.	0.22	0.74	0.09	0.01	0.72	0.04	1.29	1.03	0.38

Source: own elaboration.

Note: n.e.c. means not elsewhere classified.

4.B. Estimation of the transformation matrix $\mathbf{U}$

In this appendix we describe the procedure followed to estimate matrix $\mathbf{U}$ that transforms household expenditure on consumption purposes into equivalent expenditure on products. Our starting point is the 1995 transformation matrix supplied by INE, which converts 61 household expenditures classified by CPA into 47 household expenditure classified by COICOP valued at purchaser' prices.

Let $\mathbf{U}^{\mathbf{INE}}_{61x47}$ be the original transformation matrix of row coefficients supplied by INE, we can calculate a matrix $\mathbf{N}^{\mathbf{INE}}_{61x47}$ so that:

$$\mathbf{N}^{\mathbf{INE}}_{61x47} = \hat{\mathbf{c}}^{\mathbf{CPA\,95}}_{61x61}\mathbf{U}^{\mathbf{INE}}_{61x47} \qquad (4.B.1)$$

Where $\hat{\mathbf{c}}^{\mathbf{CPA\,95}}_{61x61}$ is the diagonal matrix of vector of household expenditure in 1995 classified by 61 CPA products $\mathbf{c}^{\mathbf{CPA\,95}}_{61x1}$[122]. Matrix $\mathbf{N}^{\mathbf{INE}}_{61x47}$ is bi-proportional; that is, total sum of rows equals total sum of columns. Thus, adding up the rows of $\mathbf{N}^{\mathbf{INE}}_{61x47}$ matrix we get the COICOP household expenditure $\mathbf{c}^{\mathbf{COICOP\,95}}_{1x47}$ vector, while adding up its columns we get the CPA household expenditure $\mathbf{c}^{\mathbf{CPA\,95}}_{61x1}$ vector:

$$\mathbf{c}^{\mathbf{COICOP\,95}}_{1x47} = \mathbf{i}'_{1x61}\mathbf{N}^{\mathbf{INE}}_{61x47} \qquad (4.B.2)$$

$$\mathbf{c}^{\mathbf{CPA\,95}}_{61x1} = \mathbf{N}^{\mathbf{INE}}_{61x47}\mathbf{i}_{47x1} \qquad (4.B.3)$$

Where $\mathbf{i}'_{1x61}$ and $\mathbf{i}_{47x1}$ denote a row and a column vector of ones, respectively. Although elements of $\mathbf{c}^{\mathbf{COICOP\,95}}_{1x47}$ are valuated at purchaser's prices and elements of $\mathbf{c}^{\mathbf{CPA\,95}}_{61x1}$ are valuated at basic prices, the total household expenditure has the same amount valuated at purchaser's prices. This is so because in $\mathbf{c}^{\mathbf{CPA\,95}}_{61x1}$ there is a row including trade and transport margins and net taxes on products (see Figure 4.B.1 below).

However, we need to estimate matrix $\mathbf{U}_{nxs}$ of dimension 46x47, which differs greatly from the original $\mathbf{U}^{\mathbf{INE}}_{61x47}$. The former should refer to the year 2000; it should convert household expenditures classified by COICOP into CPA, i.e. we need a matrix of column coefficients; it should have dimension 46x47, i.e. 46 CPA rows and

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[122] We get the $\mathbf{c}^{\mathbf{CPA\,95}}_{61x1}$ from the 1995 supply table. We aggregate the original 110 CPA products of household final consumption expenditure vector into 61 rows.

47 COICOP columns; and lastly, matrix $\mathbf{U}_{46x47}$ should not include net taxes on products because we need to transform COICOP household expenditures valued at purchaser's prices into CPA household expenditures valued at basic prices.

Thus, bearing in mind all these requirements we estimate matrix $\mathbf{U}_{46x47}$ following the next steps:

- **Updating**: From $\mathbf{c}_{61x1}^{\mathbf{CPA\,00}}$ and $\mathbf{c}_{1x47}^{\mathbf{COICOP\,00}}$ we update the matrix $\mathbf{N}_{61x47}^{\mathbf{INE}}$ of 1995 to 2000 using the RAS method. The $\mathbf{c}_{61x1}^{\mathbf{CPA\,00}}$ vector is calculated from the 2000 supply table of the Spanish input-output framework, base 1995; and the $\mathbf{c}_{1x47}^{\mathbf{COICOP\,00}}$ vector is calculated from the information about household consumption expenditures by COICOP supplied by 2000 Spanish national accounts, base 1995. Thus, we obtain a $\mathbf{N}_{61x47}$ matrix for 2000.
- **From 61 CPA to 46 CPA with net taxes on products in a separated row**: As mentioned before, our aim is to estimate a $\mathbf{U}_{46x47}$ matrix that did not include net taxes on products. In order to avoid incompatibilities between matrices, the CPA divisions of $\mathbf{U}_{46x47}$ should be suitable to CPA/NACE divisions of $\mathbf{J}_{9x46}$ matrix. Since we cannot aggregate the $\mathbf{N}_{61x47}$ directly, we have to follow a two-fold process.

  First, following the structure of the 2000 symmetrical input-output table estimated in Chapter 2, we disaggregate $\mathbf{N}_{61x47}$ into $\mathbf{N}_{(70+1)x47}$, i.e. the 70 CPA/NACE divisions and one row that represents the net taxes on products. As Figure 4.B.1 shows, we specifically disaggregate 'Trade and transport services', 'Education services', 'Human and veterinary health services; and social services', 'Public sanitation services', and 'Recreational, cultural, and sporting services' rows. For doing so, first, we calculate the row coefficient matrix $\mathbf{U}_{61x47}^{\mathbf{row}}$ as:

  $$\mathbf{U}_{61x47}^{\mathbf{row}} = (\hat{\mathbf{c}}_{61x61}^{\mathbf{CPA\,00}})^{-1}\mathbf{N}_{61x47} \qquad (4.B.4)$$

  Then, assuming the average composition of the components of a group is the same as the average composition of the whole group, we disaggregate the 61 rows of matrix $\mathbf{U}_{61x47}^{\mathbf{row}}$ into 71 rows. After this process we have a row coefficient matrix $\mathbf{U}_{(70+1)x47}^{\mathbf{row}}$.

Secondly, from matrix $\mathbf{U}^{\mathbf{row}}_{(70+1)x47}$ and vector $\mathbf{c}^{\mathbf{CPA\,00}}_{(70+1)x1}$, we apply expression (4B.1) to calculate a new $\mathbf{N}_{(70+1)x47}$. Finally, we aggregate this $\mathbf{N}_{(70+1)x47}$ matrix into a $\mathbf{N}_{(46+1)x47}$ matrix.

Figure 4.B.1: Disaggregated divisions of the transformation matrix

Original divisions of the transformation matrix	CPA/NACE divisions	CPA/NACE codes
Trade and transport services; and taxes less subsidies on products	Services for the trade and repairs of vehicles and motorcycles; combustible retail trade services	50
	Wholesale trade and intermediaries, except of motor vehicles and motorcycles	51
	Services of retail trade, except the trade of motor vehicles, motorcycles and mopeds; personal effects and household belongings repair services	52
	Railway transportation services	601
	Services of other land transport; transportation services via pipelines	602-603
	Maritime and in-land water transport services	61
	Taxes less subsidies on products	
Education services	Market education services	80(p)
	Non-market education services	80(p)
Human and veterinary healh services; and social services	Market human and veterinary health services; Market social services	85(p)
	Non-market human and veterinary health services; Non-market social services	85(p)
Public sanitarion services	Market public sanitation services	90(p)
	Non-market public sanitation services	90(p)
Recreational, cultural, and sporting services	Market recreational, cultural and sporting services	92(p)
	Non-market recreational, cultural and sporting services	92(p)

Source: own elaboration.

- **Getting a column coefficient matrix without the net taxes on products row:** The last step is to obtain the $\mathbf{U}_{46x47}$ without net taxes on products. From $\mathbf{N}_{(46+1)x47}$ we calculate a column coefficient matrix $\mathbf{U}^{\mathbf{column}}_{(46+1)x47}$ as:

$$\mathbf{T}^{\mathbf{column}}_{(46+1)x47} = \mathbf{N}_{(46+1x47)}(\hat{\mathbf{c}}^{\mathbf{COICOP\,00}}_{47x47})^{-1} \qquad (4.B.5)$$

If we eliminate the last row of this matrix we get the $\mathbf{U}_{46x47}$, which allows for translating household expenditures classified according to COICOP valuated at purchaser's prices into household expenditures classified according to CPA valuated at basic prices. Obviously, although $\mathbf{U}_{(46+1)x47}$ is a bi-proportional matrix, $\mathbf{U}_{46x47}$ is not.

4.C. Total emission intensities of 47 COICOP groups

Figure 4.C.1: COICOP divisions and groups

12 COICOP DIVISIONS	47 COICOP GROUPS
01. Food and non-alcoholic beverages	01.1. Food
	01.2. Non-alcoholic beverages
02. Alcoholic beverages, tobacco, and narcotics	02.1. Alcoholic beverages
	02.2. Tobacco
	02.3. Narcotics
03. Clothing and footwear	03.1. Clothing
	03.2. Footwear
04. Housing, water, electricity, gas, and other fuels	04.1. Actual rentals for housing
	04.2. Imputed rentals for housing
	04.3. Maintenance and repair of the dwelling
	04.4. Water supply and miscellaneous services relating to the dwelling
	04.5. Electricity, gas, and other fuels
05. Furnishings, household equipment, and routine household maintenance	05.1. Furniture and furnishings, carpets, and other floor coverings
	05.2. Household textiles
	05.3. Household appliances
	05.4. Glassware, tableware, and household utensils
	05.5. Tools and equipment for house and garden
	05.6. Goods and services for routine household maintenance
06. Health	06.1. Medical products, appliances, and equipment
	06.2. Outpatient services
	06.3. Hospital services
07. Transport	07.1. Purchase of vehicles
	07.2. Operation of personal transport equipment
	07.3. Transport services
08. Communication	08.1. Postal services
	08.2. Telephone and telefax equipment
	08.3. Telephone and telefax services
09. Recreation and culture	09.1. Audio-visual, photographic, and information processing equipment
	09.2. Other major durables for recreation and culture
	09.3. Other recreational items and equipment, gardens, and pets
	09.4. Recreational and cultural services
	09.5. Newspapers, books, and stationery
	09.6. Package holidays
10. Education	10.1. Pre-primary and primary education
	10.2. Secondary education
	10.3. Post-secondary non-tertiary education
	10.4. Tertiary education
	10.5. Education not definable by level
11. Restaurants and hotels	11.1. Catering services
	11.2. Accommodation services
12. Miscellaneous goods and services	12.1. Personal care
	12.2. Prostitution
	12.3. Personal effects n.e.c.
	12.4. Social protection
	12.5. Insurance
	12.6. Financial services n.e.c.
	12.7. Other services n.e.c.

Source: own elaboration from INE (2004).
Note: n.e.c. means not elsewhere classified.

Table 4.C.1: Total emission intensity of the greenhouse gases of different COICOP groups, Spain 2000

Units: Index numbers, mean emissions of total expenditure of households 2000 base = 100

CO_2		**CH_4**		**N_2O**		**Synthetic gases**		**CO_2 equivalent**	
COICOP codes	*Intensity*	*COICOP codes*	*Intensity*	*COICOP codes*	*Intensity*	*COICOP codes*	*Intensity*	*COICOP codes*	*Intensity*
04.5.	755.75	**01.1.**	358.07	**01.1.**	319.32	**06.1.**	823.71	**04.5.**	658.12
07.2.	512.19	**01.2.**	323.54	**01.2.**	289.60	**12.1.**	329.90	**07.2.**	440.99
05.4.	141.23	**02.1.**	227.62	**02.1.**	205.55	**05.6.**	306.35	**05.4.**	126.96
06.1.	94.34	**09.3.**	163.24	**09.3.**	160.95	**05.2.**	279.93	**01.1.**	113.50
04.3.	88.87	**04.5.**	140.96	**06.1.**	134.83	**07.1.**	213.10	**01.2.**	106.91
04.4.	80.19	**02.2.**	119.71	**12.1.**	113.00	**03.1.**	169.79	**06.1.**	102.88
07.1.	79.21	**11.1.**	116.70	**02.2.**	110.97	**05.5.**	163.40	**02.1.**	83.05
01.1.	77.51	**11.2.**	115.17	**11.1.**	106.72	**09.3.**	159.54	**04.3.**	82.21
01.2.	74.90	**05.2.**	67.97	**11.2.**	105.41	**05.4.**	130.48	**04.4.**	76.37
05.5.	67.17	**03.2.**	61.32	**09.4.**	102.04	**03.2.**	128.83	**07.1.**	75.06
05.2.	65.37	**04.4.**	45.74	**04.5.**	82.74	**09.2.**	127.33	**09.3.**	73.67
12.1.	63.82	**09.4.**	43.57	**05.2.**	81.16	**09.1.**	125.89	**05.2.**	69.66
02.1.	61.51	**03.1.**	43.48	**04.4.**	63.63	**04.3.**	125.26	**12.1.**	69.16
07.3.	60.91	**12.1.**	42.23	**03.2.**	56.17	**05.1.**	122.44	**05.5.**	63.58
08.2.	59.91	**09.2.**	36.76	**03.1.**	53.46	**06.3.**	118.12	**05.1.**	56.24
05.1.	58.68	**06.1.**	32.51	**12.7.**	52.81	**06.2.**	118.11	**02.2.**	56.08
09.3.	58.03	**07.2.**	32.50	**05.6.**	52.16	**12.4.**	117.91	**08.2.**	55.97
09.5.	57.04	**12.3.**	29.91	**12.4.**	50.98	**08.2.**	115.02	**07.3.**	55.73
05.3.	56.27	**04.3.**	29.37	**06.2.**	50.90	**12.3.**	109.32	**09.2.**	55.03
09.2.	56.15	**05.1.**	28.85	**06.3.**	50.90	**09.5.**	108.60	**09.5.**	54.47
12.3.	54.10	**05.4.**	28.29	**05.4.**	48.26	**05.3.**	105.63	**03.1.**	52.98
09.1.	53.79	**09.5.**	27.29	**09.2.**	44.49	**01.2.**	95.54	**05.3.**	52.85
09.6.	52.25	**07.1.**	26.98	**04.3.**	43.98	**01.1.**	94.28	**12.3.**	52.07
03.1.	51.78	**12.7.**	25.90	**07.1.**	43.28	**02.1.**	83.28	**09.1.**	51.99
03.2.	49.09	**05.5.**	25.60	**09.1.**	43.13	**09.6.**	70.70	**11.1.**	51.71
02.2.	46.31	**09.1.**	24.12	**07.2.**	42.23	**02.2.**	69.36	**03.2.**	51.59
11.1.	42.09	**09.6.**	23.84	**05.1.**	39.87	**04.4.**	63.18	**11.2.**	51.39
11.2.	41.94	**05.3.**	21.63	**09.5.**	38.96	**07.2.**	60.67	**09.6.**	48.90
12.5.	35.55	**07.3.**	20.37	**12.3.**	37.40	**07.3.**	53.55	**09.4.**	39.83
05.6.	35.50	**08.2.**	19.81	**05.5.**	36.44	**11.2.**	48.39	**05.6.**	38.85
12.6.	35.18	**12.4.**	16.93	**08.2.**	31.39	**11.1.**	48.26	**12.7.**	32.66
09.4.	34.85	**06.2.**	16.87	**05.3.**	30.87	**12.7.**	44.96	**12.5.**	32.55
08.1.	32.81	**06.3.**	16.87	**09.6.**	27.74	**09.4.**	43.84	**12.6.**	32.41
08.3.	32.70	**12.6.**	14.17	**07.3.**	27.43	**04.5.**	42.02	**12.4.**	32.36
12.7.	31.56	**05.6.**	13.66	**04.1.**	17.72	**04.2.**	40.25	**06.3.**	32.34
12.4.	30.87	**12.5.**	13.34	**04.2.**	17.65	**04.1.**	40.25	**06.2.**	32.34
06.3.	30.86	**08.3.**	11.47	**12.6.**	17.04	**08.3.**	28.98	**08.3.**	29.93
06.2.	30.85	**04.1.**	11.21	**12.5.**	16.12	**12.6.**	28.72	**08.1.**	29.61
04.1.	27.98	**04.2.**	11.13	**08.3.**	14.19	**12.5.**	25.13	**04.1.**	26.28
04.2.	27.97	**10.5.**	9.58	**08.1.**	11.80	**08.1.**	22.33	**04.2.**	26.26
10.5.	18.74	**10.2.**	9.58	**10.5.**	11.01	**10.5.**	15.71	**10.5.**	17.54
10.2.	18.74	**10.1.**	9.58	**10.2.**	11.01	**10.2.**	15.70	**10.2.**	17.54
10.1.	18.74	**10.4.**	9.58	**10.1.**	11.01	**10.1.**	15.70	**10.1.**	17.54
10.4.	18.74	**08.1.**	9.29	**10.4.**	11.01	**10.4.**	15.69	**10.4.**	17.54
02.3.	*	**02.3.**	*	**02.3.**	*	**02.3.**	*	**02.3.**	*
10.3.	**	**10.3.**	**	**10.3.**	**	**10.3.**	**	**10.3.**	**
12.2.	*	**12.2.**	*	**12.2.**	*	**12.2.**	*	**12.2.**	*

Source: own elaboration.

Notes: * data not available. Although HBCS gives information about 02.3. 'Narcotics' and 12.2. 'Prostitution', these activities are not included in National Accounts.

** in National Accounts estimation of 10.3. 'Post-secondary non-tertiary education' is included in group 10.4. 'Tertiary education'.

Table 4.C.2: Total emission intensity of other gases of different COICOP groups, Spain 2000

Units: Index numbers,
mean emissions of total expenditure of households 2000 base = 100

SO_2		NO_x		NH_3	
COICOP codes	*Intensity*	*COICOP codes*	*Intensity*	*COICOP codes*	*Intensity*
04.5.	1124.62	**04.5.**	613.98	**01.1.**	381.44
05.4.	154.99	**07.2.**	502.96	**01.2.**	343.35
04.4.	142.41	**01.1.**	128.35	**02.1.**	240.06
06.1.	132.04	**01.2.**	111.99	**09.3.**	171.81
07.2.	119.67	**05.4.**	91.16	**02.2.**	123.88
07.1.	111.72	**02.1.**	86.65	**11.1.**	121.72
04.3.	98.96	**06.1.**	69.12	**11.2.**	120.06
05.2.	89.90	**09.3.**	67.99	**09.4.**	94.88
05.5.	89.81	**04.3.**	65.73	**12.1.**	76.96
12.1.	87.82	**04.4.**	60.40	**05.2.**	62.15
09.5.	81.76	**07.1.**	59.87	**06.1.**	52.98
08.2.	81.11	**05.2.**	59.34	**04.4.**	48.57
05.3.	73.55	**02.2.**	57.97	**03.2.**	46.60
09.1.	72.92	**09.6.**	55.73	**12.7.**	45.53
09.2.	72.91	**05.5.**	55.18	**03.1.**	39.12
01.2.	71.88	**11.1.**	53.99	**09.2.**	30.53
05.1.	70.92	**11.2.**	53.63	**09.1.**	25.48
01.1.	70.50	**05.1.**	53.08	**05.1.**	23.88
03.1.	70.26	**12.1.**	51.86	**12.3.**	23.40
09.3.	66.67	**07.3.**	51.43	**04.3.**	23.07
12.3.	66.11	**12.3.**	48.91	**05.6.**	21.77
03.2.	64.05	**09.2.**	48.19	**09.5.**	21.15
02.1.	62.07	**09.5.**	47.81	**12.4.**	18.04
12.5.	58.10	**08.2.**	46.73	**06.2.**	17.89
09.6.	56.82	**03.1.**	46.66	**06.3.**	17.88
12.6.	56.10	**03.2.**	46.06	**05.5.**	16.76
11.1.	52.58	**05.3.**	46.04	**07.1.**	16.62
11.2.	52.39	**09.1.**	44.11	**05.4.**	15.71
02.2.	50.88	**09.4.**	32.34	**07.3.**	15.54
05.6.	49.60	**12.7.**	27.82	**07.2.**	15.24
08.1.	48.39	**12.6.**	26.65	**09.6.**	14.92
07.3.	48.28	**05.6.**	26.42	**05.3.**	14.47
06.3.	47.68	**12.5.**	26.01	**08.2.**	12.83
06.2.	47.68	**08.3.**	25.30	**04.5.**	11.80
12.4.	47.67	**08.1.**	23.80	**04.1.**	10.38
08.3.	46.87	**12.4.**	23.20	**04.2.**	10.30
09.4.	46.35	**06.3.**	23.17	**12.6.**	9.41
12.7.	42.98	**06.2.**	23.17	**12.5.**	8.41
04.1.	40.66	**04.1.**	21.76	**08.3.**	6.98
04.2.	40.66	**04.2.**	21.74	**10.5.**	6.97
10.5.	31.98	**10.5.**	13.89	**10.2.**	6.97
10.2.	31.98	**10.2.**	13.89	**10.1.**	6.97
10.1.	31.98	**10.1.**	13.89	**10.4.**	6.97
10.4.	31.98	**10.4.**	13.88	**08.1.**	4.53
02.3.	*	**02.3.**	*	**02.3.**	*
10.3.	**	**10.3.**	**	**10.3.**	**
12.2.	*	**12.2.**	*	**12.2.**	*

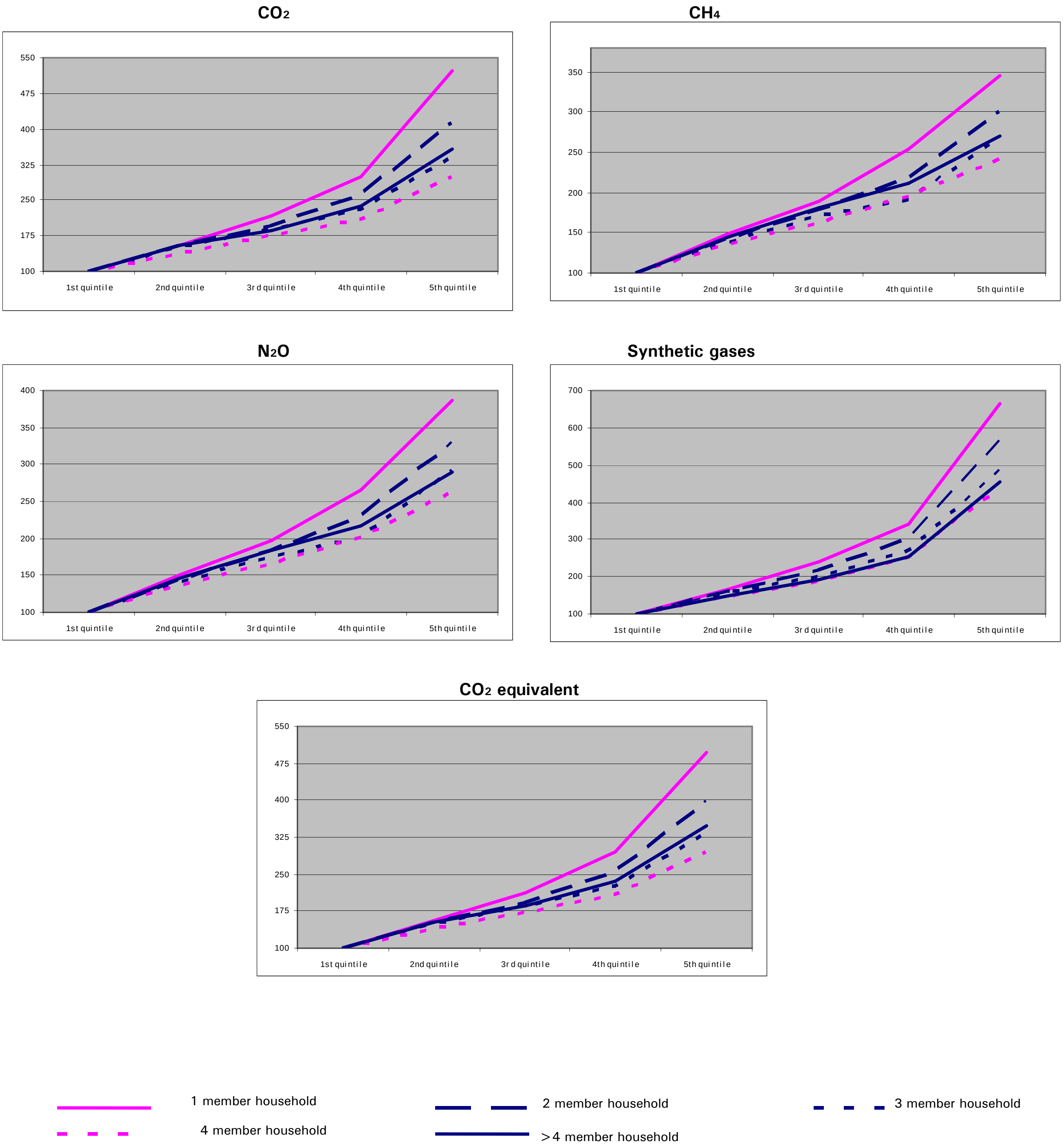
Source: own elaboration.

Notes: * data not available. Although HBCS gives information about 02.3. 'Narcotics' and 12.2. 'Prostitution', these activities are not included in National Accounts.
** in National Accounts estimation of 10.3. 'Post-secondary non-tertiary education' is included in group 10.4. 'Tertiary education'.

4.D. Graphical analysis for different size households

Figure 4.D.1: Member household mean emissions of greenhouse gases by quintiles of expenditure, Spain 2000

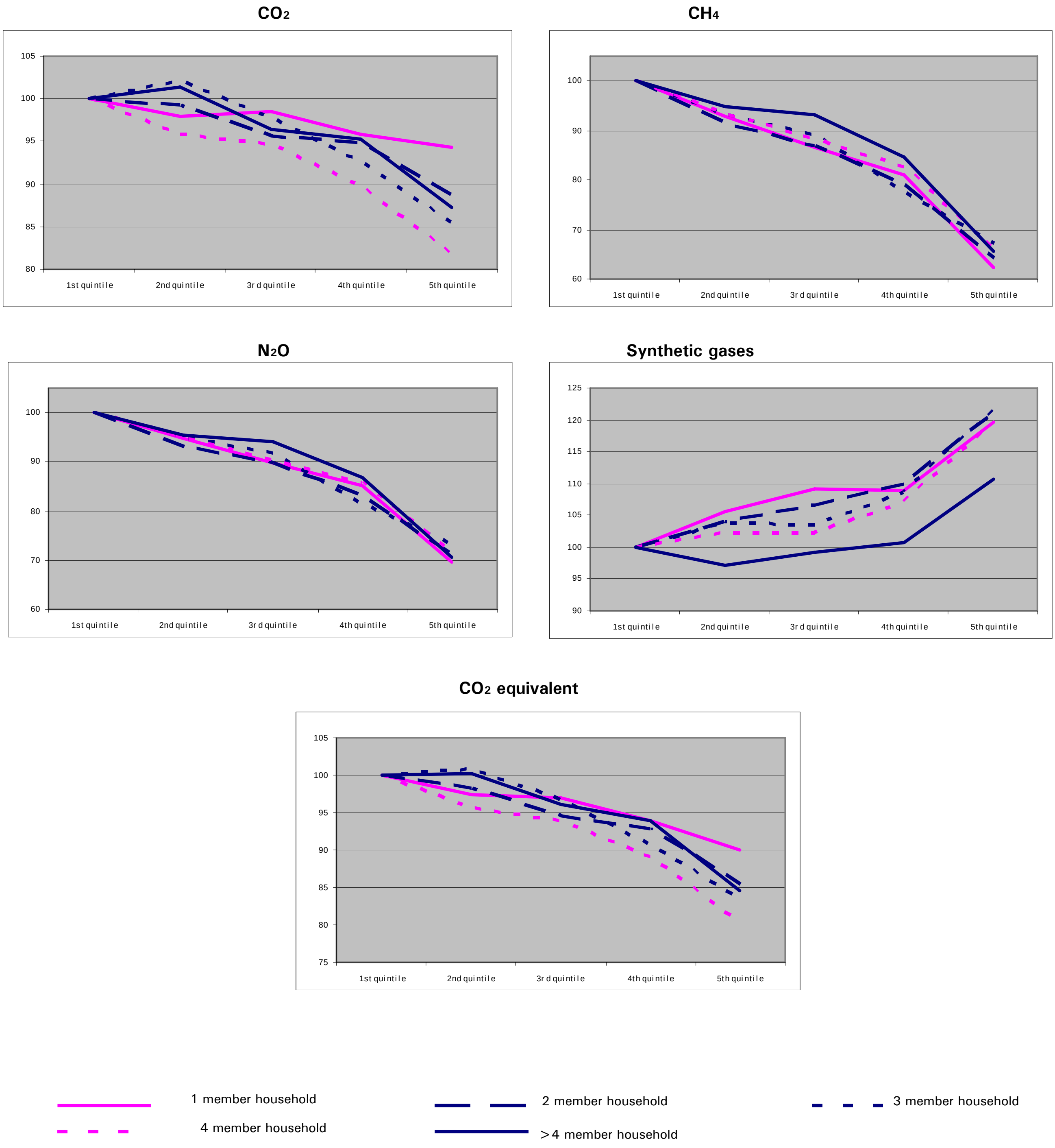
Units: first quintile base = 100.



Source: own elaboration.

Figure 4.D.2: Member household mean intensities of greenhouse gases by quintiles of expenditure, Spain 2000

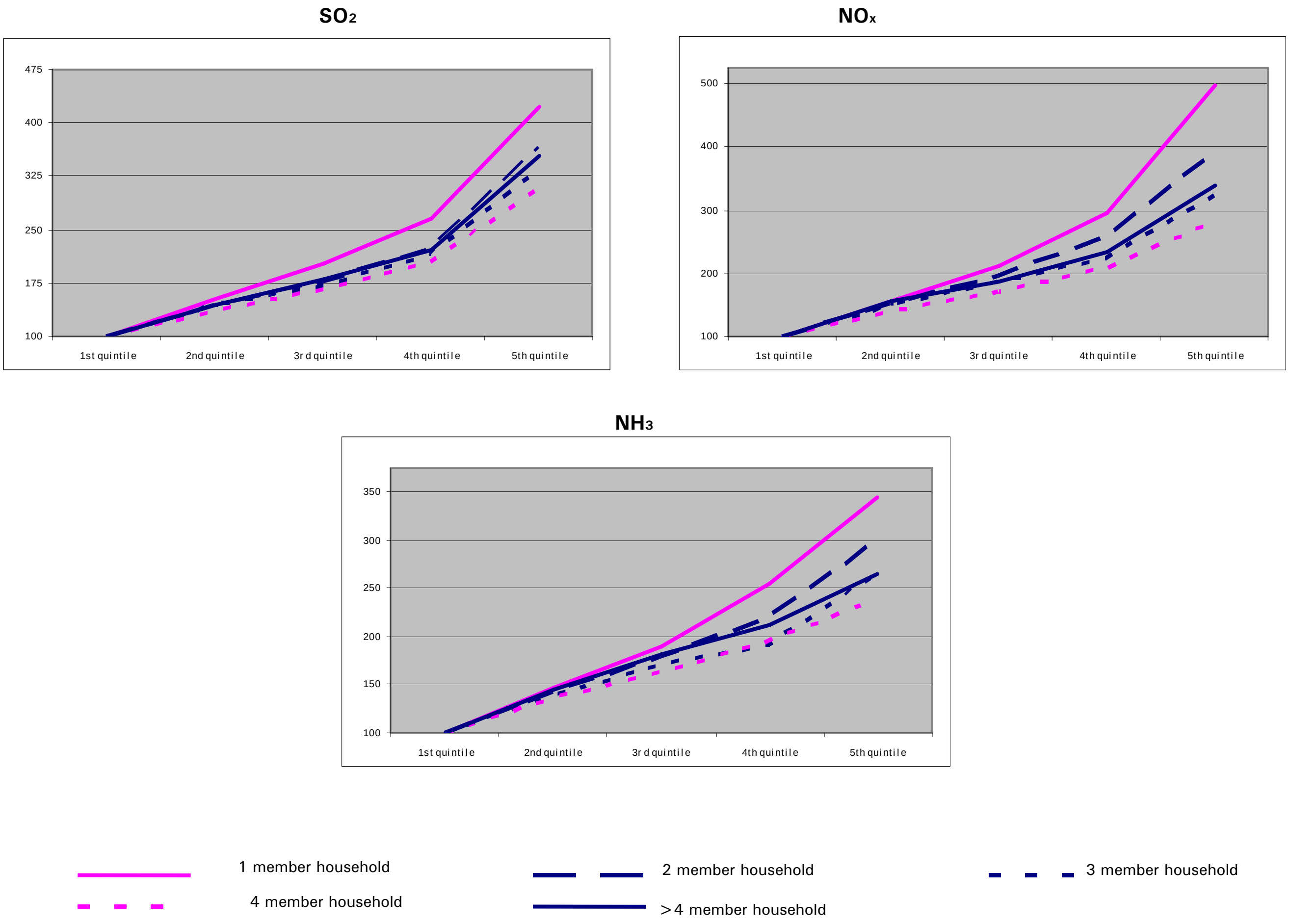
Units: first quintile base = 100.



Source: own elaboration.

Figure 4.D.3: Member household mean emissions of other gases by quintiles of expenditure, Spain 2000

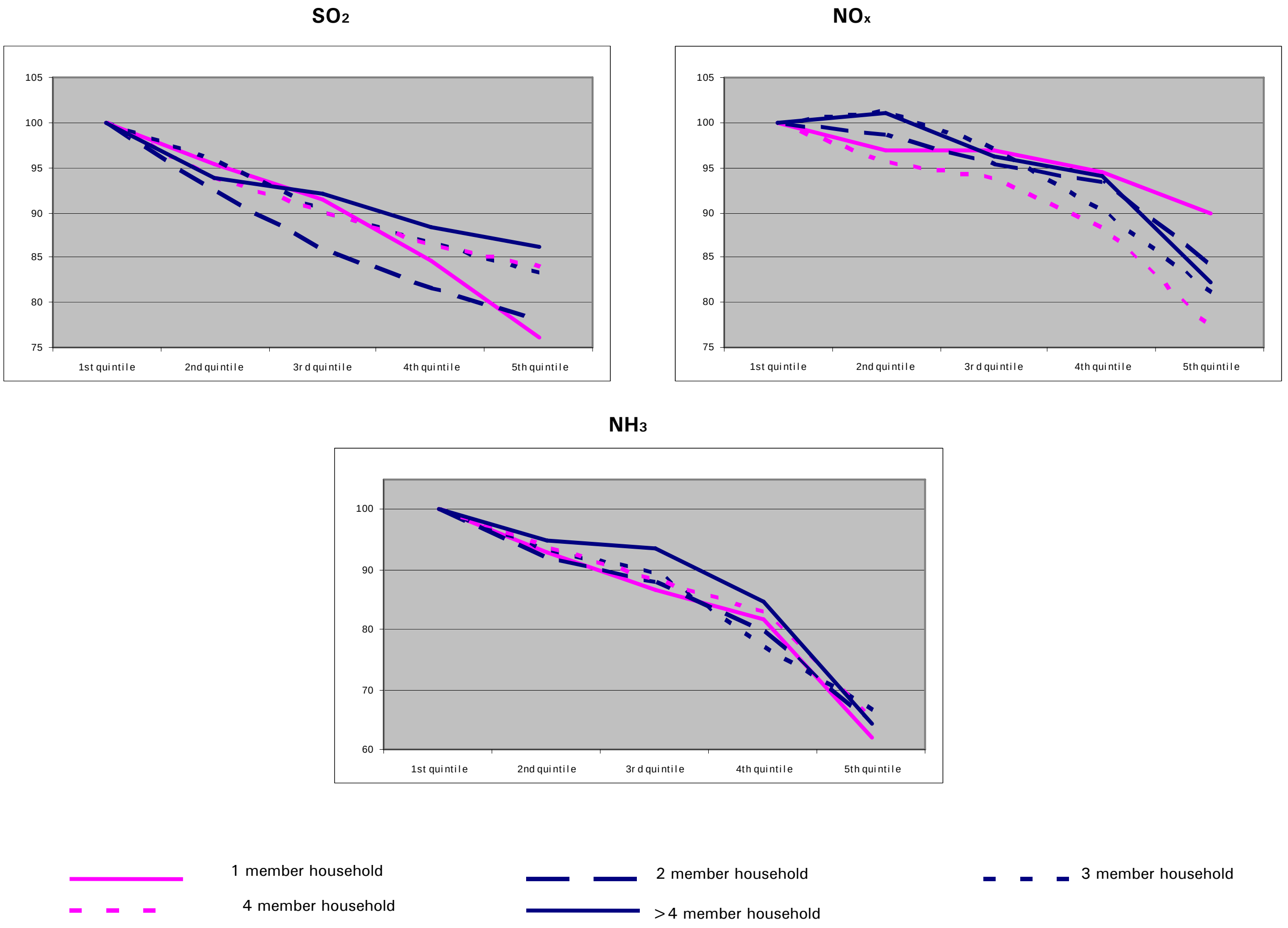
Units: first quintile base = 100.



Source: own elaboration.

Figure 4.D.4: Member household mean intensities of other gases by quintiles of expenditure, Spain 2000

Units: first quintile base = 100.



Source: own elaboration.

5. Trade and atmospheric pollution in Spain

5.1. Introduction

In the last decades, economists, policy makers, and environmental and social communities have been debating the consequences of globalization for environmental problems. One example is the question whether international trade is good for the environment, which is still open in the so-called trade-environment debate (Ekins *et al.*, 1994; van den Bergh and de Mooij, 1999). However, given the multiplicity of perspectives and factors that should be taken into account, it is widely accepted that this kind of questions does have neither a simple nor an easy answer.

On one hand, the literature stimulated by the empirical work of Grossman and Krueger (1991), which analysed the environmental implications of North American Free Trade Agreement (NAFTA), support the view that gains of national income induced by free trade will increase the demand for environmental quality and will make new investment in pollution abatement affordable. This literature is mainly based on environmental Kuznets curve hypothesis that establishes there is an inverted U relationship between environmental effects and per-capita income. This hypothesis suggests that environmental damages increase at lower income levels but once a critical level of per-capita income has been reached, the environmental damages decline thereafter (Grossman and Krueger, 1991; Shafik and Bandyopadhyay, 1992).

Arguments against, however, establish that even if free trade succeeded in raising incomes and consumption, this would only lead to more pollution. So, as Daly (1974) has long observed, economic growth will indeed be environmentally harmful. As activity levels rise, the environmental constraints to growth may become more and more binding and, in extreme cases, environmental impacts may threaten the resilience of the ecological system on which economic activities depend (Arrow *et al.*, 1995). Moreover, it has been considered the possibility of environmental Kuznets curve not being derived from a genuine environmental improvement but from an exportation of environmental problems to other territories (Stern *et al.*, 1996; Muradian and Martínez-Alier, 2001).

Countries' activities frequently cause environmental pressures that affect, at least in part, to other countries. Sometimes, the spatial displacement of environmental pressures to other territories is unavoidably because it depends on characteristics of the environmental problem, such as atmospheric pollution that crosses borders or river pollution that travels through countries downstream. However, other times this spatial displacement is due to relocation of production processes abroad and/or substitution of domestic production by imports. Consequently, by means of international trade consumption in one country would be linked to emissions produced in other countries and, therefore, atmospheric pollution produced in one country does not need to be the same as emissions that have been actually generated to satisfy its consumption.

In conformity with the preceding, the emission responsibility of any country can be defined from two different perspectives: the producer or the consumer standpoint[123] (Proops *et al.*, 1993; Steenge, 1999; Munksgaard and Pedersen, 2001). The former establishes that any country is responsible for those emissions associated with domestic production regardless of where it will be consumed. Whereas the latter determines the country's responsibility depending on its consumption, i.e. a country is responsible for those emissions generated in order to satisfy its domestic final demand regardless of where it has been produced. This difference, far to be only a theoretical distinction, could have important political implications, such as

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[123] Although the producer and consumer responsibilities are the terminology commonly used in the literature, it is important to advise that the term 'consumer responsibility' may be misleading. In the literature this term refers not only to emissions derived from household consumption but also includes those generated by government spending and gross investment; that is, it refers to domestic final demand. In order to avoid this confusion in this chapter we will use the term 'final user responsibility' to refers to 'consumer responsibility'.

the increasing debate on the 'ecological debt' concept (Martínez-Alier, 1993) about the environmental pressures caused by the North supported by the South (Torras, 2003), or negotiations in international agreements about global environmental problems.

Since the validation of the Kyoto protocol in 1997, various countries are concerning in reducing their emissions of some atmospheric pollutants. Concretely, the Kyoto protocol establishes for each country that has ratified the agreement emissions ceilings on six specified greenhouse gases[124]. This target should be reached on average in the five-year accounting period 2008-2012 taking 1990 as a base year. At Kyoto the 15 states members of the European Union (EU) are treated as a single unit and it has been negotiated an overall target for all of them. Concretely, the emission ceiling for the EU is 92 percent of 1990 emissions (United Nations, 1997). However, in subsequent internal distributions of responsibilities decided within the EU different national targets were established for each state member, ranging from 72 percent of Luxembourg to 127 percent of Portugal[125]. In this redistribution of responsibilities Spain, whose per-capita emissions were lower than the EU average, is allowed to increase its emissions by 15% over the 1990 level. Nevertheless, Spain is too far away to fulfil its agreement since in 2006 the Spanish emissions were 49.54% higher (Ministerio de Medio Ambiente, 2008)[126].

These national targets, as well as the official data for monitoring countries' achievements, have been established on the basis of emissions generated by domestic production neglecting part of the emissions embodied in international trade. When we consider domestic production emissions the emissions embodied in exports are included but not those embodied in imports. Consequently, it has been argued that open economies that increase exports of intensive pollutant commodities should make a considerable effort in order to carry out its national target. Munksgaard and Pedersen (2001) suggested that international trade should be taken into account to achieve equitable and feasible reduction targets.

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[124] The commitment refers to the aggregation of six gases measured in CO_2 equivalent units, i.e. carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs).

[125] Council Decision 2002/358/EC of 25 April 2002 concerning the approval, on behalf of the European Community, of the Kyoto protocol to the United Nations framework convention on climate change and the joint fulfilment of commitments thereunder.

[126] According to Rodrigo and Santamarta (2008) in 2007 Spanish emissions were 52.35% higher than the 1990 level.

The aim of this chapter is twofold. On one hand, to estimate what is actually the emission responsibility of Spanish domestic final demand in order to determine whether the official data overestimate or underestimate the reality. And, on the other hand, to estimate the emissions embodied in Spanish international trade with the purpose of analysing what should be the influence of the international trade on not fulfilling the national target established by the Kyoto protocol for Spain. With these objectives in mind, in this chapter we apply a multiregional input-output model to define responsibility emission balance and trade emission balance of Spain for nine different gases: the six greenhouse gases regulated by Kyoto protocol, i.e. CO_2, CH_4, N_2O, SF_6, HFCs, and PFCs; and three gases related to local environmental problems, i.e. SO_2, NO_x, and NH_3. We compute the model for two years using Spanish NAMEA data of 1995 and 2000. Our main result shows that Spain has been a 'net exporter' of all gases in both years; the only exception to this was the NH_3 in 2000.

The input-output model used in this chapter allows for connecting the producer/final user responsibility and the trade emission concepts theoretically. Moreover, it allows us to prove how the official data, generally used to control the achievement of the national targets, do not illustrate emissions actually generated by the domestic final demand of one country, showing that this model can complement the available official information likewise. Finally, the fact of applying the model to compute emission generated not only by greenhouse gases but also by three local gases, it is important since it may provide evidence for stimulating the debate about political implications of exporting different kinds of atmospheric pollutants. If one country exports local or regional pollutants it would mean that this country is shifting environmental costs to other countries. However, when we are considering global pollutants, as the greenhouse gases, it would mean that the country's responsibility in global environmental pressures is greater than it could seem. The latter would be of relevance for international agreements as Kyoto protocol, although it seems very difficult to get global commitments about the total emissions of which a country is responsible for regardless of where they have been produced[127].

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[127] The distinction amongst sort of gases has been analysed in the literature. Using a static, two-country differentiated by income general equilibrium model, Copeland and Taylor (1994) studied trade in a world where pollution is a local public 'bad'. This study was extended in Copeland and Taylor (1995), considering pollution as a global public 'bad'. The welfare effects of trade in both cases are fundamentally different. While in the former trade increases welfare because it is assumed an ideal world in which government regulate pollution optimally and hence eliminate market failures; in the latter, due to pollution crosses borders, uncoordinated regulation of pollution at the national level

As shown the large number of works gathered in the comprehensive survey of Jayadevappa and Chhatre (2000), since the 1970's there has been a growing interest on the complex interactions between economic growth, trade, and environment. However, in the last years there have been an increase of works that compare the emissions associated with exports and imports applying input-output analysis[128] for different countries such as Germany and United Kingdom (Proops *et al.*, 1993), Japan (Kondo *et al.*, 1998), Denmark (Munksgaard and Perdersen, 2001), Brazil (Machado *et al.*, 2001), Spain (Sánchez-Chóliz and Duarte, 2004), Italy (Mongelli *et al.*, 2006), India (Dietzenbacher and Mukhopadhyay, 2007), and Turkey (Tunç *et al.*, 2007).

Although there are considerable differences amongst them, all of these studies analyse relationships between one country and the rest of the world, assuming that the rest of the world has the same technology as the country analysed. In this kind of works this assumption is frequently adopted due to the available data. However, improvements in data availability and quality have made possible, in some cases, to develop and apply more sophisticated models considering different regions and taking into account different technologies between regions. Thus, bilateral trade studies have been carried out between Japan and Canada (Hayami and Nakamura, 2002), Japan and South Korea (Rhee and Chung, 2006), and Japan and the United States (Ackerman *et al.*, 2007). Other works have considered more regions such as Ahmad and Wyckoff (2003), who estimated the emissions embodied in international trade of goods of 24 OECD countries; Lenzen *et al.* (2004) calculated the trade balance for five regions (Denmark, Germany, Sweden, Norway and the rest of the world); Nijdam *et al.* (2005) analysed the impacts of Dutch household consumption considering the Netherlands and three different world regions, and Peters and Hertwich (2006a, 2006b), estimated the environmental impacts of Norway but considering all its trading partners aggregated into seven regions.

It should be mentioned that some of the works (Proops *et al.*, 1993; Hayami and Nakamura, 2002; Rhee and Chung, 2006; Lenzen *et al.*, 2004; Peters and Hertwich, 2006b; and Ackerman *et al.*, 2007) have been theoretically developed by means of a multiregional input-output model (Isard, 1951; Moses, 1955). However, the principal drawback to this approach is the difficulty of getting the necessary and

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cannot eliminate all market failures and, consequently, free trade not raise welfare. Copeland and Taylor (2003) developed a unified theoretical framework.

[128] See Wiedmaan *et al.* (2007) for a review of these works.

detailed data on interregional transactions[129]. Moreover, even in these works it is necessary to make some assumption about the technology of the rest of the world when it is considered as a region in the model. Nevertheless these works are a sign of the importance of considering different technologies when estimating the emissions embodied in trade, pointing out the idea of working towards an authentic environmental world trade model (Duchin, 2005) and the need to improve data[130].

The reminder of the chapter proceeds as follows. In Section 5.2, we develop an environmentally extended multiregional input-output model. The data sources and data preparation are presented in Section 5.3. In Section 5.4, we analyse the empirical results obtained for Spain. Some conclusions and further research are considered in Section 5.5. Finally, in the Appendix we present some mathematical details and extra results.

5.2. Theoretical approach: a multiregional input-output model

The model proposed in this chapter is a multiregional environmentally extended input-output model[131]. This model allows us to estimate both emission responsibility of domestic final demand and emissions embodied in international trade. In this section we first present the specification of the economy. Then, we determine the emissions associated with domestic production and those embodied in imports. Finally, the responsibility and trade emission balances are defined.

5.2.1. The economy

Let us divide the economy into two regions $r = 1, 2$, which could differ in both production technology and atmospheric emission patterns. Since we are interested in determining emission responsibility of one particular region and not in specific bilateral relationships between regions, we define region 1 as the region or the country we want to analyse and region 2 as the rest of the world. According to this specification, we assume that region 1 is a small, open economy and that all imports

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[129] Miller (1998) differentiates the multiregional input-output model (MRIO) from the interregional input-output model (IRIO). The former was designed to overcome some of the IRIO demanding data requirement.

[130] For an environmental application of a World Trade Model with Bilateral Trade (WTMBT) see Strømman *et al.* (2005).

[131] For a clear description of multiregional input-output models see Miller and Blair (1985) chapter 3 and Miller (1998).

of the economy are competitive in the sense that all imported products are also being produced by the domestic region[132].

In this economy any region r is composed of n sectors, which produce one product that may be used by other sectors as an intermediate input or consumed as a final product by final user categories such as households, government, or investment. Since in this economy there are two regions, it means that each sector can sell its product either inside the region or to the rest of the world. Thus, let z_{ij}^r be the monetary value of sales from sector i to sector j inside the region, s_{ij}^r be the monetary value of sales from sector i to sector j outside the region, h_i^r be the value of sales of sector i to final users inside the region (domestic final demand), and e_i^r be the value of sales of sector i to final users outside the region (foreign final demand), then the total value of goods produced by sector i in region r would be:

$$x_i^r = [z_{i1}^r + z_{i2}^r + \ldots + z_{in}^r] + [s_{i1}^r + s_{i2}^r + \ldots + s_{in}^r] + h_i^r + e_i^r \tag{5.1}$$

Arranging the transactions of all sectors in this economy in matrix terms we have:

$$\mathbf{x} = \mathbf{Zi} + \mathbf{y} \tag{5.2}$$

Where $\mathbf{i}$ is a column vector of ones and $\mathbf{x}$, $\mathbf{Z}$, and $\mathbf{y}$ are partitioned matrices and/or vectors that represent the gross output, the intersectorial transactions, and the final uses in the economy:

$$\mathbf{x} = \begin{bmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \end{bmatrix}; \qquad \mathbf{Z} = \begin{bmatrix} \mathbf{Z}^1 & \mathbf{S}^1 \\ \mathbf{S}^2 & \mathbf{Z}^2 \end{bmatrix}; \qquad \mathbf{y} = \begin{bmatrix} \mathbf{h}^1 + \mathbf{e}^1 \\ \mathbf{h}^2 + \mathbf{e}^2 \end{bmatrix} \tag{5.3}$$

Notice that the intersectorial transactions inside region 1 are symbolised by $\mathbf{Z}^1$, i.e. the intraregional transaction matrix; whereas $\mathbf{S}^1$ gathers the transactions from sectors in region 1 to sectors in region 2, i.e. the interregional transaction matrix. Similarly, $\mathbf{h}^1$ and $\mathbf{e}^1$ stand for the domestic final demand and foreign final demand, respectively. The same notation is used for region 2.

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[132] Bulmer-Thomas (1982), United Nations (1999), and Peters and Hertwich (2004) present some examples about the differences between competitive and non-competitive imports in input-output analysis. However, due to available data for Spain we have only considered the competitive ones.

Multiplying the intersectorial transaction matrix $\mathbf{Z}$ by the inverse of diagonal matrix of the gross output vector $\mathbf{x}$ we obtain the partitioned matrix of direct input coefficients:

$$\mathbf{A} = \mathbf{Z}(\hat{\mathbf{x}})^{-1} = \begin{bmatrix} \mathbf{A}^1 & \mathbf{M}^1 \\ \mathbf{M}^2 & \mathbf{A}^2 \end{bmatrix} \tag{5.4}$$

Where $\mathbf{A}^1$ and $\mathbf{A}^2$ are the intraregional direct input coefficient matrices; $\mathbf{M}^1$ is the interregional direct input coefficient matrix from region 1 to region 2; and $\mathbf{M}^2$ the interregional direct input coefficient matrix from region 2 to region 1. It is worth noting that since the value of goods produced in the rest of the world ($\mathbf{x}^2$) is considerable much bigger than the value of sales from sectors of region 1 to sectors of region 2 ($\mathbf{S}^1$), $\mathbf{M}^1$ can be considered to be negligible and/or insignificant and, therefore, it is supposed to be zero[133].

Taking into account this, the above expression (5.2) can be rewritten as $\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{y}$, from which we get straightforwardly the solution of the input-output model as $\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}$ where $\mathbf{I}$ denotes the identity matrix. In matrix terms we have:

$$\begin{bmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \end{bmatrix} = \begin{bmatrix} (\mathbf{I} - \mathbf{A}^1) & \mathbf{0} \\ -\mathbf{M}^2 & (\mathbf{I} - \mathbf{A}^2) \end{bmatrix}^{-1} \begin{bmatrix} \mathbf{h}^1 + \mathbf{e}^1 \\ \mathbf{h}^2 + \mathbf{e}^2 \end{bmatrix} \tag{5.5}$$

Thus, the gross output produced in region 1 and in region 2 would be:

$$\mathbf{x}^1 = (\mathbf{I} - \mathbf{A}^1)^{-1}(\mathbf{h}^1 + \mathbf{e}^1) \tag{5.6}$$

$$\mathbf{x}^2 = (\mathbf{I} - \mathbf{A}^2)^{-1}\mathbf{M}^2(\mathbf{I} - \mathbf{A}^1)^{-1}(\mathbf{h}^1 + \mathbf{e}^1) + (\mathbf{I} - \mathbf{A}^2)^{-1}(\mathbf{h}^2 + \mathbf{e}^2) \tag{5.7}$$

5.2.2. Emissions embodied in gross output production

As mentioned above, this chapter concerns with the responsibility emission balance and the trade emission balance of region 1. However, for determining these concepts we need to estimate the emissions associated with the gross output production in

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[133] Matrices $\mathbf{A}^1$ and $\mathbf{A}^2$ are also called domestic input coefficient matrices; and $\mathbf{M}^1$ and $\mathbf{M}^2$ imported input coefficient matrices. Therefore, $\mathbf{A}^1 + \mathbf{M}^2$ and $\mathbf{A}^2 + \mathbf{M}^1$ represent the total input coefficient matrices of each region 1 and region 2, in that order. Notice that in Chapter 2 (see Section 2.3) these matrices have been represented as $\mathbf{A}^d$, $\mathbf{A}^m$, and $\mathbf{A} = \mathbf{A}^d + \mathbf{A}^m$, respectively. However, for the sake of clarity in this chapter we have preferred the former notation.

each region. Thus, as it has been explained in Section 2.4 of Chapter 2 the matrix of emission coefficients of any region should be represented by $\mathbf{W^r}$, whose w_{lj}^{r} element represents the domestic emissions of pollutant l emitted per unit of industry j's output in region r:

$$\mathbf{W^r} = \mathbf{Q^r}(\hat{\mathbf{x}}^\mathbf{r})^{-1} \tag{5.8}$$

Where $\mathbf{Q^r}$ is the matrix of direct emissions. Now, from expression (5.8) and bearing in mind (5.6) and (5.7) we can determine the emissions generated in each region by the emission vectors of dimension *kx1* $\mathbf{r^1}$ and $\mathbf{r^2}$ such as:

$$\mathbf{r^1} = \mathbf{W^1}(\mathbf{I}-\mathbf{A^1})^{-1}(\mathbf{h^1}+\mathbf{e^1}) \tag{5.9}$$

$$\mathbf{r^2} = [\mathbf{W^2}(\mathbf{I}-\mathbf{A^2})^{-1}\mathbf{M^2}(\mathbf{I}-\mathbf{A^1})^{-1}(\mathbf{h^1}+\mathbf{e^1})]+[\mathbf{W^2}(\mathbf{I}-\mathbf{A^2})^{-1}(\mathbf{h^2}+\mathbf{e^2})] \tag{5.10}$$

Expression (5.9) represents total emissions (direct and indirect) generated in region 1 that are required to fulfil both the domestic final demand of region 1 and the foreign final demand from region 2. Besides this, expression (5.10) also includes the emissions generated in region 2 by producing those inputs that region 1 needs to produce their total final demand, i.e. domestic plus foreign final demand.

5.2.3. Responsibility and trade emission balances

The above expressions (5.9) and (5.10) are essential to define both the responsibility emission balance and the trade emission balance. In this subsection we define both concepts showing that they can be two different approaches to the same concept.

As mentioned above, the emission responsibility of any region can be defined from two different perspectives: the producer and/or the final user responsibility[134]. From the producer point of view, for instance, region 1 would be responsible for the emissions generated by their production regardless of where it will be consumed, i.e. inside or outside the region:

$$\mathbf{rp^1} = \mathbf{W^1}(\mathbf{I}-\mathbf{A^1})^{-1}(\mathbf{h^1}+\mathbf{e^1}) \tag{5.11}$$

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[134] It is worth to recall that in the literature it is widely extended the term 'consumer responsibility' instead of 'final user responsibility'. However, in order to avoid some confusions we prefer to use the latter (see footnote 122).

On the other hand, from the final user standpoint region 1 would be responsible for all emissions caused by their ‘consumption’ regardless of where it has been produced. In this case, vector $\mathbf{ru^1}$ should include not only the emissions associated with final demand of region 1 on region 1 gross output ($\mathbf{h^1}$) and on region 2 gross output ($\mathbf{e^2}$), but also those yielded by the imported inputs required to produce $\mathbf{h^1}$, i.e. the emissions gathered in the second bracket. Thus, we get:

$$\mathbf{ru^1} = [\mathbf{W^1(I-A^1)^{-1}h^1}] + [\mathbf{W^2(I-A^2)^{-1}M^2(I-A^1)^{-1}h^1}] + [\mathbf{W^2(I-A^2)^{-1}e^2}] \quad (5.12)$$

In order to compare the emissions produced by region 1 with those required by region 1’s consumption we can define the responsibility emission balance ($\mathbf{reb^1}$) as the difference between the producer responsibility and the final user responsibility vectors such as:

$$\mathbf{reb^1} = [\mathbf{W^1(I-A^1)^{-1}e^1}] - [\mathbf{W^2(I-A^2)^{-1}M^2(I-A^1)^{-1}h^1}] - [\mathbf{W^2(I-A^2)^{-1}e^2}] \quad (5.13)$$

Obviously, those emissions generated and consumed inside region 1, i.e. $[\mathbf{W^1(I-A^1)^{-1}h^1}]$, are not included in this balance.

However, when it comes to analysing the emissions embodied in international trade of any region we should compare emissions embodied in exports with those emissions embodied in imports. On one hand, the emissions embodied in exports of region 1, $\mathbf{re^1}$, should be defined as those emissions generated inside region 1 in order to satisfy the foreign final demand plus those generated in region 2 in order to produce those imported inputs that region 1 needs to produce this foreign demand. The latter are, in fact, imported emissions that will be re-exported afterwards:

$$\mathbf{re^1} = [\mathbf{W^1(I-A^1)^{-1}e^1}] + [\mathbf{W^2(I-A^2)^{-1}M^2(I-A^1)^{-1}e^1}] \quad (5.14)$$

On the other hand, the emissions embodied in imports of region 1, $\mathbf{ri^1}$, should include emissions embodied in imported inputs and imported final products. That is:

$$\mathbf{ri^1} = \mathbf{W^2(I-A^2)^{-1}[M^2(I-A^1)^{-1}(h^1+e^1)+e^2]} \quad (5.15)$$

Now, given the $\mathbf{re^1}$ and $\mathbf{ri^1}$ vectors, we can define the trade emission balance vector $\mathbf{teb^1}$ as the difference between them such as:

$$\mathbf{teb^1} = [\mathbf{W^1}(\mathbf{I}-\mathbf{A^1})^{-1}\mathbf{e^1}] - [\mathbf{W^2}(\mathbf{I}-\mathbf{A^2})^{-1}\mathbf{M^2}(\mathbf{I}-\mathbf{A^1})^{-1}\mathbf{h^1}] - [\mathbf{W^2}(\mathbf{I}-\mathbf{A^2})^{-1}\mathbf{e^2}] \quad (5.16)$$

Notice that expression (5.16) does not consider those imported emissions that will be exported afterwards, i.e. $[\mathbf{W^2}(\mathbf{I}-\mathbf{A^2})^{-1}\mathbf{M^2}(\mathbf{I}-\mathbf{A^1})^{-1}\mathbf{e^1}]$.

Although $\mathbf{reb^1}$ and $\mathbf{teb^1}$ have been derived from different definitions, both have finally the same expression and, therefore, can be interpreted in the same way. So, if these balances have a positive sign it implies that emissions embodied in exports are higher than those embodied in imports, i.e. the region is a 'net importer' of emissions. Likewise, since official data informs about emissions generated by domestic production, this region should actually be less responsible for the environmental pollution that it is reported. On the contrary, if the sign is negative it means that the emissions embodied in region's imports are higher than those embodied in its exports, i.e. the region is a 'net exporter' of emissions. At the same time, this region should actually be more responsible. In the last case, the responsibility and/or trade emission balances would be indicating the emissions that are being spared by this region, whereas the first case would indicate the contrary[135].

a) A simplification of the model

The model presented above considers regions with different technologies and different emission patterns. However, usually the availability of data regarding the technology of the rest of the world is an important constraint. Aware of this limitation, and bearing in mind the possibility of applying this model for Spain we assume that both regions use the same technology and have the same emission patterns. Therefore, since $\mathbf{M^1} = 0$ this assumption implies $\mathbf{A^2} = \mathbf{A^1} + \mathbf{M^2}$ and $\mathbf{W^2} = \mathbf{W^1}$. Moreover, since our purpose is to estimate the emission responsibility of the Spanish domestic final demand, this assumption is especially interesting for this chapter. Assuming the rest of the world produces commodities following the same 'production recipes' as Spain implies that we are estimating, in fact, the actual emissions avoided or saved by Spain as it purchases part of the commodities overseas (see Section 2.4 in Chapter 2).

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[135] Moreover, the responsibility and trade emission balances can be also interpreted as an environmental opportunity cost or profit depending if the sign is positive or negative, respectively.

Thus, for region 1 the responsibility emission balance (5.13) and the trade emission balance (5.16) can therefore be written as the following expression where $\mathbf{eb}^{1*}$ represents both emission balances[136]:

$$\mathbf{eb}^{1*} = [\mathbf{W}^1(\mathbf{I} - \mathbf{A}^1)^{-1}\mathbf{e}^1] - [\mathbf{W}^1(\mathbf{I} - \mathbf{A}^1 - \mathbf{M}^2)^{-1}\mathbf{M}^2(\mathbf{I} - \mathbf{A}^1)^{-1}\mathbf{h}^1] - [\mathbf{W}^1(\mathbf{I} - \mathbf{A}^1 - \mathbf{M}^2)^{-1}\mathbf{e}^2] \quad (5.17)$$

From this expression, responsibility and trade emission balances by sectors are obtained straightforward. Let $\hat{\mathbf{e}}^1$, $\hat{\mathbf{h}}^1$, and $\hat{\mathbf{e}}^2$ be the diagonal matrices of the $\mathbf{e}^1$, $\mathbf{h}^1$, and $\mathbf{e}^2$ vectors we get the sectorial emission balances as a matrix such as:

$$\mathbf{EB}^{1*} = [\mathbf{W}^1(\mathbf{I} - \mathbf{A}^1)^{-1}\hat{\mathbf{e}}^1] - [\mathbf{W}^1(\mathbf{I} - \mathbf{A}^1 - \mathbf{M}^2)^{-1}\mathbf{M}^2(\mathbf{I} - \mathbf{A}^1)^{-1}\hat{\mathbf{h}}^1] - [\mathbf{W}^1(\mathbf{I} - \mathbf{A}^1 - \mathbf{M}^2)^{-1}\hat{\mathbf{e}}^2] \quad (5.18)$$

Notice that under the assumption of the same technology, total emission balances obtained by expression (5.17) are the same as those obtained by the next expression (5.19)[137]:

$$\mathbf{eb}^{1**} = \mathbf{W}^1(\mathbf{I} - \mathbf{A}^1 - \mathbf{M}^2)^{-1}(\mathbf{e}^1 - \mathbf{m}^1) \quad (5.19)$$

Where $\mathbf{A}^1 + \mathbf{M}^2$ represents the total input coefficient matrix of region 1 and $\mathbf{m}^1$ is the vector of total imports of region 1. However, as shown below in Section 5.4.3, this is not true when analysing sectorial emission balances. That is, although the total of both emission balances are the same, emission balances by sectors calculated by expression (5.18) do not fit in with those obtained using its counterpart expression (5.20):

$$\mathbf{EB}^{1**} = \mathbf{W}^1(\mathbf{I} - \mathbf{A}^1 - \mathbf{M}^2)^{-1}(\hat{\mathbf{e}}^1 - \hat{\mathbf{m}}^1) \quad (5.20)$$

5.3. Data set

The basic data source of this chapter are the 1995 and 2000 Spanish supply and use tables and environmental accounts for air emissions described in Chapter 2 (INE, 2005; INE, 2006). However, up to now we have only used the total input coefficient matrix $\mathbf{A}$, whereas in this chapter we also need the domestic and imported input coefficient matrices, i.e. $\mathbf{A}^1$ and $\mathbf{M}^2$. Thereby, in this chapter we estimate matrices

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[136] From here on, we will use the term ‘emission balances’ when we referrer to both balances at the same time, i.e. responsibility and trade emission balances.

[137] For a mathematical demonstration see Appendix 5.A.

of total and domestic input coefficients ($\mathbf{A}$ and $\mathbf{A^1}$) according to the technology industry hypothesis (see Section 2.6 of Chapter 2) and the imported input coefficient matrix $\mathbf{M^2}$ as the difference between $\mathbf{A}$ and $\mathbf{A^1}$ (Bulmer-Thomas, 1982, p. 154).

As in previous chapters, we consider nine different atmospheric pollutants, i.e. the six greenhouse gases (CO_2, CH_4, N_2O, SF_6, HFCs, and PFCs)[138] and three local gases (SO_2, NO_x, and NH_3). Notice that in this chapter we only take into account the emissions produced by sectors, excluding CH_4 emissions from waste management and neglecting direct emissions from households.

5.4. Empirical results

In this section we present the empirical analysis for Spain. Firstly, we show the main results and compare the emission data officially reported by the NAMEA system with those emissions obtained in our model. After this, we analyse the emission balances for the Spanish economy and for 46 economic sectors. As pointed out above, we carry out the computation of the model for two years 1995 and 2000 and for nine different atmospheric pollutants assuming same technology and same emission patterns for all regions.

5.4.1. Main results

Tables 5.1 and 5.2 illustrate for both years the potential of input-output perspective and, specifically, of the model presented in this chapter. They show total emissions of Spain considering emissions embodied in each component of the model, i.e. domestic and foreign final demand on domestic production, imported inputs to carry out the domestic production, and final demand on imported production. Although in these tables there is a kind of 'double accounting', i.e. they include emissions embodied in imports but they do not exclude those emissions embodied in exports, it is important to show the importance of emissions embodied in imports regarding total emissions in Spain.

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[138] The so-called synthetic greenhouse gases SF_6, HFCs, and PFCs have been grouped and the six greenhouse gases have been unified measuring their emissions in CO_2 equivalent units according with the global warming potentials established by the Intergovernmental Panel of Climate Change (IPCC, 1997).

Table 5.1: Results of the model, Spain 1995

Units: thousand tonnes and %

	Emissions embodied in domestic production (NAMEA*)			Emissions embodied in imports				Total emissions
	Domestic final demand	Foreign demand	Total domestic emissions	Inputs for domestic final demand	Inputs for foreign demand	Final demand on imported production	Total imported emissions	MODEL
	(1)	(2)	(1+2)/6 (%)	(3)	(4)	(5)	(3+4+5)/6 (%)	(6) = 1+2+3+4+5
Greenhouse gases								
CO_2	152037.42	51666.58	68.50	45322.86	23776.46	24563.49	31.50	297366.81
CH_4	806.62	305.36	70.09	241.16	68.93	164.43	29.91	1586.49
N_2O	48.96	19.10	69.24	14.82	5.54	9.87	30.76	98.29
Synthetic gases**	1954.10	1631.14	48.96	1789.42	1090.86	856.67	51.04	7322.19
Total in CO_2 equivalent	**186108.19**	**65630.27**	**68.32**	**56771.21**	**28031.09**	**31933.56**	**31.68**	**368474.33**
Other gases								
SO_2	1349.33	410.44	70.89	344.41	189.28	189.04	29.11	2482.50
NO_x	790.05	261.09	68.47	236.77	108.22	138.95	31.53	1535.07
NH_3	218.97	84.90	72.48	56.25	14.34	44.76	27.52	419.22

Source: own elaboration from 1995 Spanish NAMEA.
* NAMEA data are the official data reported by INE. Here we have excluded CH_4 emissions from waste management and direct emissions from households.
** Synthetic gases are total SF_6, HFCs, and PFCs emissions measured in CO_2 equivalent units.

Table 5.2: Results of the model, Spain 2000

Units: thousand tonnes and %

	Emissions embodied in domestic production (NAMEA*)			Emissions embodied in imports				Total emissions
	Domestic final demand	Foreign demand	Total domestic emissions	Inputs for domestic final demand	Inputs for foreign demand	Final demand on imported production	Total imported emissions	MODEL
	(1)	(2)	(1+2)/6 (%)	(3)	(4)	(5)	(3+4+5)/6 (%)	(6) = 1+2+3+4+5
Greenhouse gases								
CO_2	166432.00	72200.00	59.74	67976.76	48423.29	44394.63	40.26	399426.67
CH_4	813.02	438.36	67.91	254.54	109.82	226.96	32.09	1842.69
N_2O	51.59	27.59	66.58	16.42	8.62	14.71	33.42	118.92
Synthetic gases**	3175.79	3059.64	45.97	2840.84	2282.48	2204.37	54.03	13563.11
Total in CO_2 equivalent	**202672.91**	**93018.55**	**60.52**	**81252.07**	**55683.65**	**55924.62**	**39.48**	**488551.80**
Other gases								
SO_2	1082.84	417.03	65.08	322.83	240.79	241.26	34.92	2304.74
NO_x	791.55	349.87	57.88	359.00	241.59	230.02	42.12	1972.04
NH_3	250.01	133.93	71.90	61.23	22.80	66.02	28.10	534.00

Source: own elaboration from 2000 Spanish NAMEA.
* NAMEA data are the official data reported by INE. Here we have excluded CH_4 emissions from waste management and direct emissions from households.
** Synthetic gases are total SF_6, HFCs, and PFCs emissions measured in CO_2 equivalent units.

From these tables we can highlight the big difference between emissions reported by NAMEA data, which are the official data published by INE, and total emissions generated by the economy computed by the model. As said above, the official data only take into account domestic emissions, i.e. column 1 plus column 2, but they do not consider those emissions associated with Spanish imports, i.e.

columns 3, 4, and 5. This fact is not of minor importance, since in 1995 the emissions embodied in Spanish imports represented a third of total emissions generated, and even more in 2000 (almost the 40%)[139].

5.4.2. Responsibility and trade emission balances

If we now look at emission balances we can check that both balances fit in, even though they are derived from different approaches (Tables 5.3 and 5.5). Thus, both results can be interpreted in a similar way. On one hand, if the responsibility emission balance is positive (or negative) it means that pollution has been emitted inside the country is higher (or lower) than the pollution required to satisfy domestic final demand. On the other hand, if we have a positive (or negative) trade emission balance it indicates that this country is 'importing' (or 'exporting') pollution from (or to) others countries.

Table 5.3: Responsibility from different perspectives and responsibility emission balance, Spain 1995 and 2000

Units: thousand tonnes and %

	1995			2000		
	Producer responsibility	**Final user responsibility**	**Responsibility emission balance**	**Producer responsibility**	**Final user responsibility**	**Responsibility emission balance**
	(1)	(2)	(3) = (1-2)	(4)	(5)	(6) = (4-5)
Greenhouse gases						
CO_2	203704.00	221923.76	**-18219.76**	238632.00	278803.39	**-40171.39**
CH_4	1111.98	1212.20	**-100.22**	1251.37	1294.52	**-43.15**
N_2O	68.06	73.65	**-5.60**	79.18	82.71	**-3.53**
Synthetic gases*	3585.24	4600.19	**-1014.95**	6235.43	8221.00	**-1985.57**
Total in CO_2 equivalent	**251738.47**	**274812.97**	**-23074.50**	**295691.46**	**339849.60**	**-44158.14**
Other gases						
SO_2	1759.77	1882.78	**-123.01**	1499.86	1646.93	**-147.06**
NO_x	1051.14	1165.76	**-114.63**	1141.43	1380.58	**-239.15**
NH_3	303.87	319.98	**-16.11**	383.94	377.27	**6.68**

Source: own elaboration from 1995 and 2000 Spanish NAMEA.
* Synthetic gases are total SF_6, HFCs, and PFCs emissions measured in CO_2 equivalent units.

In Table 5.3 we compare the Spanish producer and final user responsibility in 1995 and 2000. As it shown, the final user responsibility is greater than the producer responsibility for all the atmospheric pollutants considered both in 1995 and 2000 with the exception, however, of NH_3 in the last year. That is, what would be consider the 'authentic' responsibility of Spain in total emissions, i.e. the final user

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[139] Similar findings have been reported in Sánchez-Chóliz and Duarte (2004) for Spain, although they present information only for CO_2 emissions in 1995. According to their calculations, the 64% of CO_2 emissions had been generated in the national production process, whereas the 36% had been generated abroad. In Table 5.1 these percentages are 69% and 32%, respectively.

perspective, is greater than the responsibility reported from the official data, i.e. the producer perspective.

Furthermore, Table 5.4 shows important information regarding how official statistics can be underestimating or overestimating the evolution of the responsibility of the Spanish domestic demand from 1995 to 2000. Looking at the two first columns, we see that in relative terms the 'authentic' responsibility had been underestimating for all gases with the exception of NH_3 in 2000. From these two columns we can also see that this underestimation had increased for some gases such as CO_2, synthetic greenhouse gases, SO_2, and NO_x; whereas for others such difference has diminished in relative terms, this is the case of CH_4, N_2O, and obviously in NH_3. As a direct consequence, columns 3 and 4 show that for the first group (CO_2, synthetic greenhouse gases, SO_2, and NO_x) the increase of responsibility was underestimated in official statistics, or its decrease was overestimated as in SO_2; whereas for the second group (CH_4, N_2O, and NH_3.) the increase of responsibility was exaggerated. Globally, if we considered the six greenhouse gases aggregated the result is obviously close to the CO_2: according to the statistics the emissions would have increased 17.46%; however, including the effects of international trade the increase would have been higher, around 23.67%.

Table 5.4: Responsibility ratio and evolution of emissions according different perspectives, Spain 1995 and 2000

Units: base numbers and %

	Final user responsibility-to-producer responsibility ratio (base = 100)		Evolution of emissions 1995-2000 according to	
	1995	2000	Producer responsibility	Final user responsibility
	(1)	(2)	(3)	(4)
Greenhouse gases				
CO_2	108.94	116.83	17.15	25.63
CH_4	109.01	103.45	12.54	6.79
N_2O	108.22	104.46	16.34	12.30
Synthetic gases*	128.31	131.84	73.92	78.71
Total in CO_2 equivalent	**109.17**	**114.93**	**17.46**	**23.67**
Other gases				
SO_2	106.99	109.81	-14.77	-12.53
NO_x	110.91	120.95	8.59	18.43
NH_3	105.30	98.26	26.35	17.90

Source: own elaboration from 1995 and 2000 Spanish NAMEA.
* Synthetic gases are total SF_6, HFCs, and PFCs emissions measured in CO_2 equivalent units.

As we pointed out before, the same results can be obtained from a different approach. Thus, comparing emissions embodied in exports with those embodied in imports we can calculate what we have defined as the trade emission balance. As

Table 5.5 reveals, Spain is an emission 'net exporter' for all atmospheric pollutants, both in 1995 and 2000. Again there is only one exception, the NH_3 in 2000. Moreover this 'exporter' role has been emphasised for all the gases but those three related to agricultural and food activities, i.e. CH_4, N_2O, and NH_3.

Table 5.5: Trade emission balance, Spain 1995 and 2000

Units: thousand tonnes and %

	1995			2000			
	Emission embodied in exports	Emission embodied in imports	Trade emission balance	Emission embodied in exports	Emission embodied in imports	Trade emission balance	Variation (%)
	(1)	(2)	(3) = (1-2)	(4)	(5)	(6) = (4-5)	(6-3)/(3)
Greenhouse gases							
CO_2	75443.04	93662.81	**-18219.76**	120623.29	160794.67	**-40171.39**	120.48
CH_4	374.29	474.51	**-100.22**	548.17	591.32	**-43.15**	-56.95
N_2O	24.63	30.23	**-5.60**	36.21	39.74	**-3.53**	-36.88
Synthetic gases*	2722.00	3736.96	**-1014.95**	5342.12	7327.69	**-1985.57**	95.63
Total in CO_2 equivalent	**93661.36**	**116735.86**	**-23074.50**	**148702.21**	**192860.34**	**-44158.14**	**91.37**
Other gases							
SO_2	599.72	722.73	**-123.01**	657.82	804.88	**-147.06**	19.55
NO_x	369.31	483.94	**-114.63**	591.46	830.61	**-239.15**	108.63
NH_3	99.24	115.35	**-16.11**	156.73	150.05	**6.68**	-141.45

Source: own elaboration from 1995 and 2000 Spanish NAMEA.
* Synthetic gases are total SF_6, HFCs, and PFCs emissions measured in CO_2 equivalent units.

5.4.3. Responsibility and trade emission balances by sectors

With the purpose of specifying which sectors could explain the results obtained above, we also calculate sectorial emission balances for 46 sectors in 1995 and 2000 computing expression (5.18).

So far we analyse the emission balances by sectors (Table 5.8 and Table 5.9) we realise that although the structure of emission patterns by sectors is similar in both years, there are some differences that should be commented. In Tables 5.6 and 5.7 we select those sectors whose emission balances represents more than 10% of total emission balances of each gas for both years. Table 5.6 shows the key sectors for the greenhouse gases, whereas Table 5.7 does for the other three gases.

Regarding negative emission balances of CO_2, SO_2, and NO_x, we find that the main sectors in 1995 were 'Construction', 'Manufacture of food products, beverages and tobacco', and 'Hotels and restaurants'; however, in 2000 only the first sector, i.e. 'Construction', maintained this importance.

Table 5.6: Emission balance key sectors for greenhouse gases, Spain 1995 and 2000

		1995		
CO_2	CH_4	N_2O	Synthetic gases*	Total in CO_2 equivalent
S32 Construction S8 Manufacture of food S34 Hotels and restaurants	S8 Manufacture of food S34 Hotels and restaurants	S8 Manufacture of food S34 Hotels and restaurants	S32 Construction S44 Health and social work S8 Manufacture of food	S32 Construction S8 Manufacture of food S34 Hotels and restaurants

		2000		
CO_2	CH_4	N_2O	Synthetic gases*	Total in CO_2 equivalent
S32 Construction	S8 Manufacture of food S34 Hotels and restaurants	S8 Manufacture of food S34 Hotels and restaurants	S32 Construction S44 Health and social work S8 Manufacture of food	S32 Construction S8 Manufacture of food S34 Hotels and restaurants

Source: own elaboration from 1995 and 2000 Spanish NAMEA.
* Synthetic gases are total SF_6, HFCs and PFCs emissions measured in CO_2 equivalent units.

Table 5.7: Emission balance key sectors for other gases, Spain 1995 and 2000

	1995	
SO_2	NO_x	NH_3
S32 Construction S8 Manufacture of food S34 Hotels and restaurants	S32 Construction S8 Manufacture of food S34 Hotels and restaurants	S8 Manufacture of food S34 Hotels and restaurants

	2000	
SO_2	NO_x	NH_3
S32 Construction	S32 Construction	S1 Agriculture

Source: own elaboration from 1995 and 2000 Spanish NAMEA.

With respect to CH_4, N_2O, and NH_3, we get more interesting results. In 1995, the emission balances of the three gases were negative and those sectors more connected with the transformation and distribution of food products, i.e. 'Manufacture of food products, beverages and tobacco' and 'Hotels and restaurants', explained together more than 50% of the total emission balances for each gas[140]. These sectors, even though their emission balances diminished in 2000, remained being the key sectors for CH_4 and N_2O gases. Nonetheless, in 2000 NH_3 was the only sector that presented positive emission balances and, in this case, the key sector was 'Agriculture, hunting and related services activities', which explained the 94% of total emission balances for it gas.

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[140] 'Manufacture of food products, beverages and tobacco' and 'Hotels and restaurants' sectors explain the 64% of total emission balances of CH_4, the 55% of N_2O, and the 76% of NH_3.

Finally, concerning synthetic greenhouse gas balances 'Construction', 'Health and social work' and 'Manufacture of food products, beverages and tobacco' were the key sectors both in 1995 and in 2000.

In summary, in both years the greatest exporter sectors in terms on total CO_2 emissions measured in equivalent units were: 'Construction', 'Manufacture of food products, beverages, and tobacco' and 'Hotels and restaurants'. Probably, the strong growth of the construction activity in Spain during the last years, materialised in an import increasing of 656.30% (see Table 5.B.1 in Appendix 5.B), may explain part of the evolution of the responsibility and trade emission balances during the period 1995-2000[141]. However, due to the different forces running under the input-output model we computed, determining the different factors that affect the emission balances is far to be easy. We should consider not only the evolution of exports and imports but also changes in domestic and imported technical coefficients, emission patterns, and also the evolution of the domestic final demand that usually requires imported inputs to be produced.

For instance, if we focused on sector 44, i.e. 'Health and social work', we can see that in 1995 and 2000 both the exports and imports of this sector were zero (see Table 5.B.1 in Appendix 5.B). Therefore, one may expect null emission balances. However, if we look at Tables 5.8 and 5.9 we realise that the emission balances of this sector were negative for all gases and in both years. This is because the emission balances computed take into account not only how much 'Health and social work' this sector has exported and/or imported, which in this case is zero, but also emissions embodied in all the imported inputs that this sector needs to produce the 'Health and social work' that is going to be exclusively consumed inside the country. We think this point is of relevance because although under the assumption of same technology we obtain the same emission balances with expressions (5.17) and (5.19), this is not true when we apply counterpart expressions to calculate emission balance by sectors, i.e. expressions (5.18) and (5.20).

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[141] The Spanish construction sector mainly imports manufactures of coke and refined petroleum products, manufactures of chemical products, manufacture of other non-metallic mineral products (such as cement, concrete, and ceramic products), manufacture of basic metal and fabricated metal products. Those are the most pollutant sectors concerning CO_2, SO_2, and synthetic greenhouse gases.

Table 5.8: Responsibility and trade emission balances by sector, Spain 1995

Units: tonnes

		Greenhouse gases					Other gases		
		CO_2	CH_4	N_2O	Synthetic gases*	Total in CO_2 equivalent	SO_2	NO_x	NH_3
S1	Agriculture, hunting, and related services activities	1682919.53	131647.13	6019.62	-18506.97	6295085.08	5234.52	28793.02	37981.99
S2	Forestry, logging, and related services activities	18425.97	627.89	29.38	-16.94	40702.13	51.05	404.66	181.55
S3	Fishing	-919127.74	-996.85	-75.16	-4779.34	-968139.99	-3335.77	-13326.53	-200.13
S4	Mining of coal and lignite; extraction of peat	-3324.26	-2.63	-0.52	-110.99	-3651.05	-25.82	-16.42	-0.85
S5	Extraction of crude petroleum, natural gas; uranium and thorium ores	10797.95	41.77	0.65	24.93	11901.78	39.05	92.50	0.34
S6	Mining of metal ores	45525.46	17.93	2.79	438.64	47206.09	162.02	560.45	2.54
S7	Other mining and quarrying	214020.75	226.65	15.56	2077.21	225682.64	2050.30	1044.36	16.15
S8	Manufacture of food products, beverages, and tobacco	-5100829.45	-90254.87	-4661.14	-190705.87	-8631841.41	-35558.93	-37549.59	-25317.13
S9	Manufacture of textile	-255062.81	-869.93	-185.09	-47666.97	-378375.36	-2070.02	-910.28	-435.37
S10	Manufacture of wearing apparel; dressing, and dyeing of fur	-1618163.69	-8348.12	-620.62	-80589.77	-2066454.61	-14631.95	-7729.47	-2212.86
S11	Tanning and dressing of leather; manufac. of luggage, handbags, saddler, harness, and footwear	-148976.14	-1812.59	-149.85	-17782.11	-251274.70	-897.88	-1033.67	-682.38
S12	Manufacture of wood and of products of wood and cork, except furniture	129187.03	130.36	12.87	390.69	136303.57	936.17	848.19	28.56
S13	Manufacture of pulp, paper, and paper products	527359.60	1143.74	78.66	3435.65	579199.14	4808.84	2338.68	206.07
S14	Publishing, printing, and reproduction of recorded media	-490880.88	-1263.20	-106.17	-16529.97	-566850.14	-4193.78	-2206.10	-242.22
S15	Manufacture of coke, refined petroleum products, and nuclear fuel	366314.41	-8820.18	131.53	-13283.05	208581.31	29976.91	-14418.00	-79.61
S16	Manufacture of chemicals and chemicals products	1950899.04	-819.97	1445.71	438434.81	2820283.33	20848.26	3955.82	2202.05
S17	Manufacture of rubber and plastic products	384586.97	1065.11	-35.95	-22402.96	373406.86	4644.12	1685.10	-45.38
S18	Manufacture of other non-metallic mineral products	6260393.25	1622.14	310.54	10873.18	6401599.83	32837.48	17598.01	93.28
S19	Manufacture of basic metals	6334091.37	5441.98	623.44	273156.06	6914796.32	48974.86	17946.99	279.86
S20	Manufacture of fabricated metal products, except machinery and equipment	-85336.72	-589.54	-38.41	-13519.87	-123144.32	184.35	-292.19	-60.49
S21	Manufacture of machinery and equipment	-2172275.09	-3221.57	-294.09	-90866.88	-2421963.19	-17240.64	-8358.14	-367.68
S22	Manufacture of office machinery and computers	-1004923.90	-1305.45	-144.47	-38945.15	-1116069.24	-8219.82	-4045.15	-211.42
S23	Manufacture of electrical machinery and apparatus	276850.68	-52.11	5.98	18297.17	295906.23	2620.78	1348.34	-14.02
S24	Manufacture of radio, television and communication equipment and apparatus	-896889.92	-1244.96	-131.12	-36919.57	-1000601.16	-7412.84	-3535.96	-179.77
S25	Manufacture of medical, precision and optical instruments, watches and clocks	-965807.06	-1195.16	-123.28	-33249.07	-1062370.37	-7779.53	-3833.65	-167.96
S26	Manufacture of motor vehicles, trailers, and semi-trailers	-1163680.84	-3483.85	-355.02	-98326.06	-1445222.89	-6966.33	-5400.11	-656.27
S27	Manufacture of other transport equipment	-417858.55	-682.48	-75.35	-26052.47	-481600.29	-3065.02	-1505.04	-106.70
S28	Manufacture of furniture	-1682251.81	-3782.12	-314.39	-70658.22	-1929794.07	-13528.94	-6984.92	-718.34
S29	Recycling	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S30	Electricity, gas, steam, and hot water supply	-966068.87	-7425.94	-92.06	-10866.00	-1161416.96	-6234.54	-6132.78	-81.46
S31	Collection, purification, and distribution of water	-107160.67	-327.05	-16.92	-3720.19	-122995.08	-844.24	-508.07	-26.03
S32	Construction	-8007562.72	-13910.47	-1239.08	-289793.73	-8973590.18	-61523.78	-32923.46	-2089.80
S33	Wholesale and retail trade; repair of motor vehicles, motorcy., and personal and household goods	-1533331.05	-4988.45	-374.95	-93422.21	-1847744.06	-11487.79	-6510.60	-691.37
S34	Hotels and restaurants	-4311767.07	-66208.72	-3340.94	-127323.05	-6865165.88	-29376.48	-33377.53	-18105.04
S35	Land transport; transport via pipelines	250327.55	-278.87	-9.00	-7574.08	234108.56	-1396.44	3612.84	-41.75
S36	Water transport	1400001.89	492.51	63.50	1044.52	1431072.75	15698.32	25373.35	113.10
S37	Air transport	1103159.27	-160.22	44.41	-1295.28	1112266.33	2192.44	3378.28	18.66
S38	Supporting and auxiliary transport activities; activities of travel agencies	210945.94	131.77	8.34	-2781.05	213517.68	1372.61	1443.71	10.24
S39	Post and telecommunications	-104227.09	-250.26	-14.29	-2813.06	-116726.33	-618.11	-497.13	-25.17
S40	Financial intermediation	-230413.82	-803.72	-42.35	-6815.53	-267235.97	-1163.00	-1245.14	-105.45
S41	Real estate, renting, and business activities	-1270536.81	-3395.02	-244.75	-52381.92	-1470087.28	-9259.23	-5876.75	-508.67
S42	Public administration and defence; compulsory social security	-1534759.24	-4486.03	-273.25	-47086.45	-1760759.25	-11733.02	-7094.50	-666.66
S43	Education	-552726.70	-1880.98	-98.53	-14861.85	-637634.00	-4202.50	-2901.04	-249.75
S44	Health and social work	-2941871.93	-7093.45	-1056.59	-247983.55	-3666360.03	-25581.33	-12503.04	-2233.97
S45	Other community, social, and personal service activities	-899755.94	-2858.85	-276.66	-33495.89	-1079052.97	-7293.77	-4337.29	-718.09
S46	Private households with employed persons	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	TOTAL	**-18219764.11**	**-100224.61**	**-5596.99**	**-1014953.16**	**-23074501.15**	**-123009.39**	**-114628.27**	**-16107.42**

Source: own elaboration from 1995 Spanish NAMEA and computing expression (18).

* Synthetic gases are total SF_6, HFCs and PFCs emissions measured in CO_2 equivalent units.

Table 5.9: Responsibility and trade emission balances by sector, Spain 2000

Units: tonnes

		Greenhouse gases					Other gases		
		CO_2	CH_4	N_2O	Synthetic gases*	Total in CO_2 equivalent	SO_2	NO_x	NH_3
S1	Agriculture, hunting, and related services activities	2589646.84	197174.87	9681.13	-23558.73	9707910.31	4902.17	41111.44	62172.29
S2	Forestry, logging, and related services activities	41819.59	1307.23	65.47	104.64	89672.09	80.06	769.22	411.43
S3	Fishing	-935863.65	-988.27	-80.00	-7936.20	-989353.05	-2502.09	-12653.55	-227.37
S4	Mining of coal and lignite; extraction of peat	-1172.35	48.00	-0.18	-40.28	-259.57	-4.19	-6.00	-0.41
S5	Extraction of crude petroleum, natural gas; uranium and thorium ores	-217130.69	-350.62	-14.81	-688.92	-229773.67	-367.76	-1648.54	-10.72
S6	Mining of metal ores	105951.72	48.89	6.67	1516.53	110562.30	231.18	1244.78	8.03
S7	Other mining and quarrying	269878.31	271.33	27.01	7930.09	291880.64	1882.22	1387.28	39.93
S8	Manufacture of food products, beverages, and tobacco	-5571931.78	-67986.80	-3783.09	-271911.98	-8444325.21	-25708.55	-35098.36	-20447.06
S9	Manufacture of textile	-271921.06	-481.92	-154.93	-54601.40	-384669.63	-1302.31	-1117.86	-350.97
S10	Manufacture of wearing apparel; dressing, and dyeing of fur	-2157668.79	-8656.32	-647.93	-164502.65	-2704813.68	-12706.77	-10147.02	-2340.99
S11	Tanning and dressing of leather; manufac. of luggage, handbags, saddler, harness, and footwear	-341217.27	-1948.56	-159.44	-24754.82	-456319.05	-1641.19	-1957.29	-705.09
S12	Manufacture of wood and of products of wood and cork, except furniture	196938.80	113.63	17.30	2217.69	206905.01	955.60	1112.33	24.99
S13	Manufacture of pulp, paper, and paper products	844343.56	1749.70	114.64	7256.21	923881.49	5554.21	3490.76	345.42
S14	Publishing, printing, and reproduction of recorded media	-553115.06	-1309.46	-106.32	-23691.85	-637263.37	-3031.26	-2601.16	-283.04
S15	Manufacture of coke, refined petroleum products, and nuclear fuel	-436102.04	-7599.09	152.10	-18000.97	-566533.38	49037.20	-33328.17	-182.84
S16	Manufacture of chemicals and chemicals products	1010040.66	-1842.82	1338.13	751703.00	2137864.94	10968.28	-2179.18	2352.84
S17	Manufacture of rubber and plastic products	717248.01	1764.31	39.51	79083.66	845629.32	5895.47	2750.21	127.02
S18	Manufacture of other non-metallic mineral products	8193855.81	1933.58	382.04	22317.04	8375210.10	33252.87	22589.25	156.02
S19	Manufacture of basic metals	7161252.67	5861.61	588.64	172134.35	7638959.33	43976.83	20961.07	324.31
S20	Manufacture of fabricated metal products, except machinery and equipment	-376228.55	-1242.56	-71.95	-24999.89	-449626.89	-733.85	-2234.87	-107.77
S21	Manufacture of machinery and equipment	-3813734.42	-5294.60	-447.25	-144585.90	-4208153.52	-21418.22	-15978.32	-689.40
S22	Manufacture of office machinery and computers	-1545252.27	-1968.91	-190.31	-64133.58	-1709729.50	-8922.80	-6512.53	-333.48
S23	Manufacture of electrical machinery and apparatus	147408.44	-437.29	-10.03	35421.22	170536.19	1376.90	311.95	-35.20
S24	Manufacture of radio, television and communication equipment and apparatus	-2261106.98	-2686.73	-265.10	-86070.39	-2485779.23	-13250.16	-9105.02	-408.25
S25	Manufacture of medical, precision and optical instruments, watches and clocks	-1292405.39	-1553.77	-145.89	-48444.15	-1418704.15	-7461.93	-5292.59	-231.89
S26	Manufacture of motor vehicles, trailers, and semi-trailers	-6177645.14	-10050.37	-927.39	-331600.28	-7007792.62	-33090.18	-27092.52	-1615.58
S27	Manufacture of other transport equipment	-811776.89	-1228.53	-111.93	-34793.31	-907068.72	-4339.81	-3446.89	-176.25
S28	Manufacture of furniture	-2283504.62	-5345.13	-397.30	-90885.14	-2609799.07	-12525.99	-10566.63	-1159.53
S29	Recycling	-127.96	-0.21	-0.01	-3.87	-140.79	-0.68	-0.59	-0.02
S30	Electricity, gas, steam, and hot water supply	-1778712.20	-10655.97	-168.06	-14399.63	-2068984.80	-1583.48	-13590.24	-156.54
S31	Collection, purification, and distribution of water	-172475.71	-411.20	-21.47	-5217.26	-192982.82	-797.26	-913.45	-35.45
S32	Construction	-12460965.09	-20462.03	-1674.59	-465503.97	-13875293.31	-63959.16	-55426.22	-3412.09
S33	Wholesale and retail trade; repair of motor vehicles, motorcy., and personal and household goods	-3892452.38	-7653.69	-661.62	-232926.56	-4491208.18	-17741.80	-18954.83	-1009.45
S34	Hotels and restaurants	-5584275.15	-63976.58	-3424.47	-198014.23	-8187382.93	-24710.39	-37377.91	-18746.32
S35	Land transport; transport via pipelines	353429.17	619.29	4.57	-6754.38	361097.10	-1990.31	3602.95	10.74
S36	Water transport	1242618.51	274.67	47.06	2100.26	1265076.07	11024.90	22520.64	63.80
S37	Air transport	2073058.60	-222.02	66.45	-2371.55	2086625.24	1701.61	6267.94	10.83
S38	Supporting and auxiliary transport activities; activities of travel agencies	190621.62	152.55	6.47	-50.88	195780.78	1012.17	1297.23	23.10
S39	Post and telecommunications	-443488.76	-839.00	-55.62	-13387.06	-491737.14	-1884.46	-2205.91	-113.90
S40	Financial intermediation	-423777.39	-1075.33	-62.33	-13386.44	-479067.09	-953.98	-2405.32	-154.87
S41	Real estate, renting, and business activities	-2574045.84	-5972.43	-420.47	-120512.34	-2950323.73	-10835.07	-13338.91	-896.31
S42	Public administration and defence; compulsory social security	-2342071.30	-5815.72	-342.29	-69057.71	-2639368.61	-10817.48	-11837.35	-890.90
S43	Education	-966026.61	-2791.69	-157.97	-27011.69	-1100635.67	-4426.29	-5281.92	-469.01
S44	Health and social work	-3990323.30	-8178.89	-1119.36	-418218.63	-4927300.26	-22136.89	-17770.51	-2548.69
S45	Other community, social, and personal service activities	-1632980.34	-5439.90	-447.68	-65336.94	-1951336.35	-8069.39	-8497.27	-1654.32
S46	Private households with employed persons	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	TOTAL	**-40171386.68**	**-43146.74**	**-3532.57**	**-1985568.85**	**-44158135.07**	**-147062.00**	**-239149.86**	**6677.03**

Source: own elaboration from 2000 Spanish NAMEA and computing expression (18).

* Synthetic gases are total SF_6, HFCs and PFCs emissions measured in CO_2 equivalent units.

As shown in Appendix 5.C, emission balances by sectors applying expression (5.20) (Tables 5.C.1 and 5.C.2) differ from those obtained with expression (5.18) (Tables 5.8 and 5.9), although total emission balances are the same. Whereas the latter take into account not only emissions embodied in exports and imports of each sector, but also the emissions embodied in those imported inputs that each sector needs to produce its commodity; the former only consider the first ones. Consequently, when analysing responsibility and/or trade emission balances by sectors we should be cautious about the expression we use and of the possibility of misinterpreting sectorial results calculated with expression (5.20)[142].

5.5. Final remarks

In this chapter we dealt with two issues. On one hand, we analysed whether the official data has been overestimating or underestimating the emissions generated by Spanish domestic final demand; and, on the other hand, we studied what should have been the influence of the international trade on not fulfilling the national target established by the Kyoto protocol for Spain. For doing so, we developed a multiregional environmentally extended input-output model, which allows for defining two concepts: the responsibility emission balance and the trade emission balance. The former is defined as the difference between emissions generated by domestic production of any country or region and the emissions that have been generated to satisfy its domestic final demand; whereas the latter is the difference between emissions embodied in total exports and emissions embodied in total imports.

We computed the model for Spain and the rest of the world. We obtained results for 1995 and 2000 and for nine different atmospheric pollutants: those associated with global environmental pressures, i.e. greenhouse gases (CO_2, CH_4, N_2O, SF_6, HFCs, and PFCs) and three gases related to local and specific environmental problems (SO_2, NO_x, and NH_3). However, in spite of recent improvements in data availability and quality, when analysing relationships between one country and the rest of the world some assumptions are still necessary to be made. Therefore, in this chapter we assumed that the rest of the world used the

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[142] See for instance Machado *et al.* (2001) and Mongelli *et al.* (2006), they calculated trade emission balances by sectors applying similar expressions to our expression (5.20).

same technology as Spain. This assumption implies that what we actually estimated the emissions Spain would has generated if it had decided to produce all imported products by itself.

We found that the Spanish final user responsibility was greater than the producer responsibility for all the atmospheric pollutants in both 1995 and 2000, with the exception of NH_3 in the last year. This result showed that the NAMEA data, which only take into account the emissions produced by domestic production but not those embodied in imports, do not illustrate actual emissions generated by the domestic final demand of a country. This conclusion may be also pertinent when speaking about official data generally used to control the achievements of national targets established by the Kyoto protocol. Especially, we found that the Spanish NAMEA data underestimated the emission increases of the greenhouse gases measured in CO_2 equivalent units from 1995 to 2000 at 6.21 percentage points. As expected, the results obtained from the trade emission balance were the same. We conclude that Spain was a 'net exporter' of emissions in both years, with the exception of NH_3 in 2000, showing that emissions embodied in Spain's imports exceeded the emissions embodied in Spain's exports.

So, in summary, Spain required more emissions to meet its domestic final demand than those domestically generated. Consequently, Spain was avoiding to produce some of these atmospheric pollutants inside its territory by means of 'exporting' emissions to other countries. The implications of this result vary depending on the kind of atmospheric pollutant we consider. Therefore, when speaking about local and regional gases, i.e. SO_2, NO_x, and NH_3, it would mean that Spain was shifting environmental costs to other countries. However, in the case of global pollutants as the greenhouse gases it would mean that the country's responsibility was greater than it could seem. The latter may be of relevance for international agreements, although it seems very difficult to get commitments about total emissions regardless of where they have been produced of which a country is responsible for.

Finally, analysing the emission balances by sectors we observed that 'Construction', 'Manufacture of food products, beverages, and tobacco', and 'Hotels and restaurants' were the sectors that exported more emissions. The economic growth of 'Construction' sector may explain part of these results. However, the variety of forces running under input-output models hinder the determination and analysis of the different factors affecting the responsibility and trade emission balance. Therefore, further research towards this direction should be worthy.

In this chapter we also showed that under the same technology assumption, we could obtain the same total emission balances either applying the trade emission balance defined in this model or calculating the emissions embodied in net exports through the total input coefficient matrix. However, when analysing sectorial emission balances, we should be cautious about which of the above expressions we use, since the results obtained by sectors were not the same. This issue deserves more consideration in future research.

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Appendix

5.A. Equivalence of expressions for the emissions balances

In this appendix we show that under same technology assumption expressions (5.A.1) and (5.A.2) are equivalent. That is, if $\mathbf{A}^2 = \mathbf{A}^1 + \mathbf{M}^2$ and $\mathbf{W}^2 = \mathbf{W}^1$ then $\mathbf{eb}^{1*} = \mathbf{eb}^{1**}$:

$$\mathbf{eb}^{1*} = [\mathbf{W}^1(\mathbf{I} - \mathbf{A}^1)^{-1}\mathbf{e}^1] - [\mathbf{W}^1(\mathbf{I} - \mathbf{A}^1 - \mathbf{M}^2)^{-1}\mathbf{M}^2(\mathbf{I} - \mathbf{A}^1)^{-1}\mathbf{h}^1] - [\mathbf{W}^1(\mathbf{I} - \mathbf{A}^1 - \mathbf{M}^2)^{-1}\mathbf{e}^2] \quad (5.A.1)$$

$$\mathbf{eb}^{1**} = \mathbf{W}^2(\mathbf{I} - \mathbf{A}^2)^{-1}(\mathbf{e}^1 - \mathbf{m}^1) \quad (5.A.2)$$

Take expression (5.A.3) as starting point:

$$\mathbf{eb}^1 = [\mathbf{W}^1(\mathbf{I} - \mathbf{A}^1)^{-1}\mathbf{e}^1] - [\mathbf{W}^2(\mathbf{I} - \mathbf{A}^2)^{-1}\mathbf{M}^2(\mathbf{I} - \mathbf{A}^1)^{-1}\mathbf{h}^1] - [\mathbf{W}^2(\mathbf{I} - \mathbf{A}^2)^{-1}\mathbf{e}^2] \quad (5.A.3)$$

From expression (15) we know that imports in region 1 are $\mathbf{m}^1 = \mathbf{M}^2(\mathbf{I} - \mathbf{A}^1)^{-1}(\mathbf{h}^1 + \mathbf{e}^1) + \mathbf{e}^2$. So, we get:

$$\mathbf{e}^2 = \mathbf{m}^1 - \mathbf{M}^2(\mathbf{I} - \mathbf{A}^1)^{-1}(\mathbf{h}^1 + \mathbf{e}^1) \quad (5.A.4)$$

Substituting (5.A.4) in (5.A.3) we have:

$$\mathbf{eb}^1 = [\mathbf{W}^1(\mathbf{I} - \mathbf{A}^1)^{-1}\mathbf{e}^1] - [\mathbf{W}^2(\mathbf{I} - \mathbf{A}^2)^{-1}\mathbf{M}^2(\mathbf{I} - \mathbf{A}^1)^{-1}\mathbf{h}^1] - \{\mathbf{W}^2(\mathbf{I} - \mathbf{A}^2)^{-1}[\mathbf{m}^1 - \mathbf{M}^2(\mathbf{I} - \mathbf{A}^1)^{-1}(\mathbf{h}^1 + \mathbf{e}^1)]\} \quad (5.A.5)$$

From (5.A.5) we can simplify expression $\mathbf{W}^2(\mathbf{I} - \mathbf{A}^2)^{-1}\mathbf{M}^2(\mathbf{I} - \mathbf{A}^1)^{-1}\mathbf{h}^1$ and we will obtain:

$$\mathbf{eb}^1 = [\mathbf{W}^1(\mathbf{I} - \mathbf{A}^1)^{-1}\mathbf{e}^1] - [\mathbf{W}^2(\mathbf{I} - \mathbf{A}^2)^{-1}\mathbf{m}^1] + [\mathbf{W}^2(\mathbf{I} - \mathbf{A}^2)^{-1}\mathbf{M}^2(\mathbf{I} - \mathbf{A}^1)^{-1}\mathbf{e}^1] \quad (5.A.6)$$

Now expression (5.A.6) would be equal to (5.A.2) if $\mathbf{W}^2(\mathbf{I} - \mathbf{A}^2)^{-1}\mathbf{e}^1 = [\mathbf{W}^1(\mathbf{I} - \mathbf{A}^1)^{-1}\mathbf{e}^1] + [\mathbf{W}^2(\mathbf{I} - \mathbf{A}^2)^{-1}\mathbf{M}^2(\mathbf{I} - \mathbf{A}^1)^{-1}\mathbf{e}^1]$. If $\mathbf{A}^2 = \mathbf{A}^1 + \mathbf{M}^2$ and $\mathbf{W}^2 = \mathbf{W}^1$ we can write it as:

$$\mathbf{W}^1(\mathbf{I} - \mathbf{A}^1 - \mathbf{M}^2)^{-1}\mathbf{e}^1 = [\mathbf{W}^1(\mathbf{I} - \mathbf{A}^1)^{-1}\mathbf{e}^1] + [\mathbf{W}^1(\mathbf{I} - \mathbf{A}^1 - \mathbf{M}^2)^{-1}\mathbf{M}^2(\mathbf{I} - \mathbf{A}^1)^{-1}\mathbf{e}^1] \quad (5.A.7)$$

So, operating and simplifying we get:

$$\mathbf{W}^1(\mathbf{I}-\mathbf{A}^1-\mathbf{M}^2)^{-1}[\mathbf{I}-\mathbf{M}^2(\mathbf{I}-\mathbf{A}^1)^{-1}]\mathbf{e}^1=[\mathbf{W}^1(\mathbf{I}-\mathbf{A}^1)^{-1}\mathbf{e}^1] \qquad (5.A.8)$$

$$\mathbf{W}^1(\mathbf{I}-\mathbf{A}^1-\mathbf{M}^2)^{-1}[(\mathbf{I}-\mathbf{A}^1)-\mathbf{M}^2][(\mathbf{I}-\mathbf{A}^1)^{-1}]\mathbf{e}^1=[\mathbf{W}^1(\mathbf{I}-\mathbf{A}^1)^{-1}\mathbf{e}^1] \qquad (5.A.9)$$

$$\mathbf{W}^1(\mathbf{I}-\mathbf{A}^1)^{-1}\mathbf{e}^1=\mathbf{W}^1(\mathbf{I}-\mathbf{A}^1)^{-1}\mathbf{e}^1 \qquad (5.A.10)$$

■Proof demonstrated.

5.B. Evolution of total exports and total imports of Spain from 1995 to 2000

Table 5.B.1 below shows the evolution of total exports and total imports of Spain from 1995-2000.

5.C. Emission balances by sectors calculated by computing expression (5.20)

Tables 5.C.1 and 5.C.2 below show the emission balance by sectors calculated by computing expression (5.20) instead of expression (5.18) for years 1995 and 2000, respectively.

Table 5.B.1: Evolution of total exports and total imports, Spain from 1995 to 2000

Units: Million € and %

		Total exports 1995	Total imports 1995	Total exports 2000	Total imports 2000	Export variation (%)	Import variation (%)
		e	m	e	m	e	m
S1	Agriculture, hunting, and related services activities	4921.01	4711.33	7027.00	4877.60	42.80	3.53
S2	Forestry, logging, and related services activities	63.43	198.29	154.60	498.60	143.73	151.46
S3	Fishing	129.06	662.97	319.80	764.90	147.80	15.37
S4	Mining of coal and lignite; extraction of peat	0.20	514.14	1.40	875.70	605.88	70.32
S5	Extraction of crude petroleum, natural gas; uranium and thorium ores	3.13	5408.22	3.40	15513.30	8.79	186.85
S6	Mining of metal ores	54.60	653.96	98.50	1151.80	80.42	76.13
S7	Other mining and quarrying	255.23	303.02	503.50	527.10	97.27	73.95
S8	Manufacture of food products, beverages, and tobacco	5180.59	7492.93	9219.30	10842.80	77.96	44.71
S9	Manufacture of textile	1717.24	2068.15	2919.30	3693.80	70.00	78.60
S10	Manufacture of wearing apparel; dressing, and dyeing of fur	826.37	1744.76	1999.80	3773.30	142.00	116.26
S11	Tanning and dressing of leather; manufac. of luggage, handbags, saddler, harness, and footwear	1549.62	888.68	2227.40	1740.80	43.74	95.89
S12	Manufacture of wood and of products of wood and cork, except furniture	480.77	876.37	930.90	1810.90	93.63	106.64
S13	Manufacture of pulp, paper, and paper products	1367.40	2705.85	2220.60	3851.30	62.40	42.33
S14	Publishing, printing, and reproduction of recorded media	615.00	480.33	1144.30	819.80	86.07	70.67
S15	Manufacture of coke, refined petroleum products, and nuclear fuel	1707.97	1782.27	6254.30	5433.70	266.18	204.88
S16	Manufacture of chemicals and chemicals products	6349.48	10879.31	11272.50	18270.40	77.53	67.94
S17	Manufacture of rubber and plastic products	2280.92	2636.36	4183.70	4520.00	83.42	71.45
S18	Manufacture of other non-metallic mineral products	2336.29	1108.09	3772.40	1972.20	61.47	77.98
S19	Manufacture of basic metals	4058.13	5550.10	5889.90	9060.40	45.14	63.25
S20	Manufacture of fabricated metal products, except machinery and equipment	1807.18	2063.39	3495.30	3872.80	93.41	87.69
S21	Manufacture of machinery and equipment	4497.02	7515.61	8650.10	15945.90	92.35	112.17
S22	Manufacture of office machinery and computers	1030.83	2713.79	1945.50	5323.40	88.73	96.16
S23	Manufacture of electrical machinery and apparatus	2178.45	3091.31	4004.20	5366.60	83.81	73.60
S24	Manufacture of radio, television and communication equipment and apparatus	1760.30	3295.21	3628.20	9584.50	106.11	190.86
S25	Manufacture of medical, precision and optical instruments, watches and clocks	646.32	2416.35	1421.50	4354.20	119.94	80.20
S26	Manufacture of motor vehicles, trailers, and semi-trailers	16751.56	12784.06	29237.60	29476.60	74.54	130.57
S27	Manufacture of other transport equipment	1647.11	1207.34	3791.90	3072.70	130.22	154.50
S28	Manufacture of furniture	1347.69	1513.90	2629.90	3254.70	95.14	114.99
S29	Recycling	0.00	0.00	0.00	0.00	-	-
S30	Electricity, gas, steam, and hot water supply	20.39	129.93	124.30	118.20	509.72	-9.03
S31	Collection, purification, and distribution of water	0.00	0.00	0.00	0.00	-	-
S32	Construction	8.88	1.19	8.00	9.00	-9.94	656.30
S33	Wholesale and retail trade; repair of motor vehicles, motorcy., and personal and household goods	4817.21	647.69	8712.50	956.00	80.86	47.60
S34	Hotels and restaurants	0.00	76.91	0.00	131.00	-	70.33
S35	Land transport; transport via pipelines	1712.34	189.85	3385.40	370.00	97.71	94.89
S36	Water transport	907.07	21.29	1062.00	67.00	17.08	214.73
S37	Air transport	1594.23	999.36	3282.00	1998.00	105.87	99.93
S38	Supporting and auxiliary transport activities; activities of travel agencies	1222.66	1205.97	2397.00	1766.00	96.05	46.44
S39	Post and telecommunications	432.43	298.52	738.00	812.00	70.66	172.01
S40	Financial intermediation	614.75	475.71	1880.00	1292.00	205.82	171.59
S41	Real estate, renting, and business activities	3860.81	5231.80	10346.00	13125.00	167.97	150.87
S42	Public administration and defence; compulsory social security	0.00	0.00	0.00	0.00	-	-
S43	Education	0.00	0.00	0.00	0.00	-	-
S44	Health and social work	0.00	0.00	0.00	0.00	-	-
S45	Other community, social, and personal service activities	240.31	814.65	776.00	2050.00	222.91	151.64
S46	Private households with employed persons	0.00	0.00	0.00	0.00	-	-
	TOTAL	**80993.97**	**97358.98**	**151658.00**	**192944.00**	**87.25**	**98.18**

Source: Own elaboration from 1995 and 2000 Spanish input-output framework.

Table 5.C.1: Responsibility and trade emission balances by sector computing expression (5.20), Spain 1995

Units: tonnes

		Greenhouse gases					Other gases		
		CO_2	CH_4	N_2O	Synthetic gases*	Total in CO_2 equivalent	SO_2	NO_x	NH_3
S1	Agriculture, hunting and related services activities	156447.61	8179.06	384.12	2535.89	449820.77	763.82	2007.51	2355.28
S2	Forestry, logging and related services activities	-52813.34	-1515.52	-71.68	-387.67	-107246.99	-196.83	-980.34	-434.31
S3	Fishing	-1198838.40	-951.26	-80.37	-3313.10	-1247042.07	-3757.54	-18663.43	-207.94
S4	Mining of coal and lignite; extraction of peat	-320701.20	-19073.79	-26.78	-3506.39	-733058.44	-3107.61	-1786.49	-27.34
S5	Extraction of crude petroleum, natural gas; uranium and thorium ores	-8480297.12	-32211.89	-547.79	-33354.18	-9359915.61	-32336.05	-71025.89	-350.55
S6	Mining of metal ores	-557832.18	-308.29	-40.09	-7283.12	-584017.42	-2236.17	-6397.84	-42.42
S7	Other mining and quarrying	-47646.69	-64.54	-4.01	-609.46	-50853.83	-443.77	-233.86	-4.64
S8	Manufacture of food products, beverages and tobacco	-1745331.61	-39554.61	-1907.46	-26791.49	-3194083.75	-10355.87	-16718.34	-11222.54
S9	Manufacture of textile	-286358.30	-1658.11	-111.69	-11999.73	-367803.02	-2705.50	-1391.18	-429.81
S10	Manufacture of wearing apparel; dressing and dyeing of fur	-501926.92	-2272.30	-157.08	-16030.58	-614371.85	-4604.35	-2416.32	-571.30
S11	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness & footwear	354445.31	2329.03	122.69	10302.82	451690.53	3128.39	1816.85	495.67
S12	Manufacture of wood & of products of wood & cork, except furniture; manufacture of...	-228128.76	-682.61	-45.16	-3380.55	-259844.96	-1693.50	-1502.45	-164.02
S13	Manufacture of pulp, paper and paper products	-1203782.38	-2765.40	-197.18	-18953.28	-1341933.63	-10713.14	-5379.87	-482.33
S14	Publishing, printing and reproduction of recorded media	80910.02	154.93	13.79	1678.92	90117.98	762.57	357.19	29.52
S15	Manufacture of coke, refined petroleum products and nuclear fuel	-214488.86	-321.77	-20.06	-468.16	-227931.53	-2214.14	-933.45	-6.65
S16	Manufacture of chemicals and chemicals products	-5648299.95	-7545.42	-2638.68	-716122.95	-7340868.38	-53410.06	-19754.46	-4532.17
S17	Manufacture of rubber and plastic products	-268194.22	-508.12	-71.90	-16673.73	-317826.55	-2668.69	-1038.83	-128.19
S18	Manufacture of other non-metallic mineral products	3841343.35	1484.20	213.69	13389.02	3952145.02	20775.20	11222.44	107.20
S19	Manufacture of basic metals	-2915254.98	-3081.31	-301.09	-122056.11	-3195356.67	-22353.25	-9291.30	-183.94
S20	Manufacture of fabricated metal products, except machinery and equipment	-241660.71	-276.36	-26.28	-8128.77	-263740.41	-2043.12	-925.14	-27.25
S21	Manufacture of machinery and equipment	-2255187.86	-2505.04	-276.97	-78369.47	-2472024.43	-18631.80	-8559.31	-311.53
S22	Manufacture of office machinery and computers	-1001043.17	-1168.12	-135.80	-35445.82	-1103117.55	-8162.01	-4030.70	-194.39
S23	Manufacture of electrical machinery and apparatus	-791368.37	-898.07	-92.06	-38714.12	-877480.89	-6568.76	-3265.85	-107.68
S24	Manufacture of radio, television and communication equipment and apparatus	-996451.71	-1057.93	-124.10	-30129.22	-1087269.91	-8444.65	-3841.48	-146.20
S25	Manufacture of medical, precision and optical instruments, watches and clocks	-891597.72	-1044.68	-112.18	-29813.03	-978124.82	-7348.30	-3667.57	-157.39
S26	Manufacture of motor vehicles, trailers and semi-trailers	3293614.05	4152.21	468.25	126475.87	3652443.81	28726.64	12139.99	638.52
S27	Manufacture of other transport equipment	316969.72	358.92	43.21	10343.71	348246.65	2645.96	1135.98	55.38
S28	Manufacture of furniture	-104955.28	-178.71	-16.62	-2967.40	-116827.03	-806.37	-504.49	-36.57
S29	Recycling	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S30	Electricity, gas, steam and hot water supply	-515952.90	-670.85	-15.53	-424.39	-535279.05	-7357.69	-2008.98	-4.39
S31	Collection, purification and distribution of water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S32	Construction	5856.13	7.48	0.63	80.42	6287.56	38.26	23.08	1.39
S33	Wholesale and retail trade; repair of motor vehicles, motorcycles & personal and household goods	1238977.59	1840.28	157.52	21497.18	1347951.84	10702.69	6053.91	309.03
S34	Hotels and restaurants	-28382.10	-385.46	-19.01	-348.83	-42719.70	-218.38	-218.89	-106.94
S35	Land transport; transport via pipelines	987364.30	1534.58	78.72	3936.79	1047929.96	4909.68	7292.16	67.70
S36	Water transport	1601637.09	1016.18	92.64	4334.94	1656030.93	17253.49	26463.97	179.73
S37	Air transport	741677.78	532.48	47.49	1770.12	769350.52	2600.56	2955.08	61.45
S38	Supporting and auxiliary transport activities; activities of travel agencies	7529.42	16.01	0.96	76.81	8241.36	52.71	45.23	2.42
S39	Post and telecommunications	19271.20	24.23	1.61	141.88	20420.11	181.15	78.00	2.27
S40	Financial intermediation	46826.92	77.78	4.89	375.17	50351.02	481.50	183.83	10.56
S41	Real estate, renting and business activities	-260345.53	-386.47	-39.40	-4388.58	-285062.56	-2335.09	-1084.92	-83.95
S42	Public administration and defence; compulsory social security	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S43	Education	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S44	Health and social work	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S45	Other community, social and personal service activities	-155794.36	-845.33	-148.22	-2232.56	-221728.17	-1319.35	-782.11	-459.11
S46	Private households with employed persons	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	TOTAL	***-18219764.11***	***-100224.61***	***-5596.99***	***-1014953.16***	***-23074501.15***	***-123009.39***	***-114628.27***	***-16107.42***

Source: Own elaboration from 1995 Spanish NAMEA.

* Synthetic gases are total SF_6, HFCs, and PFCs emissions measured in CO_2 equivalent units.

Table 5.C.2: Responsibility and trade emission balances by sector computing expression (5.20), Spain 2000

Units: tonnes

		Greenhouse gases					Other gases		
		CO_2	CH_4	N_2O	Synthetic gases*	Total in CO_2 equivalent	SO_2	NO_x	NH_3
S1	Agriculture, hunting, and related services activities	1628181.92	82009.54	4102.45	35489.64	4657630.14	4853.83	19660.63	25792.74
S2	Forestry, logging, and related services activities	-155672.40	-4006.72	-204.22	-2530.59	-305651.67	-397.48	-2420.88	-1256.16
S3	Fishing	-891907.94	-713.70	-62.48	-4144.37	-930409.70	-1982.57	-13481.59	-179.51
S4	Mining of coal and lignite; extraction of peat	-479200.74	-32626.59	-42.10	-6668.20	-1184077.18	-2912.26	-2930.71	-51.92
S5	Extraction of crude petroleum, natural gas; uranium and thorium ores	-24058230.99	-38732.15	-1617.11	-64772.45	-25437682.56	-39439.15	-183709.67	-1114.53
S6	Mining of metal ores	-1263284.31	-744.51	-88.71	-20939.88	-1327360.40	-3129.67	-13940.28	-118.35
S7	Other mining and quarrying	-16838.80	-21.13	-1.79	-506.59	-18344.53	-107.81	-87.64	-2.69
S8	Manufacture of food products, beverages, and tobacco	-1143647.35	-23739.44	-1214.79	-23024.38	-2041786.35	-4470.31	-9754.37	-7347.34
S9	Manufacture of textile	-535593.46	-2597.22	-179.27	-46900.39	-692609.60	-3288.15	-2530.01	-700.05
S10	Manufacture of wearing apparel; dressing, and dyeing of fur	-863439.27	-3236.52	-229.24	-54115.69	-1056587.43	-5235.40	-3994.46	-849.97
S11	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness & footwear	217887.46	1374.98	68.68	11237.87	279290.27	1254.07	1071.11	297.43
S12	Manufacture of wood and of products of wood and cork, except furniture	-470323.77	-1681.00	-110.50	-10763.94	-550642.28	-2256.31	-2986.76	-468.63
S13	Manufacture of pulp, paper, and paper products	-1407686.81	-3045.29	-202.18	-25351.13	-1559666.16	-8665.69	-6183.03	-562.06
S14	Publishing, printing, and reproduction of recorded media	146898.99	266.40	22.49	4038.54	163504.82	947.81	633.17	57.57
S15	Manufacture of coke, refined petroleum products, and nuclear fuel	1730146.80	1845.60	145.35	3853.77	1817817.33	10039.11	8846.97	65.72
S16	Manufacture of chemicals and chemicals products	-7309974.58	-9064.55	-2868.82	-1325767.45	-9715431.66	-45246.16	-26898.13	-5349.64
S17	Manufacture of rubber and plastic products	-212874.71	-383.66	-50.69	-28064.74	-264711.09	-1414.43	-840.55	-101.46
S18	Manufacture of other non-metallic mineral products	4694685.38	1780.43	250.31	23949.19	4833618.79	19384.08	13869.24	166.61
S19	Manufacture of basic metals	-5266706.38	-5690.01	-461.08	-132964.18	-5662093.99	-30710.91	-18758.92	-362.22
S20	Manufacture of fabricated metal products, except machinery and equipment	-301244.36	-345.74	-29.42	-8190.26	-325816.81	-1847.51	-1196.01	-39.65
S21	Manufacture of machinery and equipment	-4080881.70	-4724.33	-453.89	-134496.85	-4455294.98	-23527.82	-16422.61	-705.65
S22	Manufacture of office machinery and computers	-1696580.35	-2023.09	-201.72	-66832.62	-1868430.25	-9933.81	-7067.57	-357.11
S23	Manufacture of electrical machinery and apparatus	-994571.48	-1097.52	-104.62	-59681.59	-1109731.99	-5799.49	-4113.78	-146.05
S24	Manufacture of radio, television and communication equipment and apparatus	-3123378.60	-3302.93	-348.96	-104400.86	-3405318.38	-18658.57	-12218.96	-514.11
S25	Manufacture of medical, precision and optical instruments, watches and clocks	-1190622.14	-1369.41	-132.53	-44875.98	-1305339.80	-7082.94	-4921.22	-221.07
S26	Manufacture of motor vehicles, trailers, and semi-trailers	-169934.62	-207.39	-20.84	-8251.32	-189001.59	-1059.56	-655.86	-32.75
S27	Manufacture of other transport equipment	461424.77	516.14	55.19	19639.15	509011.87	2693.21	1742.53	81.50
S28	Manufacture of furniture	-324481.85	-573.86	-49.03	-12009.99	-363740.98	-1679.56	-1555.05	-131.33
S29	Recycling	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S30	Electricity, gas, steam, and hot water supply	31475.19	34.36	1.04	25.47	32545.55	317.33	118.11	0.29
S31	Collection, purification, and distribution of water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S32	Construction	-621.60	-0.81	-0.07	-11.62	-670.83	-2.93	-2.42	-0.18
S33	Wholesale and retail trade; repair of motor vehicles, motorcycles & personal and household goods	2490329.55	7264.49	499.54	88091.37	2885832.85	14857.61	11917.51	1908.62
S34	Hotels and restaurants	-38882.97	-461.05	-24.22	-740.27	-56812.18	-210.56	-269.51	-139.82
S35	Land transport; transport via pipelines	1859551.43	2824.91	155.89	14188.15	1981387.26	5567.98	11781.39	196.08
S36	Water transport	1495949.58	710.14	76.79	6358.04	1541025.13	12250.79	23903.39	125.63
S37	Air transport	1557453.49	710.80	86.13	6200.75	1605279.99	3028.92	6186.20	97.39
S38	Supporting and auxiliary transport activities; activities of travel agencies	241324.21	439.18	29.41	5430.24	265095.02	1123.54	1384.54	76.59
S39	Post and telecommunications	-16850.57	-21.37	-1.55	-216.74	-17995.74	-106.66	-66.88	-3.33
S40	Financial intermediation	145216.28	224.73	15.64	1749.44	156534.74	1029.25	567.69	41.08
S41	Real estate, renting, and business activities	-540083.32	-886.27	-80.99	-13245.44	-597048.33	-3403.93	-2242.54	-238.07
S42	Public administration and defence; compulsory social security	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S43	Education	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S44	Health and social work	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S45	Other community, social, and personal service activities	-318396.67	-1852.24	-260.66	-6352.95	-444452.40	-1839.88	-1582.93	-1236.55
S46	Private households with employed persons	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	TOTAL	**-40171386.68**	**-43146.74**	**-3532.57**	**-1985568.85**	**-44158135.07**	**-147062.00**	**-239149.86**	**6677.03**

Source: Own elaboration from 2000 Spanish NAMEA.

* Synthetic gases are total SF_6, HFCs, and PFCs emissions measured in CO_2 equivalent units.

6. Summary, conclusions, and future work

6.1. Summary of results

The aim of this study was to analyse different aspects of the interdependences between the economy and the environment applying the same methodology, i.e. the input-output approach. The study has been structured in four self-contained essays, each of them faced different and specific research questions.

After an introductory chapter, in Chapter 2 we explained the input-output framework emphasising those characteristics that make it a suitable approach to study the relationships between the economy and the environment; one of these characteristics is, of course, its capacity for simultaneously accommodating monetary and physical units. The close integration between the theoretical model and the database is one of the strongholds of this approach. Taking this characteristic into account, we described how the input-output framework and the environment were introduced into the well established system of national accounts. Since the following chapters were applications for Spain, we also explained the procedure to obtain an environmentally extended input-output table for Spain in 1995 and 2000 considering nine types of atmospheric emissions: carbon dioxide (CO_2); methane (CH_4); nitrous oxide (N_2O); a group of synthetic greenhouse gases that includes sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs); sulphur oxides (SO_x); nitrogen oxides (NO_x); and ammonia (NH_3). The last three gases are related to local and regional environmental problems such as acidification and eutrophication, whereas the rest are the six greenhouse gases regulated by the Kyoto protocol. Using the Spanish database we applied an environmentally extended input-output model to describe the Spanish situation regarding atmospheric pollution in 1995 and 2000. The results showed the capability of input-output approach to reveal indirect effects that could not be directly observed in the economy and also to reallocate emissions from the producer to the final users viewpoint. Adopting the final users' perspective, household consumption appeared to be the most important component in almost all gases, only superseded by exports in the case of the synthetic greenhouse gases.

As showed in Chapter 2, Spanish emissions increased in almost all gases from 1995 to 2000; however, the simple comparison carried out in this chapter did not tell anything about the causes underlying this change. In Chapter 3, we performed a structural decomposition analysis to break down the variation of atmospheric pollution in Spain in this period into three main determinants. We decomposed the change in emissions into three 'sources': the eco-technological effect, the structure effect, and the level effect. The results obtained for the nine gases showed that the emissions of almost all gases increased during this period and only SO_2 decreased. The most influencing source on emission growth was the level of final uses, whereas technological changes had a positive effect on the reduction of emissions in virtually all the gases (it was negative only in NH_3 and in the synthetic greenhouse gases). Despite the positive impact of the eco-technological effect, however, it was only strong enough to counteract the level effect in the case of SO_2. Regarding the other effect, shifts in the composition of final uses generally led to increase emissions and only in CH_4, N_2O, and NH_3 it provoked a modest reduction.

In Chapter 4 we analysed the emissions associated with consumption of different household types in 2000 since private consumption was the most important component of final uses. Generally, the passive representation of households as final consumers in the national accounts partially hide the role played for them into environmental pressures. Households not only pollute on own account when driving a car or heating their homes, they also consume goods and services whose production processes also generate pollution. In this chapter we considered not only household direct emissions but also those emissions indirectly generated by their consumption. The results for 47 COICOP groups showed that expenditures on

‘Electricity, gas, and other fuels’ and ‘Operation of personal transport equipment’ were the most pollutant in terms of CO_2, SO_2, and NO_x. In contrast, ‘Food’ and ‘Catering services’ expenditures stood out as the most polluting goods in terms of CH_4, N_2O, and NH_3. Finally, for the synthetic greenhouse gases we highlighted the expenditures on ‘Purchases of vehicles’, ‘Clothing’, and ‘Medical products, appliances, and equipment’. In order to study the influence of income growth on emissions generated by private consumption we classified Spanish households according to their expenditure level. We found that the more a household expended, the more emissions it generated; however, its structure of consumption was less polluting with the only exception of the synthetic greenhouse gases. The expenditure elasticity estimated in this chapter confirmed these results.

In a world where countries are more and more interconnected, exports and imports becomes important issues. However, the previous chapters did not tell too much about the effects of these two components on atmospheric pollution. In Chapter 5, by applying a multiregional input-output model, we evaluated the Spanish trade emission balance in 1995 and 2000. The results showed that emissions embodied in Spain’s imports exceeded the emissions embodied in Spain’s exports indicating that Spain was a ‘net exporter’ of emissions in both years, with the exception of NH_3 in 2000. In this chapter, we demonstrated that the international responsibility of one country can be also estimated from a different perspective, the so-called responsibility emission balance that was defined as the difference between producer responsibility and final user responsibility. As expected we found that Spain generally required more emissions to meet its domestic final demand than those domestically generated (again the only exception to this was the NH_3 in 2000).

Having reached this point, it is important to make an important remark regarding the technology of the rest of the world that had been implicitly or explicitly assumed through all the study. Despite recent improvements in data availability and quality, when analysing relationships between one country and the rest of the world it is still necessary to make some assumptions regarding the technology of an economy called ‘the rest of the world’ because of the important constraint that supposes to get this kind of data. In this study we assumed that the rest of the world uses the same technology as Spain. This assumption, also named the self-sufficiency assumption, implies that in this study we actually estimated the emissions Spain would has generated if it had produced all imported products by itself.

6.2. Conclusions

In this study each chapter gathered its corresponding and specific conclusions; however, the results from this study contribute jointly to show the way economic activities affect environmental problems and threw light upon two issues from different viewpoints. One of these issues concerns the environmental effects of economic growth and the other the environmental policy.

As pointed out in the introduction of this study, the effects of economic growth on the environment are not clear and the debate are still open. Although it can be argued that a period of five years (1995-2000) is not excessively longer and also that the quality of data is not very good, the results of this study offer significant and relevant elements to explain the relationship between economic growth and emissions in Spain. Specifically, we analysed three main factors mentioned in the introduction: the technology-scale-composition effects, the individual preferences, and the international trade. First, we are drawn to the conclusion that although the technological progress had positive effects in the reduction of emissions, it was not able to counteract the negative effect provoked by the increase of final demand. The only exception to this was precisely one of the gases related to local and regional environmental pressures, i.e. SO_2. On the other hand, the composition effect was really small and only it presented a positive impact for CH_4, N_2O, and NH_3 that did not contribute enough to neutralise the negative impact. Second, it is also argued that as income grows, people achieve a higher standard of living and care more for the quality of environment and demand for less pollutant goods and services. In fact, our results confirmed this claim but also showed that this trend only accounts for a weak or relative delinking between income growth and emissions but not for an absolute or strong delinking, which would be necessary to get an environmental improvement. Finally, we conclude that Spain is displacing environmental pressures to other countries through international trade since the emissions embodied in its imports were greater than those embodied in its exports.

Regarding the environmental policy, we are drawn to the conclusion that Spain would need to implement urgently policies aimed at shifting the level and structure of final uses. However, the execution of measures to reduce consumption levels does not seem to be very popular either in political or economical terms. The other alternative, focused on altering the structure of final uses, seems to be more feasible. In this study we provided a basis for planning environmental policy aimed at reducing emissions from final consumption. Having information about which are the more pollutant products, policy makers can apply economic instruments to altering the composition of consumer baskets towards more environmentally friendly products. Probably, the most common instrument are the environmental taxes. In this study we have not simulated effects of this kind of taxes, but our outcomes are relevant for the debate on social effects of these taxes suggesting, for instance, that taxes on greenhouse gas emissions could have some regressive effects. However, they are not the only solution, other political instruments such as environmental information campaigns or green label programmes can also give an incentive to households to change their consumption patterns. Nevertheless, the best option to achieve the reduction of gas emissions may be the combination of technology and demand policies as the case of SO_2, in which policies targeting technological developments manage to counteract the effect of the level of final uses.

6.3. Future work

> "Ending up a thesis is one thing, finishing a research (if possible at all) is another. Answers raise new questions, solutions define new problems, results call for a generalization or a sharpening, assumptions for a relaxation, gaps need to be filled up, and loose ends are to be tied up. Of course, this holds also for the present research." (Dietzenbacher, 1991, pp. 266-267)

When you are almost finishing typing your thesis and you reach this part of the work, you feel it is difficult to deal with it. You have to think about the direction(s) of your future research when you have not finished this one yet. However, when I read the last paragraph I realised that it is true. Finishing a thesis is really different from finishing a research. A careful and critical look back at the finished chapters can show you how to continue with your research in the near future. This section is devoted to this aim and some of these possibilities are pointed out below.

In Chapter 5 we displayed the importance of taking international trade into account when analysing the relationship between economic activity and environment. However, the structural decomposition analysis performed in Chapter 3 did not consider this issue. An interesting study, therefore, would be to analyse the influence of shifting trade patterns on the evolution of Spanish emissions, distinguishing imports used as intermediate inputs or as final goods and services. On the other hand, in Chapter 4 we limited the analysis to study the relationship between household expenditure level and emissions; however, the information compiled in household budget continuous survey about other socio-economic and demographic characteristics opens up to extend the analysis to other variables. The inclusion of the study level, the age of the breadwinner or the place where the household is settled (i.e. in a rural or urban area), for instance, may provide new and different insights to analyse the relationship between household consumption and emissions. Finally, the environmentally extended multiregional input-output model applied in Chapter 5 may be a useful framework to analyse another worrisome environmental problem that has gained importance in Spain in the last years. We are referring to the scarcity of water in some Spanish regions. This research, however, entails an additional effort regarding the database since there is not any true multiregional input-output table including the different regions in Spain up to our knowledge.

Nevertheless, new research questions have also risen during the elaboration of this study. Due to the nature of these questions, however, they should be considered as a further research and not simply extensions of this study. The first question deals with the thorny issue of environmental responsibility. Nowadays, the ‘polluter pays principle’ seems to be the best known background principle for environmental management. This principle, basically based on Pigou’s (1920) idea, states that whenever damage is done or has to be repaired the polluter should be the prime accountable agent and should internalise the costs associated with production externalities, i.e. the polluter should pay. This basic principle has determined the basis of most environmental taxes, the structure of environmental statistics, and even the control instruments for Kyoto protocol. However, there are a number of drawbacks surrounding the idea of this principle. This set of problems basically concerns the interpretation of who is actually the ‘polluter’. If we shift our attention towards environmental long-run effects and consider broader concepts such as ‘sustainability’, why then we only address to the firm as the ‘polluter’? In fact, both producers and consumers by their investment and consumption patterns stimulate the generation of noxious substances or excessive resource use. So, in this new context why we do not consider that may be the 'user' or even the 'victim' should pay? Steenge (1997, 1999, 2004) proposes to reconsider this issue and advocates to consider other solutions provided by market-based incentive schemes such as Coase (1960) pointed out. Really, the capacity of input-output approach to reallocate emissions allows also for reassigning environmental responsibilities and it opens up a field in which input-output models can give new insights for future environmental policy in a new context.

The second question is also connected with the latter and it deals with the tricky and not less thorny issue of fixed capital goods. In Chapters 2 and 4 we have already called the attention on this issue. The point is that in the basic input-output model investment expenditures on replacement and expansion capital are exogenously considered without taking into account their connections with output levels. When the emissions are reassigned from the 'producer' to the 'user' viewpoint, the atmospheric pollutants generated in producing capital goods are usually assigned to the gross capital formation category. However, part of these capital is used in present production processes whereas the rest will be use in subsequent years. Hence, part of these emissions should be first imputed to the present producers and then reassigned to the corresponding categories of final uses. Moreover, when considering long-run environmental effects we should take into account that the current technology is the consequence of past investments so, part of the emissions generated previously should also be imputed to the present producers. Obviously, it also holds for the future: the upcoming technology will be the consequence of current investments and, obviously, of own current savings since one euro lent to a bank or spent for sock soon finds its way into a investment project whether it be a construction project, a new business, and so on.

Finally, as Duchin (1998) pointed out technology and lifestyle may be the organising concepts for analysing the so-called 'sustainable' development. Whereas technology may provide the link between the economy and the natural world, lifestyle may link the economy and social system. These concepts can be arranged into a so-called 'structural matrix' and once the data were set, input-output approach may provide the theoretical framework to analyse how changes in consumption patterns, for instance, can provoke changes in output, employment and also in pollution in a comprehensive way. In this study technology and lifestyles have been considered and analysed by the same theoretical approach but in independently chapters. An integral analysis will evidently give new and interesting insights.

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Resumen (summary in Spanish)

6.1. Resumen

La Conferencia de Naciones Unidas sobre el Medio Ambiente y el Desarrollo que tuvo lugar en Río de Janeiro en 1992, identificó los patrones de producción y de consumo actuales como las mayores causas del continuo deterioro del medio ambiente. De hecho, en los últimos años la atención se ha ido centrando principalmente en analizar los efectos que tiene el crecimiento económico sobre el medioambiente. Los resultados de estos estudios ofrecen argumentos en todas direcciones mostrando que las relaciones entre el crecimiento económico y el medio ambiente son indudablemente complejas.

El propósito de esta tesis es el de analizar algunos de los factores que determinan las interdependencias existentes entre la economía y el medio ambiente. Aunque la actividad económica afecta al medio ambiente de forma muy diversa, el objeto de estudio de este trabajo está centrado en el análisis de un único problema medio ambiental: la contaminación atmosférica. Concretamente se consideran nueve gases diferentes. Por un lado los seis gases de efecto invernadero regulados por el protocolo de Kioto: dióxido de carbono (CO_2), metano (CH_4), óxido nitroso (N_2O), hexafluoruro de azufre (SF_6), hidrofluorocarbonos (HFCs), y perfluorocarbonos (PFCs). Y por otro lado, tres gases relacionados con problemas medioambientales de carácter más local y/o regional como son la acidificación y la eutrofización: óxidos de azufre (SO_x), óxidos de nitrógeno (NO_x), y amoniaco (NH_3).

Desde la década de 1990, el debate sobre los efectos medioambientales del crecimiento se ha visto fuertemente influenciado por la llamada hipótesis de la curva de Kuznets ambiental. Esta hipótesis establece que puede encontrarse una relación de U invertida entre las presiones medioambientales y la renta per cápita. Esta idea se basa en el hecho de que el crecimiento de la renta per cápita puede provocar cambios en los procesos de producción y/o demanda final de manera que las economías con un mayor nivel de renta per cápita presentarían niveles absolutos de contaminación menores como consecuencia de patrones producción y de consumo menos contaminantes. Según la literatura sobre la curva de Kuznets ambiental, tres son los factores principales que, provocados por el propio proceso de crecimiento económico, podrían explicar una mejora medioambiental. Estos son: los efectos tecnología-escala-composición, las preferencias individuales de los consumidores, y el comercio internacional.

Considerando que todos los otros factores permanecen constantes, el primer factor establece que el crecimiento económico afectaría a la calidad medioambiental a través de tres canales diferentes. Por un lado, el incremento de producción requeriría no solo más inputs sino también más recursos naturales y más residuos que contribuirían a la degradación del medio ambiente. Así pues, el efecto escala del crecimiento económico causaría un impacto negativo en la calidad medioambiental. Sin embargo, el crecimiento económico también puede tener un impacto positivo en el medio ambiente a través de los llamados efecto composición y efecto tecnológico. Por un lado, a medida que la renta crece la estructura de la economía tiende a cambiar gradualmente incrementando aquellas actividades que producen menos contaminación. Y por otro, el crecimiento económico puede venir acompañado de un progreso técnico que permitiría reemplazar tecnologías obsoletas por otras menos contaminantes. La hipótesis de la curva de Kuznets ambiental sugiere que el impacto negativo del efecto escala tiende a prevalecer en las etapas iniciales del crecimiento económico pero que en etapas posteriores este impacto negativo puede ser superado por el impacto positivo de los efectos composición y tecnológico.

El segundo factor hace referencia a las preferencias de los consumidores. Según esta argumentación, una vez alcanzado un determinado nivel de renta los consumidores tienden a consumir menos bienes y servicios privados para ‘consumir’ más ‘calidad medioambiental’. Sin embargo, la ‘calidad medioambiental’ es, en la mayoría de los casos, un bien público que no puede ser ‘comprado’ en el mercado sino que su provisión debe decidirse en el terreno de las políticas públicas. Además, en algunas ocasiones el supuesto consumo de ‘calidad medioambiental’ implica que determinados costes medioambientales sean desplazados temporal o espacialmente a otras generaciones u otros territorios. En ambos casos, cuando la degradación medioambiental afecta a otros individuos las preferencias del consumidor dejarían de ser un factor determinante.

Finalmente, el tercer factor considerado es el comercio internacional. Posiblemente, éste sea el factor más importante a tener en cuenta cuando se analiza las relaciones entre el crecimiento económico y el medio ambiente. Por un lado, el comercio internacional puede contribuir al incremento del tamaño de la economía a través, especialmente, de las exportaciones; en consecuencia, se produciría un incremento de los problemas medioambientales en el territorio donde se lleva a cabo dicha producción independientemente de donde se vaya a consumir. Este hecho podría ser definido como una ‘importación’ de problemas medioambientales. Pero por otro lado, el comercio internacional puede motivar la difusión de tecnología menos contaminante, contribuyendo de este modo a reducir las presiones medioambientales en diferentes territorios o países. A parte de los diferentes impactos que puede tener el comercio internacional sobre el medio ambiente, debe tenerse en cuenta que en economías abiertas pueden encontrarse curvas de Kuznets medioambientales que de hecho no representen una mejora genuina, sino que sean el resultado de una ‘exportación’ de problemas medioambientales a otros territorios como consecuencia del comercio internacional.

En cualquier caso, la respuesta a la pregunta si el crecimiento económico es positivo o no para el medio ambiente, no es única ni mucho menos fácil de encontrar. Este estudio contribuye al análisis de las relaciones entre el crecimiento económico y el medio ambiente. Para ello, el presente trabajo se ha estructurado en cuatro capítulos independientes que examinan la relación entre la actividad económica y las emisiones atmosféricas en España durante el periodo 1995-2000 desde diferentes perspectivas. Cada uno de estos capítulos pretende dar respuesta a una pregunta de investigación diferente y específica aplicando, eso sí, el mismo marco teórico en todos ellos, el análisis input-output. En el capítulo 2 se describe dicha metodología y la base de datos del estudio. En el capítulo 3 se tienen en cuenta los efectos tecnología-escala-composición. El papel que juegan los consumidores es considerado en el capítulo 4. En el capítulo 5 se analiza la influencia del comercio internacional. Finalmente, en el capítulo 6 se recogen las conclusiones del trabajo.

Las bases del análisis input-output fueron establecidas por Wassily Leontief, premio Nobel de economía en 1973, a finales de la década de 1920 y 1930. Esta metodología se centra en el estudio de las interrelaciones entre las diferentes partes del sistema económico, conocidas con el nombre de interdependencias. Tal y como señaló el propio Leontief, y como viene mostrando el creciente número de estudios y trabajos publicados al respecto, las características fundamentales del análisis input-output hacen que éste sea un enfoque apropiado para analizar no solo las interdependencias dentro de la economía sino también las interrelaciones entre la economía y el medio ambiente.

En el capítulo 2 se describe detalladamente la metodología y las bases de datos utilizadas a lo largo de todo el trabajo. En primer lugar se explica el análisis input-output, haciendo especial énfasis en aquellas características que lo hacen apropiado para el estudio de las interdependencias entre la economía y el medio ambiente. Una de estas características es, sin duda alguna, la capacidad para trabajar simultáneamente con unidades físicas y monetarias. Es decir, en los modelos input-output los impactos medio ambientales pueden ser medidos en unidades físicas, mientras que las transacciones económicas pueden seguir computándose en unidades monetarias. Este hecho permite analizar algunos de los impactos que la actividad económica tiene sobre el medio ambiente, los cuales al no tener una contraprestación monetaria no quedan recogidos por el mercado. En segundo lugar, el análisis input-output permite incorporar diferentes supuestos relacionados con políticas medioambientales. Es decir, los modelos input-output pueden asumir que empresas y consumidores maximizan beneficios y utilidades, o bien, incorporar otros supuestos más cercanos con la idea de desarrollo sostenible como, por ejemplo, que las empresas adoptaran tecnologías que no minimizaran el coste pero que fueran medio ambientalmente más deseables. Finalmente, la versatilidad de los modelos input-output para ser aplicados a diferentes niveles de agregación permite analizar dentro del mismo enfoque problemas medioambientales generados por una empresa individual, un sector económico, o por la economía en su conjunto. Es por ello, que a lo largo de estos años dentro del marco input-output se han desarrollado diferentes modelos medioambientales con el objetivo de analizar no solo problemas de contaminación atmosférica sino también otros aspectos como el consumo de agua, los residuos, el balance de materiales, etc. En este estudio, sin embargo, se aplica el modelo input-output ampliado medioambientalmente.

Uno de los aspectos fundamentales del análisis input-output es la fuerte integración entre el modelo teórico y la base de datos. Teniendo en cuenta este aspecto, en el capítulo 2 también se describe cómo el marco teórico input-output, en general, y la relación del sistema económico con el medio ambiente, en particular, han sido introducidas en el sistema de cuentas nacionales internacionalmente establecido. Puesto que los tres capítulos siguientes muestran diferentes aplicaciones para España del modelo input-output ampliado medioambientalmente, en este capítulo se especifica el proceso para obtener una tabla input-output ampliada medioambientalmente que permita aplicar directamente el modelo anteriormente mencionado. Concretamente, con el objetivo de describir la situación de España respecto a la contaminación atmosférica en los años 1995 y 2000, en este capítulo se presentan algunos de los resultados obtenidos.

Estos resultados muestran la capacidad del análisis input-output para revelar efectos indirectos que no pueden ser observados directamente en la economía. Por ejemplo, aunque las principales fuentes de emisiones directas son los sectores económicos, éstos simplemente producen los productos que finalmente van a ser consumidos por los hogares, gobierno, y sector exterior, o bien, usados como inversión por parte de las empresas. Así pues, las emisiones producidas por los sectores pueden ser atribuidas a los usuarios finales como emisiones indirectas o imputadas. Considerando las emisiones totales, es decir las directas más las indirectas, el consumo privado y las exportaciones son los componentes de los usos finales más contaminantes. Por ejemplo, los hogares españoles en 1995 generaron un 53.84% del total de gases de efecto invernadero de la economía (el 49.57% en el 2000). Mientras que las emisiones atribuidas a las exportaciones representaron el 22.07% y el 26.60% respectivamente.

A nivel sectorial, el análisis es análogo. Mientras que las intensidades de contaminación de la producción informan respecto a las emisiones producidas en cada sector por unidad de producto, las intensidades de uso final muestran las emisiones totales que cada sector produce directa e indirectamente para satisfacer una unidad destinada a los usos finales. Así pues, en algunas ocasiones, cuando se consideran todas las interdependencias de la economía, algunos de los sectores que aparentemente son poco contaminantes pueden revelarse como los más contaminantes. Respecto a los gases más relacionados con la energía (CO_2, SO_2, y NO_x), los sectores más contaminantes son el 'Suministro de electricidad, gas, y agua' y el 'Transporte por vía acuática'; sin embargo, cuando se tienen en cuenta todas las interdependencias de la economía la 'Fabricación de metales comunes' aparece como un sector contaminante importante. Si nos fijamos en las emisiones de CH_4, N_2O, y NH_3, al considerar las emisiones totales los sectores más contaminantes son no solo aquéllos relacionados directamente con las actividades agrícolas como 'Agricultura, ganadería, caza y actividades de servicios conexas', sino también aquellos sectores relacionados indirectamente con estas actividades como puede ser la 'Elaboración de productos alimenticios y bebidas'. Finalmente, al analizar los gases de efecto invernadero sintéticos (SF_6, HFCs, y PFCs) el cálculo de las intensidades según el uso final nos revela que el sector de 'Fabricación de productos de caucho y plástico' es el segundo sector más contaminantes después de la 'Fabricación de sustancias y productos químicos'.

El capítulo 2 también muestra la evolución de las emisiones atmosféricas en España de 1995 a 2000. Según los datos, las emisiones incrementaron en casi todos los gases con la única excepción del SO_2. Sin embargo, el análisis realizado en este capítulo no nos permite revelar ni evaluar los principales determinantes de este incremento. Así pues, en el capítulo 3 se realiza un análisis de descomposición estructural medio ambiental, cuyo objetivo es analizar los determinantes de la evolución de las emisiones atmosféricas en España desde 1995 hasta 2000. Para ello, se descompone el cambio de emisiones en tres fuentes principales. Por un lado, el llamado efecto eco-tecnológico que incluye tanto los cambios en los coeficientes técnicos como en los coeficientes de emisión, es decir, recoge los cambios en la matriz de intensidad total de emisiones. En segundo lugar, se consideran los cambios en la composición de los usos finales, es lo que se conoce como el efecto estructura. Y por último, el efecto nivel que recoge los cambios en el nivel de los usos finales. En este capítulo se cuantifican los efectos de estos tres determinantes a través de un análisis de descomposición estructural para los nueve gases mencionados anteriormente.

Puesto que hay diferentes métodos para descomponer la variación de las emisiones totales en los factores subyacentes, en este capítulo se han aplicado dos técnicas diferentes. Ambas técnicas fueron propuestas en 1998 y son equivalentes en el sentido que las dos proporcionan los mismos resultados. Una de estas técnicas fue propuesta por Sun y se trata de calcular cada determinante aplicando el método de Laspeyres y, posteriormente, dividir el efecto conjunto de los diferentes determinantes (también conocido como término de interacción) entre los diferentes efectos a partes iguales. La otra técnica fue propuesta por Dietzenbacher y Los y se basa en la idea de que si cada uno de los determinantes puede expresarse mediante un índice de Laspeyres o un índice de Paasche, entonces habrá n! (n factorial) descomposiciones totales diferentes como resultado de considerar todas las combinaciones posibles Laspeyres-Paasche. Cada de estas descomposiciones tendrá un resultado diferente, sin embargo desde un punto de vista teórico, ninguno de estos resultados será mejor que los otros. La alternativa que proponen Dietzenbacher y Los, por lo tanto, es la de calcular la descomposición resultante de la media de las n! expresiones. Cuando el número de determinantes a considerar es muy elevado, una buena aproximación es calcular la media de las dos descomposiciones polares.

No obstante, antes de llevar a cabo el análisis de descomposición estructural hay algunos aspectos sobre la base de datos que deben tenerse en cuenta. Nos estamos refiriendo a la influencia de la variación de los precios en la descomposición estructural. Como es sabido, las tablas input-output registran transacciones en precios corrientes, es decir, el valor de cada transacción es el producto entre el precio por unidad en un determinado año y el número de unidades involucradas en la transacción de ese mismo año. En consecuencia, cuando se analizan los cambios entre diferentes tablas input-output a lo largo del tiempo, los cambios observados pueden ser causados por variaciones en los precios, variaciones en las cantidades o por ambas variaciones. Así pues, para evitar la influencia de los precios en el análisis se ha procedido a deflactar la tabla input-output del año 2000 a precios constantes de 1995. Esta deflactación se ha realizado aplicando el enfoque heurístico propuesto por Dietzenbacher y Hoen.

Los resultados del análisis de la descomposición estructural medioambiental para España muestran que en el periodo 1995-2000 todos los gases incrementaron sus emisiones con la única excepción del SO_2. Ciertamente, el efecto que tuvo más influencia en el crecimiento de las emisiones fue el nivel de los usos finales. Por el contrario, los cambios en los coeficientes tecnológicos y en los coeficientes de emisión tuvieron un efecto opuesto. Así pues, puede afirmarse que el cambio tecnológico en España tuvo una influencia positiva en la reducción de emisiones de casi todos los nueve gases analizados. Las únicas excepciones de este efecto beneficioso de la tecnología fueron el NH_3 y el grupo de los tres gases de efecto invernadero sintéticos. Otro aspecto que debe destacarse es el hecho de que el efecto eco-tecnológico solo pudo contrarrestar la influencia de los otros dos efectos en el caso del SO_2. Respecto al efecto estructura, se puede concluir que en casi todos los gases los cambios en la composición de los usos finales provocó un incremento de las emisiones. No obstante, en aquellos gases más relacionados con la agricultura y la alimentación, es decir, CH_4, N_2O, y NH_3 este efecto provocó una modesta reducción de las emisiones.

El análisis de descomposición estructural a nivel sectorial nos proporciona unos resultados más detallados. Así pues, encontramos que el sector 'Comercio al por mayor y al por menor; reparación de vehículos automotores, motocicletas, y efectos personales y enseres domésticos' fue, en general, el sector más contaminante en todos los gases; mientras que el sector de 'Hoteles y restaurantes' fue el sector que más contribuyó a la reducción de las emisiones de casi todos los gases. En global, podemos afirmar que a nivel sectorial el efecto nivel fue siempre positivo independientemente del gas y del sector considerado. La tendencia del efecto estructura en cada sector fue la misma para todos los gases. Finalmente, el efecto eco-tecnología fue el único que presentó diferentes resultados tanto por sectores como por gases.

Una de las ventajas del análisis de descomposición estructural radica en el hecho de que se desarrolla dentro del enfoque input-output y que, por tanto, permite evaluar no solo las emisiones directas sino también las indirectas. Consecuentemente, este método permitiría a los políticos diseñar políticas tecnológicas o de demanda que incentivaran cambios en la economía.

El capítulo 2 mostró que la mayor parte de la contaminación atmosférica está relacionada, directa o indirectamente, con el consumo privado. Sin embargo, la representación pasiva de los hogares como consumidores finales en las cuentas nacionales ha contribuido a diluir el rol que juegan los consumidores en el medio ambiente. Los hogares no solo contaminan por la utilización de automóviles y/o calefacciones, sino por el consumo de bienes y servicios. El objetivo del capítulo 4 es el de analizar como hogares que gozan de diferente 'posición económica' contaminan de forma diferente. Para ello, se considera no solo las emisiones directas de los hogares sino también aquellas emisiones indirectamente generadas por su consumo. Combinando información de diferentes bases de datos se estiman las emisiones totales provocadas por el consumo privado de las familias españolas clasificadas según quintiles de gasto en el año 2000. Para realizar dicho análisis se han aplicado dos enfoques diferentes. Por un lado, se han estimado las emisiones per cápita y, por otro lado, las emisiones asociadas con el gasto de unidades de consumo equivalentes aplicando la escala modificada de la OCDE.

Los resultados obtenidos para 47 grupos del COICOP muestran que cuánto más gasta un hogar, más contaminación genera; sin embargo, la contaminación atmosférica emitida por unidad de consumo disminuye con el nivel de gasto, con la única excepción de los gases de efecto invernadero sintéticos. De hecho, en el año 2000 los hogares españoles con mayor 'posición económica' gastaron una proporción menor de sus presupuestos en aquellas categorías más contaminantes, es decir, 'Electricidad, gas, y otros combustibles' (CO_2, NO_x, y SO_2) y 'Alimentación' (CH_4, N_2O, y NH_3). Por el contrario, el porcentaje del gasto dedicado a 'Muebles, equipamiento del hogar, y mantenimiento doméstico' fue mayor, lo cual podría explicar la tendencia opuesta de los tres gases de efecto invernadero sintéticos. Estos resultados fueron confirmados por los valores de las elasticidades-gasto estimados. Casi todos los gases presentaron una elasticidad positiva y significativamente menor que la unidad, excepto, para los gases de efecto invernadero sintéticos cuya elasticidad fue mayor que la unidad. Estos resultados no permiten defender la existencia de una desvinculación absoluta entre el incremento del gasto y las emisiones. Para ello hubiera sido necesario encontrar valores de elasticidad-gasto negativos, lo cual sólo podría ocurrir si los bienes y servicios más contaminantes fueran 'bienes inferiores'. Por otra parte, los resultados de este capítulo 4 podrían contribuir a diseñar medidas que incentivaran el cambio de los patrones de consumo de los hogares para reducir las emisiones. Algunas opciones podrían ser la de establecer impuestos medioambientales, o realizar campañas de información o programas de etiquetaje ecológico.

Tal y como se comentó en el inicio, en un mundo en el que los países están cada vez más interconectados, las importaciones y las exportaciones se convierten en dos componentes importantes a la hora de analizar las relaciones entre el crecimiento económico y el medio ambiente. Sin embargo, en los capítulos previos no se ha tratado el efecto que tiene el comercio internacional en la contaminación atmosférica de España. El capítulo 5 tiene como objeto analizar este aspecto en profundidad.

A través del comercio internacional las actividades económicas de un país causan presiones medioambientales que afectan, al menos en parte, a otros países.

Algunas veces, este desplazamiento espacial de las presiones medioambientales es inevitable como es el caso de la contaminación atmosférica que traspasa las fronteras o la contaminación de los ríos que viaja entre diferentes países. Sin embargo, otras veces este desplazamiento espacial es debido a la relocalización de procesos de producción en el exterior o a la substitución de producción doméstica por importaciones. Así pues, el consumo de un país puede estar vinculado con las emisiones producidas en otros países y, en consecuencia, las emisiones producidas en un territorio no tienen porqué ser las mismas que las emisiones realmente generadas para satisfacer el consumo realizado en ese territorio.

Teniendo en cuenta lo anterior, la responsabilidad de emisiones de cualquier país puede ser definida desde dos perspectivas diferentes. Por un lado, desde el punto de vista del productor, un país sería responsable de aquellas emisiones asociadas con su producción doméstica independientemente de dónde fuera a ser consumida. Por otro lado, desde el punto de vista del consumidor (o usuario final), un país sería responsable de aquellas emisiones que han sido generadas para satisfacer su demanda final independientemente de dónde hayan sido producidas.

Por otro lado, desde la validación del protocolo de Kioto en 1997 varios países están preocupados en reducir las emisiones de algunos contaminantes atmosféricos. Concretamente, el protocolo de Kioto establece máximos de emisiones para seis gases de efecto invernadero (CO_2, CH_4, N_2O, SF_6, HFCs, y PFCs). Cada país que ha ratificado el acuerdo debe cumplir sus objetivos dentro del periodo 2008-2012, tomándose los niveles de emisiones del año 1990 como referencia. En el protocolo de Kioto los 15 estados miembros de la Unión Europea han sido tratados como un solo territorio y se negoció un único objetivo para todos ellos. Concretamente, el objetivo de emisiones para la Unión Europea es el 92 por ciento de las emisiones de 1990. Sin embargo, en las posteriores negociaciones internas se decidió distribuir este objetivo entre los estados miembros estableciendo diferentes objetivos para cada uno de ellos que van desde el 72 por ciento de Luxemburgo al 127 por ciento de Portugal. En esta redistribución de responsabilidades a España, cuyas emisiones per cápita eran menores que la media de la Unión Europea, se le permite incrementar las emisiones en un 15 por ciento por encima del nivel de 1990. No obstante, España se encuentra muy lejos de cumplir dicho compromiso ya que en el 2006 las emisiones eran un 49.54 por ciento mayores.

Tanto los objetivos de emisiones establecidos para cada país, como los datos oficiales que permiten controlar los compromisos alcanzados han sido establecidos sobre la base de las emisiones generadas por la producción doméstica, dejando de lado parte de las emisiones que están contenidas en el comercio internacional. Es decir, se tienen en cuenta las emisiones contenidas en las exportaciones pero no aquellas contenidas en las importaciones. Este aspecto es de especial importancia para aquellos países que presentan economías abiertas especializadas en la exportación de productos altamente contaminantes.

El objetivo del capítulo 5 es doble. Por un lado, estimar cuál es la responsabilidad de emisión de la demanda final de España para poder determinar si los datos oficiales sobreestiman o subestiman las emisiones generadas por la demanda interior. Y, por otro lado, estimar las emisiones contenidas en el comercio internacional español con el propósito de analizar cual puede ser la influencia del comercio internacional para que España no esté cumpliendo los objetivos establecidos por el protocolo de Kioto. Para llevar a cabo estos dos objetivos, en este capítulo se desarrolla un modelo input-output multirregional ampliado medioambientalmente que nos permite definir dos conceptos: el balance de responsabilidades de emisiones y la balanza comercial de emisiones. El primero de ellos, se define como la diferencia entre las emisiones generadas por la producción doméstica y las emisiones que han sido realmente generadas para satisfacer su demanda final. Por su parte, el segundo concepto es la diferencia entre las emisiones contenidas en el total de exportaciones y las emisiones contenidas en el total de importaciones del país. Una vez definidos ambos conceptos, en este capítulo se demuestra que tanto el concepto del balance de responsabilidades de emisiones como la balanza comercial de emisiones son dos enfoques diferentes que nos permiten analizar el mismo problema.

Se ha computado el modelo para España y el resto del mundo, obteniendo resultados para dos años (1995 y 2000) y para los nueves gases considerados en este trabajo. A pesar de los avances recientes sobre la disponibilidad de datos y la calidad de los mismos, cuando se trata de analizar las relaciones entre un país y el resto del mundo es necesario asumir determinados supuestos. En este capítulo asumimos que el resto del mundo utiliza la misma tecnología que España. Este supuesto implica que lo que realmente se estima son las emisiones que España hubiera generado si hubiera decidido producir en el territorio todos los bienes que, de hecho, importa.

Los resultados obtenidos muestran que la responsabilidad de España desde el punto de vista del consumidor (usuario final) es mayor que la responsabilidad calculada desde el punto de vista del productor tanto en 1995 como en 2000, con la única excepción del NH_3 en este último año. Este resultado muestra que los datos oficiales, los cuales solo tienen en cuenta las emisiones producidas por la producción doméstica pero no aquellas contenidas en las importaciones, no reflejan las emisiones realmente generadas por la demanda interior de un país. Esta conclusión, podría ser pertinente cuando estos datos oficiales son utilizados para controlar el cumplimiento de los objetivos establecidos por el protocolo de Kioto. Especialmente, encontramos que los incrementos de emisiones de los gases de efecto invernadero medidos en unidades equivalentes de CO_2 de 1995 al 2000 se subestiman en 6.21 puntos porcentuales. Por otro lado, al calcular el balance de responsabilidades de emisiones de España en 1995 y en 2000 concluimos, como era de esperar, que España es un exportador neto de emisiones en ambos años con la excepción del NH_3 en el 2000. Este resultado muestra que las emisiones contenidas en las importaciones españolas exceden a las emisiones contenidas en las exportaciones.

En resumidas cuentas, España requiere más emisiones para satisfacer su demanda interior que aquellas domésticamente producidas. De algún modo, mediante la ‘exportación’ de emisiones a otros países se ha estado evitado la producción de estos contaminantes atmosféricos en el interior del territorio. Las implicaciones de este resultado varían según el tipo de contaminante que se esté considerando. Por ejemplo, cuando se está haciendo referencia a gases con efectos locales, es decir SO_2, NO_x, y NH_3, esta ‘exportación’ de emisiones significa que España ha estado desplazando presiones medioambientales, como sería el caso de la lluvia ácida, a otros territorios. Sin embargo, en el caso de los contaminantes globales como los gases de efecto invernadero, significa que la responsabilidad del país en problemas como el calentamiento global ha sido mayor de lo que en un principio podría parecer. Pese a la relevancia de este último aspecto en acuerdos internacionales como el protocolo de Kioto, parece difícil obtener acuerdos sobre el total de emisiones vinculadas a las demandas internas independientemente de dónde hayan sido producidas.

Analizando el balance de responsabilidades de emisiones y el balance comercial de emisiones a nivel sectorial se observa que los sectores de la ‘Construcción’, ‘Elaboración de productos alimenticios y bebidas’ y ‘Hoteles y restaurantes’ fueron los sectores que exportaron más emisiones. El crecimiento económico del sector de la ‘Construcción’ en los últimos años podría explicar parte de este resultado. Sin embargo, la variedad de fuerzas subyacentes en los modelos input-output dificultan la determinación y el análisis de los diferentes factores que afectan al balance de responsabilidades de emisiones y al balance comercial de emisiones.

Finalmente, el capítulo 6 resume las conclusiones de este estudio y expone algunas líneas de investigación futura. A pesar de que cada capítulo presenta conclusiones específicas, los resultados de este estudio contribuyen conjuntamente a mostrar cómo las diversas actividades económicas afectan a los problemas medio ambientales desde puntos de vista diferentes. Así mismo, todos los capítulos en conjunto aportan diferentes perspectivas sobre dos temas importantes: los efectos medioambientales del crecimiento económico y la política medioambiental.

Tal y como se ha apuntado anteriormente, los efectos del crecimiento económico en el medio ambiente no están claros y esto hace que el debate siga abierto. Aunque se podría argumentar que un periodo de cinco años (de 1995 hasta 2000) no es excesivamente largo, los resultados de este trabajo ofrecen elementos relevantes para explicar la relación entre el crecimiento económico y las emisiones atmosféricas en España. Específicamente, se han analizado tres factores principales: los efectos tecnológico-escala-composición, las preferencias individuales, y el comercio internacional. En primer lugar, se concluye que aunque el progreso tecnológico ha tenido un efecto positivo en la reducción de emisiones, éste no ha sido suficiente para contrarrestar el efecto negativo provocado sobretodo por el incremento de la demanda final. La única excepción ha sido precisamente uno de los gases relacionados con problemas medioambientales locales y/o regionales, el SO_2. Por otra parte, el efecto composición ha sido realmente pequeño y solo ha presentado un impacto positivo en el caso del CH_4, N_2O, y NH_3. En segundo lugar, se argumentó que a medida que la renta aumenta, los estándares de vida alcanzados hacen que la gente se preocupe más de la calidad del medio ambiente, disminuyendo el consumo de bienes y servicios más contaminantes. De hecho, nuestros resultados confirman estas afirmaciones pero matizando el hecho de que la desvinculación que se da entre el crecimiento de renta y las emisiones es relativa y no absoluta, que es lo que se necesitaría para garantizar una mejora medioambiental. Finalmente, respecto al efecto del comercio internacional en la contaminación atmosférica de España, nuestro trabajo concluye que las emisiones contenidas en los bienes y servicios que España importa son mayores que las emisiones contenidas en los bienes y servicios exportados. De modo que España a través del comercio internacional ha desplazado presiones medioambientales a otros países.

Respecto al tema de la política medioambiental, los resultados de este estudio nos llevan a concluir que España necesitaría implementar con relativa urgencia políticas orientadas a modificar el nivel y la estructura o composición de los usos finales. No obstante, la ejecución de medidas para reducir los niveles de consumo no parece ser muy popular ni a nivel económico ni político. La otra alternativa que permitiría aplicar medidas enfocadas a modificar la estructura del consumo u otros usos finales es, sin embargo, más factible. En este estudio, se ofrece la base para planificar una política medioambiental orientada a reducir las emisiones relacionadas con el consumo final de los hogares españoles. Disponiendo de información respecto cuáles son los productos más contaminantes, los políticos podrían aplicar instrumentos económicos para incentivar cambios en la composición de las cestas de las compras de los consumidores. Probablemente, el instrumento más común son los impuestos medioambientales. No se ha simulado cuáles serían los efectos de este tipo de impuestos pero, nuestros resultados son relevantes para el debate sobre los efectos sociales de la aplicación de este tipo de gravámenes, sugiriendo que, por ejemplo, un impuesto sobre las emisiones de gases de efecto invernadero podría tener efectos regresivos. Sin embargo, ésta no es la única solución, otro tipo de instrumentos políticos como campañas de información medioambiental o programas de etiquetaje ecológico podrían incentivar a los hogares a cambiar sus patrones de consumo. No obstante, no se debe olvidar que normalmente la mejor opción para conseguir una reducción de las emisiones es la combinación de políticas tecnológicas y de demanda, como es el caso del SO_2, en el cual los desarrollos tecnológicos han conseguido contrarrestar los efectos del nivel de usos finales.

La última parte del capítulo 6 recoge algunas de las posibles líneas de investigación futuras. De hecho, finalizar una tesis no es sinónimo de finalizar una investigación. En algunas ocasiones las respuestas a las preguntas iniciales originan nuevas preguntas; en otras, las soluciones encontradas definen nuevos problemas; los resultados obtenidos para un caso particular pueden ser generalizados; o algunos de los supuestos de los modelos pueden ser relajados. Una relectura cuidadosa y crítica de los capítulos acabados nos permite dibujar un esbozo de cómo continuar con nuestra investigación en un futuro cercano.

Por un lado, en el capítulo 5 se destacó la importancia de tener en cuenta el comercio internacional cuando se analizan las relaciones entre las actividades económicas y el medio ambiente. Sin embargo, el análisis de descomposición estructural llevado acabo en el capítulo 3 no tuvo en consideración este aspecto. Un estudio interesante, por lo tanto, sería analizar la influencia de las variaciones de los patrones de comercio en la evolución de las emisiones españolas, distinguiendo entre importaciones utilizadas como inputs intermedios o como bienes y servicios finales. Por otro lado, el estudio realizado en el capítulo 4 se limitó a estudiar las relaciones entre el nivel de gasto de los hogares y la contaminación atmosférica; no obstante, la información que ofrece la encuesta continua de presupuestos familiares sobre características socio-económicas y demográficas abre la posibilidad de extender este análisis a otras variables. La inclusión del nivel de estudios, la edad del cabeza de familia, o el lugar de residencia del hogar, por ejemplo, podrían proveer nuevas y diferentes ideas para analizar las relaciones entre el consumo de los hogares y la contaminación atmosférica. Finalmente, el modelo input-output multirregional ampliado medioambientalmente del capítulo 5 sería un marco teórico apropiado para analizar otro problema medioambiental de importante en España en los últimos años y, previsiblemente, en el futuro. Nos estamos refiriendo a la escasez de agua en algunas regiones españolas. Esta investigación, sin embargo, supone realizar un esfuerzo adicional respecto a la base de datos ya que hasta el momento no se tiene conocimiento de la existencia de una tabla input-output multirregional que incluya las diferentes regiones de España.

Paralelamente a la elaboración de este estudio han ido surgiendo nuevas preguntas. No obstante, dada la naturaleza de las mismas deberían ser consideradas como futuras investigaciones y no como simples extensiones de este estudio. La primera cuestión está relacionada con el tema de la responsabilidad medioambiental. Actualmente, en la gestión medioambiental el principio más extendido y aplicado es el ‘principio del contaminador paga’. Este principio, basado en la idea de Pigou establece que el agente que contamina debe ser quien internalice los costes asociados con la producción de ‘externalidades’ negativas, como es el caso de la contaminación. En base a este principio se han diseñando la mayoría de los impuestos medioambientales, la estructura de las estadísticas medioambientales, e incluso instrumentos de control para el protocolo de Kioto. Sin embargo, una consideración más detallada de quién es realmente el contaminador puede hacer replantear la aplicación de este principio. ¿Por qué nos tenemos que fijar solo en la empresa como el agente contaminador? De hecho, tanto los productores como los consumidores mediante sus patrones de inversión y de consumo estimulan la generación de substancias tóxicas o el uso excesivo de recursos. Así pues, en un contexto en el que prevalezca el análisis de los efectos medioambientales a largo plazo o en el que se considere conceptos más amplios como la sostenibilidad, cabría la opción de que fueran los usuarios los que deberían pagar por la contaminación. Steenge (1997, 1999, 2004) propone reconsiderar este aspecto y considerar otras soluciones que provean de esquemas de incentivos basados en el mercado como los que Coase señaló en 1960. La capacidad del enfoque input-output para reasignar emisiones permite también reasignar responsabilidades y abriría el campo en el que los modelos input-output pueden ofrecer nuevos resultados.

La segunda cuestión está, en cierta medida, relacionada con la anterior y tiene que ver con los bienes de capital fijo. En los modelos input-output básicos, las inversiones en capital de reemplazamiento o de expansión están consideradas exógenamente sin tener en cuenta sus conexiones con los niveles de producción. Cuando las emisiones se reasignan a los diferentes componentes de los usos finales, las emisiones generadas en la producción de bienes de capital son asignadas a la categoría de formación bruta de capital. Sin embargo, parte de ese capital va a ser utilizado en los procesos de producción de años posteriores. Así pues, en realidad, parte de estas emisiones deberían ser asignadas a los diferentes sectores y, posteriormente, a las correspondientes categorías de usos finales. Además, al considerar los efectos medioambientales a largo plazo se debe tener en cuenta que la tecnología actual es el resultado de inversiones pasadas, es decir, parte de las emisiones generadas en el pasado debería imputarse a los productores presentes. Obviamente, esto mismo se puede aplicar para el futuro: la tecnología del futuro será consecuencia de las inversiones presentes y, por lo tanto, de los ahorros actuales de los consumidores ya que cualquier euro depositado en un banco o invertido en un fondo de inversiones o cartera de acciones encontrará, tarde o temprano, su camino hacia un proyecto de inversión. Indudablemente, sería interesante realizar un análisis más detallado de cómo los bienes de capital son considerados en el análisis input-output y de su relación con las presiones medioambientales como la contaminación.