ESRI

Working Paper No. 398

August 2011

Decomposition of Sectoral Greenhouse Gas Emissions: A Subsystem Input-Output Model for the Republic of Ireland

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Abstract: The analysis of gas emissions by an input-output subsystem approach provides detailed insights into pollution generation in an economy by revealing the channels by which the environmental burdens are caused and transmitted throughout the production system. In this paper we propose a decomposition of the greenhouse gas emissions by using an input-output subsystems model. The empirical application is for the Irish economy, and the economic and environmental data are for year 2005. Our results show that large asymmetries exist not only in the quantitative contribution of the different activities to greenhouse gas emissions but also in the decomposed effects of this contribution.

Keywords: input-output subsystems, greenhouse gas emissions, Ireland.

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1. Introduction

The sectoral interrelations captured by the Leontief's pioneering (economic) input-output model (Leontief, 1941) were subsequently extended to analyse the interactions between the economy and the environment. It was Leontief himself who first accounted for the pollution associated to the production system (Leontief, 1970). Since then, the environmental input-output model has become a useful tool for analysing environmental loads such as gas emissions, water uses, energy consumption and waste generation.

In the last decades, the input-output model of emissions has largely been used to study the patterns of gas pollution and how pollution is related to production activities. Among others, Alcántara and Roca (1995) used the input-output model to analyse the Spanish primary energy requirements and CO_2 emissions during the period 1980-1990. Lenzen (1998) analysed the energy and greenhouse gas flows in the Australian economy. Ostblom (1998) analysed the Swedish emissions from the point of view of the country's medium-term economic projections for economic growth. Lenzen et al. (2004) constructed a multi-region input-output model, which was used to calculate the CO_2 multipliers for five European countries, taking into account the greenhouse gases embodied in international trade. Morilla et al. (2007) defined an environmental and economic model on the basis of a social accounting matrix for Spain. For the Irish economy, O'Doherty and Tol (2007) presented an environmental input-output model to analyse waste, greenhouse gas emissions and water uses.

The input-output model of emissions, which has usually been used to study the patterns that explain the total emissions of the production system, can also be used to decompose the different channels through which sectoral emissions are produced and transmitted throughout the economy.

The subsystems input-output approach allows studying an individual sector or group of sectors that is considered a subsystem which interacts with the rest of the sectors. This approach isolates the relations of a limited number of activities from the whole system, and this shows specific information about the relations of individual units as part of the entire production sphere. The subsystems model, which was originally proposed by Sraffa (1960), Pasinetti (1973, 1988), Deprez (1990) and Scazzieri (1990) among others, has also been extended to the analysis of the environmental burdens associated with the production processes. In this field, Alcántara (1995) and Sánchez-Choliz and Duarte (2003) provided a conceptual set to illustrate the ability of the subsystems approach to show the isolated effects of individual agents on pollution generation. Alcántara and Padilla (2009) used a subsystem model to study the CO_2 emissions of the Spanish service sectors. Similarly, Cardenete and Fuentes (2011) analysed the CO_2 emissions of Spanish energy activities using a subsystem decomposition within a social accounting matrix model. Finally, Butnar and Llop (2011) applied structural decomposition analysis to a subsystem model that isolated the emissions of the Spanish service sectors.

In this paper, we define an input-output subsystems model of the greenhouse gas emissions, in which each sector is separated from the whole production system. Our model identifies the patterns through which gas pollution is generated and transmitted within the production system by capturing the individual specificities of the emissions caused by sectors of production. Our approach, which divides the sectoral emissions into different components, illustrates how the individual patterns of greenhouse gas pollution differ among sectors. With this approach, therefore, we further analyse pollution generation and provide valuable information about the process of greenhouse gas emissions. We apply this analytical context to Ireland, using both economic and environmental information for the year 2005. The greenhouse emissions we consider are the six major greenhouse gases regulated by the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), halofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6).

Our results show a different contribution of the decomposed effects to the emissions of the different activities of production. They also show important asymmetries depending on the gas analysed. Therefore, pollution abatement measures should be individually defined and individually implemented not only in terms of the different gases involved but also in terms of the different sectors of production, mainly if the aim is to mitigate the negative consequences of the production system on the environment.

The rest of the paper is organised as follows. Section 2 describes the emission subsystems approach and section 3 contains the empirical results. At the end of the paper we provide some concluding remarks.

2. A subsystems input-output model of emissions

Our study involves applying a subsystem input-output decomposition of the sectoral greenhouse emissions. The subsystems approach, which captures the channels by which pollution is produced and transmitted throughout the production system, provides useful information about the underlying patterns that explain the pollution generation of an economy.

The basic idea behind the subsystems approach is that an individual sector (or a group of sectors) can be analysed as a particular unit without modifying the main characteristics of the system of which such particular unit is part. The usefulness of the subsystems approach is that it isolates the relations of an activity from the whole system, and this provides specific information about the production relations of individual units.

Taking into account that a subsystem responds to the notion of an individual sector or group of sectors that produce a specific commodity, an input-output table allows to consider as subsystems as sectors of production reflected in this table. In this paper we take into account separately all the sectors of production and, for each one, we apply a subsystems division of its greenhouse emissions. This analysis, which decomposes the emissions of each sector into different sources, extends our knowledge about the greenhouse pollution of the production system.

The starting point of the subsystems representation consists of the decomposition of the *N* accounts of an input-output system into two categories (*M* and *S*), with 1, 2, …, *m* sectors belonging to *M* subsystem, and *m* + 1, …, *n*, belonging to the *S* subsystem. By taking into account this separation of the accounts, the input-output representation can be written as follows:

$$\begin{pmatrix} A_{MM} & A_{MS} \\ A_{SM} & A_{SS} \end{pmatrix}\begin{pmatrix} x^M \\ x^S \end{pmatrix}+\begin{pmatrix} y^M \\ y^S \end{pmatrix}=\begin{pmatrix} x^M \\ x^S \end{pmatrix}, \qquad (1)$$

where the subscripts and superscripts denote the group of accounts *M* and *S* respectively. In Equation (1), matrices *A* contain the technical input-output coefficients, the column vector $x=\begin{pmatrix} x^M \\ x^S \end{pmatrix}$ contains the sectoral production and the column vector $y=\begin{pmatrix} y^M \\ y^S \end{pmatrix}$ contains the final demand. From expression (1), we can calculate sectoral production as $x=(I-A)^{-1}y=By$ where *B* is the Leontief inverse. By taking this definition into account, the model can be written as:

$$\left[\begin{pmatrix} A_{MM} & A_{MS} \\ A_{SM} & A_{SS} \end{pmatrix}\right]\begin{pmatrix} B_{MM} & B_{MS} \\ B_{SM} & B_{SS} \end{pmatrix}\begin{pmatrix} y^M \\ y^S \end{pmatrix}+\begin{pmatrix} y^M \\ y^S \end{pmatrix}=\begin{pmatrix} x^M \\ x^S \end{pmatrix}. \qquad (2)$$

Expression (2) contains the following two equations:[1]

$$A_{MM}B_{MM}y^M + A_{MM}B_{MS}y^S + A_{MS}B_{SM}y^M + A_{MS}B_{SS}y^S + y^M = x^M,$$

$$A_{SS}B_{SM}y^M + A_{SS}B_{SS}y^S + A_{SM}B_{MM}y^M + A_{SM}B_{MS}y^S + y^S = x^S. \qquad (3)$$

The two equations in (3) show the production of the *M* and *S* subsystems, respectively. Let us assume that we are interested in analysing the *S* subsystem. Then, the interpretation of Equation (3) is as follows. The first equation, which defines the total production of *M*, can be divided into two parts. The first one, $A_{MM}B_{MS}y^S + A_{MS}B_{SS}y^S$, shows the effects of the final demand of *S* subsystem on the production of *M* and we can consider it as an *external component*. The remaining elements in the first equation of (3),

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[1] The related literature usually assumes that the final demand in one subsystem is zero and that means that this subsystem only produces for the intermediate demand (see Alcántara and Padilla (2009)). Differently to the related studies, expression (3) captures all the income relations within the production system.

$A_{MM}B_{MM}y^M + A_{MS}B_{SM}y^M + y^M$, show the production of *M* needed to cover its final demand.[2]

The left hand side of the second equation in expression (3) can be divided into different components that convey different economic meaning. The term $A_{SS}B_{SM}y^M + A_{SM}B_{MM}y^M$ shows the production of *S* required to cover the final demand of *M* or the *induced component*. The term $A_{SS}B_{SS}y^S + A_{SM}B_{MS}y^S$ is interpreted as an *internal component* that shows effects ending in *S* and starting from *S* as well. Finally, the last component, y^S, is the final demand for the *S* subsystem and can be interpreted as a *demand level component*.

To transform expression (3) into an emissions model, we use matrices C^M and C^S that contain the emissions coefficients, calculated as the emissions per unit of production in the *M* and *S* subsystems, respectively. These matrices have emissions as rows and sectors as columns. The emissions associated to the components of the *S* subsystem are equal to:

$EC_S = C^M\left(A_{MM}B_{MS} + A_{MS}B_{SS}\right)y^S$,

$NC_S = C^S(A_{SS}B_{SM} + A_{SM}B_{MM})y^M$,

$ITC_S = C^S\left(A_{SS}B_{SS} + A_{SM}B_{MS}\right)y^S$.

$DLC_S = C^S y^S$.

These expressions show the emissions associated to the external component (EC_S) – the emissions from subsystem *M* due to demand for *S* – the induced component (INC_S) – the emissions from subsystem *S* due to demand for *M* – the internal component (ITC_S) – the emissions from subsystem *S* due to demand for *S* – and the demand level component (DLC_S) – the direct emissions due to demand for *S*.[3] The total (direct and indirect) emissions (E_S) of the *S* subsystem can then be calculated as:

$$E_S = EC_S + INC_S + ITC_S + DLC_S$$

$$= C^M\underbrace{\left(A_{MM}B_{MS} + A_{MS}B_{SS}\right)}_{\text{external}}y^S + C^S\underbrace{(A_{SS}B_{SM} + A_{SM}B_{MM})}_{\text{induced}}y^M$$

$$+\ C^S\underbrace{\left(A_{SS}B_{SS} + A_{SM}B_{MS}\right)}_{\text{internal}}y^S + \underbrace{C^S y^S}_{\text{demand}} . \qquad (4)$$

The subsystem model allows analysing the emissions of a sector or group of sectors by disentangling the underlying interdependences within the production system. This extends our knowledge about the effects of particular units of production on the environment.

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[2] Note that if we focus on the *S* subsystem, this part of the *M* production does not have any interest.

[3] Note that a situation of null emissions in *S* (that is, all the elements in C^S equal to zero) means that the INT_S component, the ITC_S component and the DLC_S component are zero. However, the EC_S component can be positive, given that it reflects the emissions of *M* caused by the final demand of *S*.

We should note, however, that the decomposition is not perfect in the sense that the sum of E_S and E_M is greater than the total emissions. Particularly, the induced and external components are doubly counted – $EC_M=INC_S$ and $EC_S=INC_M$. The sum of the induced, internal and demand level components does add up to the total emissions, as does the sum of the external, internal and demand level components. The latter maps all emissions to final demand for S: y^S – we shall therefore refer to this as emissions from consumption. The former maps all emissions from sector S: C^S – we shall therefore refer to this as emissions from production.

3. Empirical application to the greenhouse emissions in Ireland

For the empirical application we used the symmetric Input-Output (IO) Table for the Irish economy with 2005 data, published by the Ireland Central Statistics Office (CSO, 2006). We also used the 2005 environmental accounts, published by the Economic and Social Research Institute (Lyons et al., 2009). The level of disaggregation in the IO table is 48 sectors while in the environmental accounts the emissions are allocated to 19 economic sectors, which correspond to the activities used in this study. We focus on the six (groups of) greenhouse gases regulated by the Kyoto Protocol. Table 1 shows the list of activities and gases under study.

The information reported by the subsystem decomposition of sectoral emissions highlights several aspects of the greenhouse pollution of the Irish production system. First, we show the total emissions of the six gases analysed. Second, we focus on the decomposition of CO_2, CH_4 and N_2O emissions into different components according to the subsystem framework. Finally, we describe the patterns that explain the HFC, PFC and SF_6 emissions.

3.1. Total greenhouse emissions

Table 2 shows the greenhouse emissions of the Irish production system in the year 2005. The CO_2 emissions are the largest component of total greenhouse gas emissions. Specifically, in 2005 the total carbon dioxide (CO_2) emissions were 38.0 million tonnes, 64.5% of which (24.5 million tonnes)[4] caused by the generation of electricity (sector 17), 17.2% of which (6.5 million tonnes) caused by transport services (sector 19), and 11.8% of which (4.5 million tonnes) caused by the production of cement (sector 9). Jointly, these three activities explain 93.5% of the total CO_2 emissions from fossil fuel combustion. Other economic activities show a correspondingly smaller contribution to climate change. Cement production is responsible for another 2.6 million tonnes of process emissions of carbon dioxide. This constitutes 100% of such emissions.

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[4] This is the sum of induced, internal and demand level components, that is, production emissions.

Table 1. Sectors of Production and Greenhouse Gases

S	Sectors	i	Gases
1	Agriculture, fishing, forestry	1	Carbon Dioxide (CO_2)
2	Coal, peat, petroleum, metal ores, quarrying	2	Methane (CH_4)
3	Food, beverage, tobacco	3	Nitrous Oxide (N_2O)
4	Textiles, clothing, leather & footwear	4	Perfluorocarbons (PFC)
5	Wood & wood products	5	Halofluorocarbons (HFC)
6	Pulp, paper & print production	6	Sulphur Hexafluoride (SF_6)
7	Chemical production		
8	Rubber & plastic production		
9	Non-metallic mineral production		
10	Metal prod. excl. machinery & transport equip.		
11	Agriculture & industrial machinery		
12	Office and data process machines		
13	Electrical goods		
14	Transport equipment		
15	Other manufacturing		
16	Fuel, power, water		
17	Construction		
18	Services (excl. transport)		
19	Transport		

Methane (CH_4) emissions are caused by livestock and landfill sites. As Table 2 shows, the agricultural sector (sector 1) has the largest contribution, with approximately 94.7% (12.5 million tonnes) of the total CH_4 emissions in 2005.

Nitrous oxide (N_2O) emissions are caused by fertilizer applications, and manure management. That explains the importance of agriculture in generating this pollution. Specifically, emissions of N_2O from agricultural sources in 2005 were estimated at 6.4 million tonnes, representing 75.8% approximately of the total value. The second largest source is power generation (sector 16) with 1.5 million tonnes and a relative contribution of 17.7%.

Table 2. Total greenhouse emissions by sector, Ireland, 2005

Sector	Gross output (bln €)	Fossil CO2	Process CO2	CH4	N2O	HFC	PFC	SF6
		(thousand tonnes of carbon dioxide equivalent)						
1	34	451	0	12525	6399	0	0	0
2	30	148	0	293	0	0	0	0
3	31	234	0	2	11	0	0	0
4	8	259	0	5	13	0	0	0
5	28	128	0	0	10	0	0	0
6	18	14	0	0	1	0	0	0
7	15	28	3	0	1	28	0	0
8	34	301	0	0	23	0	0	0
9	25	4459	2626	77	226	0	0	0
10	20	135	0	0	10	0	0	0
11	28	251	0	0	19	16	0	0
12	3	6	0	0	0	0	0	0
13	36	52	0	0	4	391	168	90
14	8	86	0	0	7	0	0	0
15	6	127	0	0	4	0	0	0
16	58	24499	0	0	1500	0	0	0
17	37	67	0	0	9	0	0	0
18	108	187	0	285	26	0	0	0
19	51	6535	0	31	181	0	0	0
Total	580	37967	2630	13220	8445	435	168	90

Halofluorocarbons (HFC) emissions amounted 0.4 million tonnes in 2005. Table 2 shows that the most influential sector is electrical goods (sector 13), with 89.8% of total emissions. Perfluorocarbons (PFC) are completely caused by the production of electrical goods (sector 13): 0.2 million tonnes of emissions.

Finally, Table 2 shows that in the year 2005 sulphur hexafluoride (SF_6) emissions amounted 90 thousand tonnes, 99.7% of which are due to the production of electrical goods (sector 13).

3.2. A closer look at carbon dioxide

The third column of Table 2 shows the sectoral contribution to total emissions of fossil carbon dioxide according to the sum of internal, induced and demand level components. Table 3 repeats that information, and adds the sectoral contribution according to the sum of the internal, external and demand level components; as well as the direct emissions ($C^S x^S$).

Power generation (sector 16) is the largest source of direct emissions. It is an even large share of production emissions, because the induced component is so large: Electricity is used in all other sectors of the economy. The external component is small, however, because power generation takes few inputs from other sectors. The consumption emissions are therefore small. A similar mechanism holds for transport (sector 19) and cement (sector 9) emissions: The induced component is large, and the external component is small. The opposite is true for services (sector 18): The induced component is small but the external component is large. Therefore, consumption emissions are large but production emissions are small. The reason is that services per se are energy extensive, but its intermediary inputs (electricity, transport) are not.

Table 3. Total carbon dioxide emissions by sector, Ireland, 2005, for three alternative measures of sectoral contribution

Sector	ITCS+INCS+DLCS	ECS+ITCS+DLCS	Direct	ITCS+INCS+DLCS	ECS+ITCS+DLCS	Direct
	(thousand tonnes of CO2)			(share)		
1	451	52	862	1.2%	0.1%	2.3%
2	148	8	60	0.4%	0.0%	0.2%
3	234	947	1096	0.6%	2.5%	2.9%
4	259	36	164	0.7%	0.1%	0.4%
5	128	6	45	0.3%	0.0%	0.1%
6	14	137	85	0.0%	0.4%	0.2%
7	28	19	486	0.1%	0.0%	1.3%
8	301	1205	112	0.8%	3.2%	0.3%
9	4459	181	3126	11.7%	0.5%	8.2%
10	135	50	151	0.4%	0.1%	0.4%
11	251	9	152	0.7%	0.0%	0.4%
12	6	12	190	0.0%	0.0%	0.5%
13	52	716	133	0.1%	1.9%	0.3%
14	86	97	97	0.2%	0.3%	0.3%
15	127	20	521	0.3%	0.1%	1.4%
16	24499	490	15136	64.5%	1.3%	39.9%
17	67	2658	505	0.2%	7.0%	1.3%
18	187	30521	2249	0.5%	80.4%	5.9%
19	6535	803	12797	17.2%	2.1%	33.7%
Total	37967	37967	37967			

The results in Table 3 are partly explained by the relative sizes of the sectors. We therefore decompose gross output along the same lines (cf. Table 2) and compute the emission intensity for the sectors and the components. The results are shown in Table 4. The average emission intensity is 117 grammes of carbon dioxide per euro output. Direct emission intensity is highest in power generation (sector 16), cement (sector 9), and transport (sector 19). For these three sectors, induced emission intensity is greater than external emission intensity. For all other sectors, it is the other way around. Comparing Table 3 to Table 4, we see that the differences between consumption and production emission intensities are smaller than the differences between consumption and production emissions. That is, the patterns in Table 3 are largely due to the structure of economic production rather than the structure of energy- and emission-intensity.

Table 4. Carbon dioxide emission intensity (gramme of carbon dioxide per euro gross output)

Sector	Direct	ITC_S+INC_S+DLC_S	EC_S+ITC_S+DLC_S	Demand	Internal	Induced	External
1	121	24	42	27	24	23	179
2	42	9	24	9	10	9	267
3	65	13	58	15	17	12	97
4	264	57	62	60	69	57	161
5	39	8	19	9	11	8	253
6	6	1	18	1	2	1	267
7	15	3	17	3	4	3	80
8	69	16	54	16	16	14	267
9	1432	315	317	324	276	314	187
10	54	12	45	12	16	12	199
11	76	16	26	17	20	16	235
12	15	3	9	3	4	3	66
13	12	3	30	3	3	2	156
14	87	19	36	20	21	18	238
15	180	38	44	41	45	37	169
16	3523	756	615	797	756	756	15
17	14	3	57	3	3	4	78
18	14	3	158	3	3	3	226
19	1074	228	223	243	231	226	130
Total	117	117	117	16	18	192	192

3.3. Decomposition of CO_2, CH_4 and N_2O, emissions

Following the logic of the input-output subsystems model, the emissions caused by a particular sector are divided into four components: external component, induced component, internal component and demand level component, depending on the drivers behind the pollution process. In this section, we quantify the emission components of the Irish greenhouse emissions in the year 2005. Specifically, we first focus on the CO_2, CH_4 and N_2O gases which, among the six gases analysed, are relatively widespread in the Irish production system.

Figure 1 illustrates the results of the decomposition of the CO_2 emissions, which have been calculated by taking into account the contribution (in percentage) of the subsystem components within the total carbon dioxide emissions in each sector of production.

Figure 1. Decomposition of sectoral CO2 emissions. Ireland, 2005

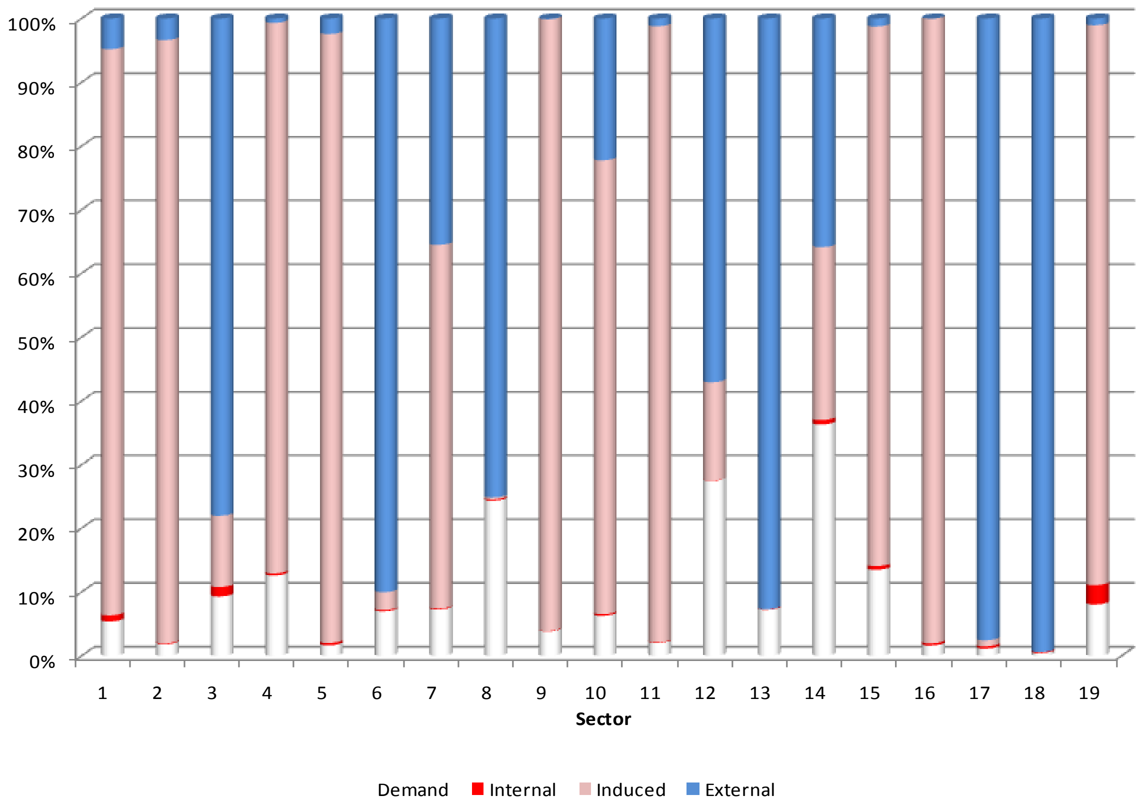

Figure 1 shows that the patterns of CO_2 emissions are very different at the sectoral level. In general, the induced component is the most important channel within the CO_2 emissions and, accordingly, this means that the production of sectors needed to cover the final demand of the other sectors cause the greatest CO_2 pollution. This result suggests that the main source of CO_2 emissions of activities depends, to a greater extent, on the final demand of the rest of the production system. Figure 1 shows, however, some important exceptions: food (sector 3), paper (sector 6), rubber and plastic (sector 8), office machines (sector 12), electrical goods (sector 13), construction (sector 17) and services (sector 18). For these activities, the external component is the most important source of CO_2 and this means that the production required from the other activities to cover the own demand is the main cause of emissions. We can also point out that some activities show a significant contribution of the demand level component to their total CO_2 emissions: sector 14 (transport equipment) with 36.3%, sector 12 (office machines) with 27.5%, sector 8 (rubber and plastics) with 24.4%, sector 15 (other industry) with 13.5% and, finally, sector 4 (textiles) with 12.6%. According to our results, therefore, these are activities in which the own final demand contributes to their CO_2 emissions with a none-negligible amount.

An important finding of the analysis of the relative contribution of the subsystems components is that the CO_2 emissions have different origins at a sectoral level and no general trends can be traced within the production system, as the origin of pollution mainly depends on the activity considered.

Figure 2. Decomposition of sectoral CH4 emissions. Ireland, 2005

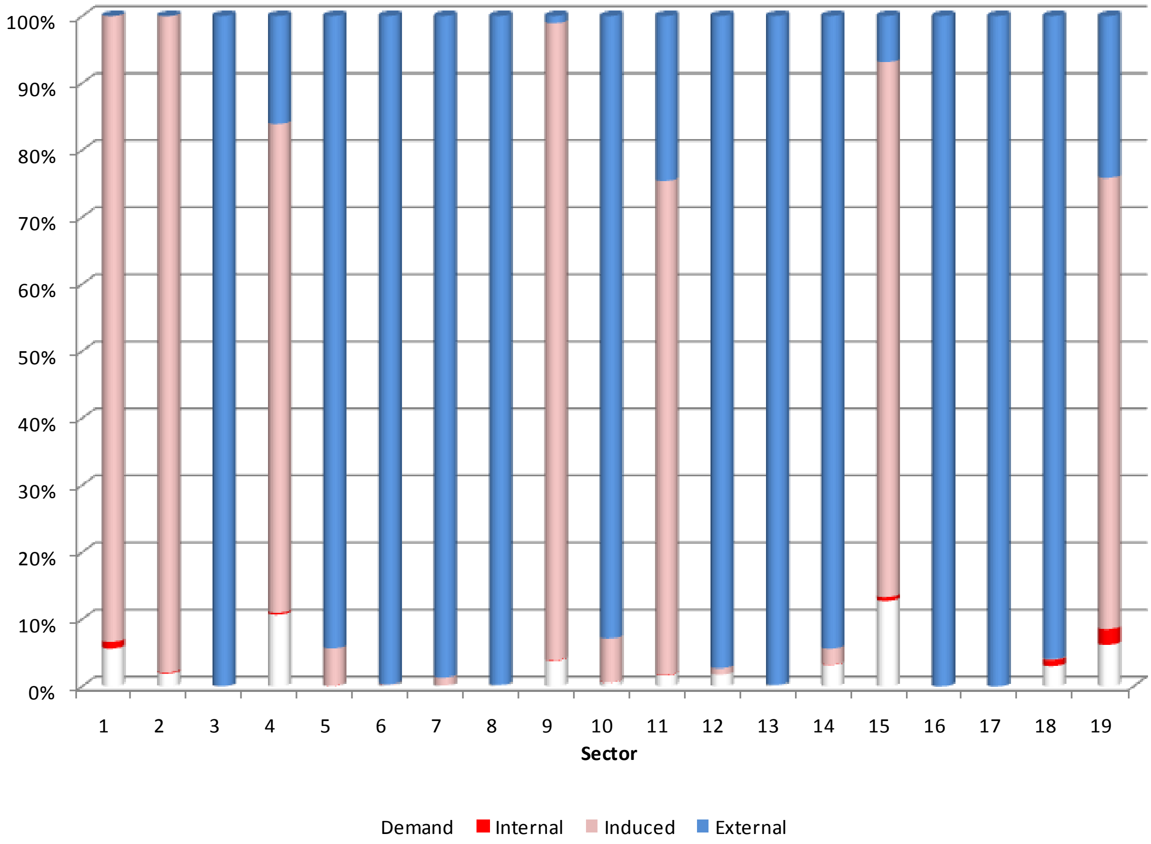

Figure 2 shows the relative contribution of the subsystem components within the sectoral emissions of methane. From this figure, the emissions caused by the sectoral demand on the other sectors (external component) are the most important source of CH_4 emissions. In fact, twelve sectors have a contribution of the external component greater than 90%. The exceptions are sector 1 (agriculture), sector 2 (coal and petroleum), sector 4 (textiles), sector 9 (minerals), sector 15 (other industry) and sector 19 (transport), in which the induced component is the most important channel. For these activities, therefore, the CH_4 emissions are mainly explained by the production required to cover the final demand of the others. Finally, note that the demand component and the internal component explain the lesser part of the CH_4 emissions.

Figure 3. Decomposition of the sectoral N2O emissions. Ireland, 2005

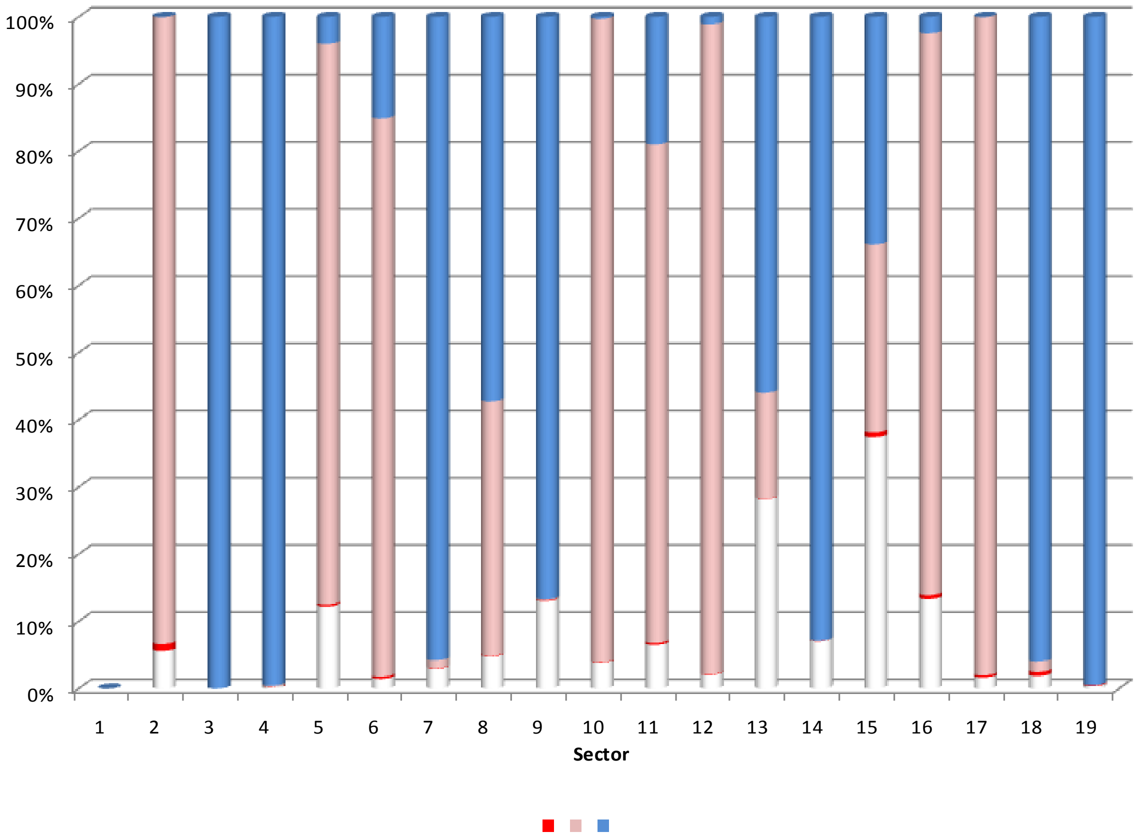

Figure 3 contains the decomposition of sectoral N_2O emissions. The contribution of the different subsystem components is very different at a sectoral level and no general rules can be traced from this analysis. The emissions caused by the final demand on the production of the other sectors (the external component) dominate in sector 2 (quarrying), sector 3 (food), sector 6 (paper), sector 13 (electrical goods), sector 17 (construction) and sector 18 (services). In all these activities the external effect is larger than 90% of total N_2O emissions. On the other hand, the induced effect is the main pollution channel in sector 1 (agriculture), sector 9 (cement), sector 11 (machinery), and sector 16 (fuel and water). Final demand is an important source of N_2O emissions in sector 14 (transport equipment), sector 12 (office machines), sector 8 (rubber and plastics), sector 15 (other industry), and sector 4 (textiles).

Comparing Figures 1, 2 and 3, there are qualitative differences in the relative contribution of the subsystem channels of emissions. As a general trend, the relative importance of the induced effects is the most important component in the CO_2 emissions. This illustrates that for CO_2 the relation of the accounts with the other parts of the system contributes most to generate emissions. If we look at the CH_4 emissions, the external component dominates in most of activities and that means that the emissions are mainly explained by the production required of the other sectors to cover the own final demand. Additionally, the final demand of activities shows a significant contribution in explaining the N_2O emissions, being larger than the demand contribution in the other two gases.

All these results suggest that the trends of CO_2, CH_4 and N_2O are not the same. This is interesting for policy purposes since it may indicate that different gases should be treated differently by sectoral abatement policies. It also may indicate that abatement measures should be sectorally defined and applied, according to the patterns of pollution in each sector of production. If the income and production connections between activities generate different emission channels, the importance of which depends on both the gas and the sector under analysis, policy measures must take into account the individual specificities that make emissions very asymmetric at a sectoral level.

3.4. Decomposition of HFC, PFC and SF_6 emissions

This section shows the emissions of HFC, PFC and SF_6 gases. These are potent industrial greenhouse gases with no natural sources.

The last column in Table 2 shows the sectoral contribution to total emissions for each gas analysed. The production of electrical goods (sector 13) is responsible for most of HFC and all of PFC and SF_6 emissions. The chemical sector also emits some HFCs. The subsystem components show a similar decomposition for this activity in the three emissions; the most important channel is the final demand components and the other channels are practically negligible. This result suggests that the reduction in the three emissions analysed could be accomplished with policies oriented towards the final demand (i.e. export) of electrical goods.

Studying the components of the subsystem model reveals the underlying effects that generate environmental consequences within the production system. This illustrates the usefulness of the subsystem input-output decomposition for disentangling the subjacent reasons that explain greenhouse pollution.

4. Conclusions

In this paper, we define an input-output subsystem model of emissions to show the channels that explain greenhouse gas emissions of the Irish production system. Specifically, we define a subsystem method that identifies four different components in the sectoral emissions, by capturing both the economic and the environmental relationships that exist among the production activities. In the empirical analysis for the Irish production system, we individually take into account the emissions of all activities and their relations with the rest of the production system. Our approach provides additional information about the complex process of pollution generation and how it is related to the production process.

Our application to the Irish greenhouse emissions reveals emissions are concentrated in a few sectors. However, alternative definitions of the sectoral contribution to total emissions show very different patterns. This is because direct emissions are concentrated in economic sectors that deliver intermediate goods and services to other sectors. The sectoral share of emissions is partly explained by differences in gross output and partly by differences in emission intensity. Differences in the intensity of direct emissions are far more pronounced than differences in the intensity of emissions taken intermediate deliveries into account.

These results suggest that sectoral emission reduction policies need to take account of trade in intermediates so as to avoid unexpected economic consequences.

Acknowledgements

The first author acknowledges funding by the Spanish *Ministerio de Educación y Cultura* (grant ECO2010-17728) and the *Generalitat de Catalunya* (grants SGR2009-322 and “Xarxa de Referència d’R+D+I en Economia i Polítiques Públiques”). The second author acknowledges funding by the Ireland Environmental Protection Agency (STRIVE programme “Towards a Green Net National Product”).

References

Alcántara, V. 1995. Economía y contaminación atmosférica: hacia un nuevo enfoque desde el análisis input-output. Doctoral Thesis Dissertation. University of Barcelona.

Alcántara, V. and Roca, J. 1995. Energy and CO_2 Emissions in Spain: Methodology of Analysis and Some Results for 1980-1990. Energy Economics 17, 221-230.

Alcántara, V. and Padilla, E. 2009. Input-output subsystems and pollution: an application to the service sector and CO_2 emissions in Spain. Ecological Economics 68, 905-914.

Butnar, I. and Llop, M. 2011. Structural decomposition analysis and input-output subsystems: an application to CO2 emissions of Spanish service sectors (2000-2005). Ecological Economics, in press.

Cardenete, M. A. and Fuentes, P. 2011. Energy consumption and CO_2 emissions in the Spanish economy. In Llop, M. (Ed.), Air pollution: measurements and control policies, Bentham E-Books.

Central Statistics Office, 2006. Supply and use and input-output tables. Cork: Central Statistics Office.

Deprez, J. 1990. Vertical integration and the problem of fixed capital. Journal of PostKeynesian Economics 13, 47-64.

Environmental Protection Agency. 2005. Irish submission to the United Nations framework convention on climate change. Johnstown Castle: Environmental Protection Agency.

Lenzen, M. 1998. Primary Energy and Greenhouse Gases Embodied in Australian Final Consumption: An Input-Output Analysis. Energy Policy 26, 495-506.

Lenzen, M., Pade, L. L. and Munksgaard J. 2004. CO_2 Multipliers in Multi-Region Input-Output Models. Economic Systems Research 16, 391-412.

Leontief, W. 1941. The structure of the American economy 1919-1939: an empirical application of equilibrium analysis. Oxford University Press.

Leontief, W. 1970. Environmental repercussions and the economic structure: an input-output approach. Review of Economics and Statistics 52, 262-271.

Lyons, S., Mayor, K. and Tol, R.S.J. 2009. Environmental accounts of the Republic of Ireland: 1990-2005. Journal of the Statistical and Social Inquiry Society of Ireland 107, 190-216.

O'Doherty, J. and Tol, R. 2007. An environmental input-output model for Ireland. The Economic and Social Review 38, 157-190.

Ostblom, G. 1998. The Environmental Outcome of Emissions-Intensive Economic Growth: A Critical Look at Official Growth Projections for Sweden up to the Year 2000. Economic Systems Research 10, 19-29.

Pasinetti, L. 1973. The notion of vertical integration in economic analysis. Metroeconomica 25, 1-29.

Pasinetti, L. 1988. Growing subsystems, vertically hiper-integrated sectors and the labour theory of value. Cambridge Journal of Economics 12, 125-134.

Morilla, C., Llanes, G. and Cardenete, M. A. 2007. Economic and environmental efficiency using a social accounting matrix. Ecological Economics 60, 774-786.

Sánchez-Choliz, J. and Duarte, R. 2003. Analysing pollution by vertically integrated coefficients, with an application to the water sector in Aragon. Cambridge Journal of Economics 27, 433-448.

Scazzieri, R. 1990. Vertical integration in economic theory. Journal of Post Keynesian Economics 13, 20-46.

Sraffa, P. 1960. Production of commodities by means of commodities. Cambridge University Press, Cambridge.

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