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This paper identifies the key sectors and linkages between sectors leading to CO2 emissions in the Spanish economy. These emissions might be related to the technology-production relationships between activities within the economy, to the CO2 emissions intensity of the sectors and to their structures of final demand. A formal analysis of these factors is carried out by means of an input-output framework combined with a sensitivity analysis and lineal programming. Those production relationships which are most CO2 emissions intensive are shown.

El trabajo identifica los sectores y relaciones claves desde el punto de vista de las emisiones de CO2 de la Economía Española. Estas emisiones están relacionadas con las relaciones tecnológico-productivas entre las actividades de la economía, con la intensidad de emisión de cada sector y con sus estructuras de la demanda final. Se lleva a cabo un análisis formal de estos

factores por medio del marco input-output junto con el análisis de sensibilidad basado en programación lineal. De esta manera se muestran las relaciones productivas más intensivas en términos de emisiones de CO_2.

CO_2 EMISSIONS IN SPAIN: SENSITIVITY ANALYSIS BASED ON LINEAR PROGRAMMING.

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1. INTRODUCTION.

This paper provides a methodology which allows the tracing of the direct and indirect CO_2 emissions associated with a product, and, thus, an assessment of the carbon embodied in a product (Machado et al 2001) in an input-output framework. Indirect emissions are those not actually caused by an agent but by the agent's demand and include the energy/carbon related to all the inputs directly and indirectly involved in the supply chain (Mongelli et al 2005). Therefore, also the CO2 emissions induced in the other sectors linked to the "key" sector are taken into account, in the sectors linked to these and so on.

For this purpose, a sensitivity analysis is carried out by means of a linear programming model.

The developed methodology is applied to Spain, identifying the linkages between sectors leading to CO_2 emissions. This will help policy makers propose a wise combination of measures targeted implementation of less CO_2 emissions intensive technologies and measures directed to behavioural change.

Accordingly, the paper is structured as follows. A background on the methodology and the links to existing literature is considered in the next section. Section 3 provides the details of the model, which will be empirically applied to the Spanish economy in section 4. The paper closes with some concluding remarks and policy recommendations.

2. AIM, METHODOLOGY, MAIN ASSUMPTIONS AND LINKS TO EXISTING LITERATURE.

The aim of this paper is to propose a methodology to identify the main linkages between activity branches leading to CO_2 emissions. The two types of productive linkages considered are:

- The *technology-production linkage* factor. The level and evolution of CO_2 emissions is related to the input-output relationships within an economy. The sales of one activity branch to another might cause higher emissions than its sales to other sectors.
- The *Demand factor*. The structure of final demand of a sector also affects its CO2 emissions. An increase in the demand for the products of one sector may cause a larger increase in total emissions that the same level of increase in the demand for the products of other sectors. Those components of final demand that contribute most to CO2 emissions should be identified.

Previous papers and models have used input-output techniques to analyse sectoral CO_2 emissions[1]. The frequently adopted hypothesis of fixed structural coefficients does not allow an analysis of changes in emissions caused by changes in the structure of the economy. They only analyse the impact on emissions of a change in demand. In contrast, our paper analyses the change in the structural coefficients.

Structural decomposition techniques analysing changes in the economic structure is an alternative approach. They consider how changes in sectors' production levels cause changes in energy consumption and GHG emissions[2]. Both the homogeneous input-output tables of two periods at constant prices and the emissions vectors should be available.

Some authors have applied an input-output approach to analyse Spanish CO_2 emissions in the past (Labandeira and Labeaga 2002, Alcántara and Padilla 2005). By identifying those structural coefficients most sensitive to CO_2 emissions, this paper provides an alternative but complementary approach.

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[1] See, among others, Proops (1988), Lenzen (1998), Munksgaard & Pedersen (2001), Machado et al (2001), Ferng (2003) and Mongelli et al (2005).

[2] This is the case of Chang & Lin (1998), de Haan (2001) and Alcántara & Duarte (2004) concerning energy consumption. Hoen & Mulder (2003) provide a decomposition of emissions changes by using the algorithms developed by Dietzenbacher & Los (1998).

Two advantages of our approach are that only one input-output table and the vector of emissions per activity branch are necessary and that an analysis of the structure of final demand (and not only of intersectoral relationships) is carried out[3].

3. THE MODEL.

3.1. Model specification.

As it is well known, the input-output tables (IOT) of an economic system consists of three interrelated matrix: a matrix of intermediate transactions *X* including purchases and sales of goods and services between activity branches, a final demand matrix *Y* representing the sales of the activity branches to the final demand components, and a primary inputs matrix *Z* representing the inputs purchased to the primary productive factors.

The equality between supply and demand should be fulfilled:

$$\sum_{ik} y_{ik} = \sum_{dj} z_{dj} \qquad (1)$$

Total sum of sales will equal total purchases in each activity branch. The value will represent the output of activity branch w_i (or w_j):

$$\sum_{j} x_{ij} + \sum_{k} y_{ik} = w_i \qquad (2)$$

$$\sum_{i} x_{ij} + \sum_{d} z_{dj} = w_j \qquad (3)$$

Technical coefficients can be defined as the ratio between each element of the intermediate transaction matrix and the output of the corresponding activity branch (column):

$$a_{ij} = \frac{x_{ij}}{w_j} \qquad \text{with i=(1,2,...,n) and j=(1,2,...,n)} \qquad (4)$$

The matrix of technical coefficients has the following structure:

[3] Tarancón and del Río (2005) is a previous paper following this approach.

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \tag{5}$$

The aggregate of final demand g_k can be defined as the sum of each demand component (per column):

$$g_k = \sum_i y_{ik} \tag{6}$$

The final demand coefficients can be calculated as:

$$h_{ik} = \frac{y_{ik}}{g_k} \qquad \text{with i=(1,2,...,n) y k=(1,2,...,m)} \tag{7}$$

Therefore, the matrix of final demand coefficients will be:

$$H = \begin{bmatrix} h_{11} & h_{12} & \dots & h_{1m} \\ h_{21} & h_{22} & \dots & h_{2m} \\ \dots & \dots & \dots & \dots \\ h_{n1} & h_{n2} & \dots & h_{nm} \end{bmatrix} \tag{8}$$

Rewriting (2) in a matrix form,

$$w = Xu_n + Yu_k \tag{9}$$

where: u_n *and* u_k are unitary vectors (nx1 and kx1, respectively).

If (5) and (8) are included in (9), then:

$$w = Aw + Hg \tag{10}$$

where: w *and* g are the vectors of output and demand aggregates, respectively.

We can define the vector (nx1) e of CO_2 emissions and, furthermore, the specific-emissions matrix (C), whose elements represent emissions per unit of product (CO_2 emissions intensity coefficients):

$$C = \begin{bmatrix} c_{11} & 0 & \dots & 0 \\ 0 & c_{22} & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & c_{nn} \end{bmatrix} \tag{11}$$

Elements in the main diagonal are:

$$c_{ii} = \frac{e_i}{w_i} \tag{12}$$

If we integrate (11) into (10), we can then calculate the CO_2 emissions vector:

$$e = C(Aw + Hg) \qquad (13)$$

(13) can also be calculated for each activity branch:

$$\begin{aligned} e_1 &= \sum_{j=1}^{n} c_{11} a_{1j} w_j + \sum_{k=1}^{m} c_{11} h_{1k} g_k \\ e_2 &= \sum_{j=1}^{n} c_{22} a_{2j} w_j + \sum_{k=1}^{m} c_{22} h_{2k} g_k \\ \dots & \quad \dots \quad \dots \\ e_n &= \sum_{j=1}^{n} c_{nn} a_{nj} w_j + \sum_{k=1}^{m} c_{nn} h_{nk} g_k \end{aligned} \qquad (14)$$

The total quantity of emissions from production will be:

$$e_{tot} = e_1 + e_2 + \ldots + e_n \qquad (15)$$

If we assume a reduction of the above quantity, the quantity of CO_2 emissions will be:

$$e_{tot(1)} = e_{tot(0)} + \Delta e_{tot(0)} \qquad (16)$$

This reduction is assumed to be caused by a change of the different coefficients of the model. Therefore, the following applies:

$$e_{i(1)} = c_{ii(0)} \left(\sum_{j=1}^{n} a_{ij}^{*} w_{j(0)} + \sum_{k=1}^{m} h_{ik}^{*} g_{k(0)} \right) \qquad (17)$$

where the "*" sign refers to those coefficients obtained by solving the model.

The identities of the system of equations in (17) will not be fulfilled for all the n activity branches. Supplementary variables (*sv*) will be added picking up the errors in the system after the new emissions level:

$$a_{ij(0)} - sv_{a_{ij}^{\inf}} \le a_{ij}^{*} \le a_{ij(0)} + sv_{a_{ij}^{\sup}} \qquad (18)$$

$$h_{ik(0)} - sv_{h_{ik}^{\inf}} \le h_{ik}^{*} \le k_{ik(0)} + sv_{h_{ik}^{\sup}} \qquad (19)$$

$$\text{with } sv \ge 0 \qquad (20)$$

The minimisation of the sum of all sv is proposed as the objective of the model:

$$\min \sum sv \qquad (21)$$

subject to the following conditions: (15), (16), (17), (18), (19) and (20).

In the following subsection an iterative process determining the sensitivity of each coefficient (a_{ij} , h_{ik}) to the total CO_2 emissions will be carried out. This sensitivity analysis will allow us to identify the most important structural relationships (production linkages) in terms of CO_2 emissions.

3.2. Sensitivity analysis.

When the supplementary variables are introduced, a feasible solution for the model is then ensured, allowing us to analyse the sensitivity of the original coefficients.

In order to do so, each of the restrictions (18) and (19) will be modified in an iterative way, relaxing the upper and the lower limits (variability limits). This allows the identification of the changes in the original coefficients (variability limits) contributing to the minimisation of the objective (21) and, thus, the determination of those coefficients most sensitive to the change in the CO_2 emissions levels proposed in (16).

Let's consider an iteration whereby the lower or upper limits of a coefficient are relaxed in the corresponding restrictions (18) or (19), so that they can be changed in order to contribute to the objective (21). If, after solving the model, a small change in that limit causes a large reduction in the objective, then we consider it as a very important coefficient. After the new emissions level, the coherence of (17) is recovered.

In order to quantify the relevance of the coefficients, the following variables are defined:

obj_{bas} is the value of objective (21). In this case, the variability limits (upper or lower) of the coefficients imposed in (18) or (19) are not relaxed.

obj_{ij} is the value of objective (21). In this case, the variability limits are relaxed.

We focus on the technical coefficients a_{ij} to calculate:

$$d_{ij}^{a} = \frac{\dfrac{obj_{bas} - obj_{ij}}{obj_{bas}}}{\dfrac{a_{ij(0)} - a_{ij}^{*}}{a_{ij(0)}}} \tag{22}$$

$ä^{a}_{ij}$ means that the level of CO_2 emissions is highly sensitive to the changes in the coefficient, which is then considered "important" (in the determination of the final CO_2 emissions level).

In a similar manner, we can build the indicators corresponding to h_{ik}:

$$d_{ik}^{h} = \frac{\dfrac{obj_{bas} - obj_{ik}}{obj_{bas}}}{\dfrac{h_{ik(0)} - h_{ik}^{*}}{h_{ik(0)}}} \tag{23}$$

The most important coefficients a_{ij} and h_{ik} can then be used to identify the most polluting productive linkages. This can be done by applying the qualitative input-output methodology. The analysis is based on the application of a filter to matrix A and H. A matrix W (n x n+k) is built whose elements will be 0 or 1, depending on whether they pass the filter or not. The filter is set on the ***d*** indicator (i. e. $d^a = d^h = 0.1$). If $d^a_{ij} > d^a$, then $w_{ij} = 1$. If $d^h_{ik} > d^h$, then $w_{i(n+k)} = 1$.

The unitary elements of W indicate that the coefficient associated to the element is important. A coefficient with a value of 1 means that it has a high ***d*** (i.e., above the filter ***d***) and is, thus, relevant.

The ***d*** relevance index for each a_{ij} and h_{ik} coefficient is calculated in Spain in the following section.

4. AN EMPIRICAL APPLICATION OF THE MODEL: THE SPANISH CASE.

In this section, we identify the economic-production relationships most important in terms of CO_2 emissions and the clusters of sectors leading to high levels of CO_2 emissions.

4.1. The data.

We use the symmetrical Spanish input-output table built by the National Statistical Office (INE) for 1995 (TSIO-95) and the 1995 CO_2 emissions vector (disaggregated by activity branch), also published by INE as part of the System of Environmental Accounting (SCA). Both the TSIO and the SCA are coherent with the definition of the different activity branches according to CNAE-93 classification, allowing us to link TSIO activity branches with CO_2-emitting branches. After the necessary adjustments (aggregation operations) have been made, 71 TSIO activity branches are converted in 44 sectors (see Annex).

Concerning the final demand matrix, the following economic aggregates per activity branch have been considered: final consumption expenditures by households (FCEH), final consumption expenditures by non-profit organisations serving households

(FCENPOSH), final consumption expenditures by government (FCEG), gross fixed capital formation (GFCF), changes in inventories and valuables (CIV), exports to the EU (UEEXP) and exports to other countries (OCEXP).

4.2. Main results.

CO_2 emissions in the Spanish activity branches in Spain reached 201.916 million tones. The 1% emissions reduction proposed for the sensitivity analysis (i.e., 199.897 million tones) leads to an incoherence in the system of equations (14). The linear programming model is then solved, and the sensitivity coefficients (22) and (23) calculated. Thus, the a_{ij} and h_{ik} coefficients have been classified in order of importance (value of *ä*).

Tables 1 and 2 show the most important coefficients in each category[4]. The second column [2] shows the value of the technical coefficient being analysed. The value of the coefficient proposed when solving the corresponding model after allowing for its variability is shown in [3], whereas [4] represents the percentage difference between [2] and [3]. [5] shows the reduction in the objective (21) when the variability of the coefficient is allowed. Finally, [6] shows the corresponding sensitivity coefficient $ä_{ij}$.

Table 1. The most relevant CO_2 emissions a_{ij} coefficients. Spain, 1995

Technical coefficients						
[1] Coefficient		[2] Actual	[3] Proposed	[4] Change (%)	[5] Reduction of infeasibilities	[6] d_{ij}
16	30	0,109653	0,098959	-9,75	100,00	10,25
28	31	0,016068	0,009368	-41,70	100,00	2,40
1	7	0,284886	0,160642	-43,61	100,00	2,29
17	24	0,089969	0,032741	-63,61	100,00	1,57
17	18	0,153036	0,054993	-64,07	100,00	1,56
28	32	0,014282	0,004996	-65,02	100,00	1,54
28	16	0,051018	0,015757	-69,12	100,00	1,45
28	7	0,012291	0,003560	-71,03	100,00	1,41
28	17	0,049029	0,013189	-73,10	100,00	1,37
28	40	0,020007	0,005013	-74,94	100,00	1,33

Source: Own elaboration.

[4] I.e., those coefficients whose change leads to the highest emissions changes.

Table 2. The most relevant CO_2 emissions h_{ik} coefficients. Spain, 1995

Final demand coefficients						
Element		**Actual**	**Proposed**	**Change (%)**	**Reduction of infeasibilities**	d_{ij}
FCEH	28	0,021007	0,018868	-10,18	100,00	9,82
FCEH	13	0,012552	0,007520	-40,09	100,00	2,49
UEEXP	17	0,050329	0,021793	-56,70	100,00	1,76
UEEXP	16	0,022809	0,008051	-64,70	100,00	1,55
OCEXP	16	0,043493	0,007678	-82,35	100,00	1,21
FCEH	31	0,190384	0,021804	-88,55	100,00	1,13
FCEH	33	0,024337	0,002548	-89,53	100,00	1,12
UEEXP	14	0,072532	0,000130	-99,82	100,00	1,00
GFCF	30	0,664890	0,000000	-100,00	92,90	0,93
OCEXP	13	0,044521	0,000000	-100,00	89,97	0,90

Source: Own elaboration.

4.2.1. Interpreting a_{ij}.

Concerning a_{ij}, the analysis of $\ddot{a}^{a}_{ij}$ allows the identification of those activity branches whose sales to other branches cause a higher emissions level:

- Sales of activity branch 16 (*other non-metallic mineral products*) to branch 30 (*construction industry*). The purchase of those products by the construction industry is the most emissions intensive productive relationship of this industry with any other industry. These highly CO_2 intensive non-metallic mineral products (cement, bricks, lime and glass) are basic materials with limited substitution possibilities and reduction possibilities. In addition, the significant “housing boom” in the last years in Spain, expected to continue in the near future, may cause CO2 emissions growth in the future. It is difficult to reduce these sectors’ specific emissions and their growth rates will continue to be significant for some time. Therefore, there is little public policy can do to change the emissions intensity of these productive relationships.
- Sales of activity branch 28 (*production and distribution of electricity and gas*) to branch 31 (*commercial sector, vehicle and repairs*). Contrary to the previous case, public policy can take effective measures to reduce the emissions linked to this productive relationship, for instance by promoting changes in the electricity generation mix. In addition to the natural shift to CCGT, the Renewable Energy

Promotion Plan is a policy initiative already implemented contributing to this. In the commercial sector, the government has recently approved a regulation (the Building Technical Code) making compulsory, from 2006, the installation of energy conservation measures in new buildings and, also, the adaptation of buildings for the integration of solar energy. Finally, the Spanish Energy Efficiency Strategy (E4) promotes the adoption of energy efficiency technologies and measures in a wide array of sectors, including commercial establishments. However, other trends will work against reduction of energy consumption, such as the expected increased installation of air conditioning devices in commercial buildings.

- Sales of activity branch 1 (agriculture, cattle raising, forestry and hunting) to branch 7 (food and drinking industry and manufactured tobacco). Agriculture is still a relatively emissions intensive sector. However, these emissions are expected to be lower in 2010 than in 2001 because, in addition to some measures being taken[5], the cultivated area is not expected to increase in the future (Spanish government 2004).

4.2.2. Interpreting h_{ik} (final demand coefficients).

The following are the h_{ik} coefficients with the highest $\ddot{a}^{h}_{ik}$:

- Final consumption expenditure by households (FCEH) in activity branch 28 (production of electricity). The high value of its $\ddot{a}^{h}_{ik}$ index confirms the relatively high emissions intensity of the electricity sector and suggests that DSM activities measures aimed at energy efficiency and changes in electricity supply towards cleaner fuels could be very effective in contributing to CO_2 emissions mitigation. This also points to the relevance of reducing electricity demand. Information and awareness raising campaigns should be implemented.
- Final consumption expenditure by households (FCEH) in activity branch 13 (coke production, refining and nuclear fuels). Technical improvements at the refinery level only have a small impact on emissions reductions because of the

[5] Reduction of mineral fertilisers, good manure management practices, control of CO_2 and methane emissions from burning stubble and from animal feed, the prohibition of burning stubble and crop residues (Tábara 2003, MINAM 2002, Spanish government 2004).

large increase in emissions caused by the transport sector, which has been experiencing high growth rates since 1990 and will continue to do so for the next 10 years.

- Exports to the EU from sector 17 (metallurgy). Emissions per unit of ton produced in the steel sector are the highest among the sectors included in the EU ETS. Therefore, exports from this sector involve high emissions because emissions from transportation of steel products add to emissions from production.

Therefore, h_{ik} coefficients show that measures should be taken to change demand patterns in some sectors. This is in contrast the interpretation of a_{ij} coefficients, which point to the implementation of measures aimed at technological change. Both behavioural and technological measures are complementary and necessary.

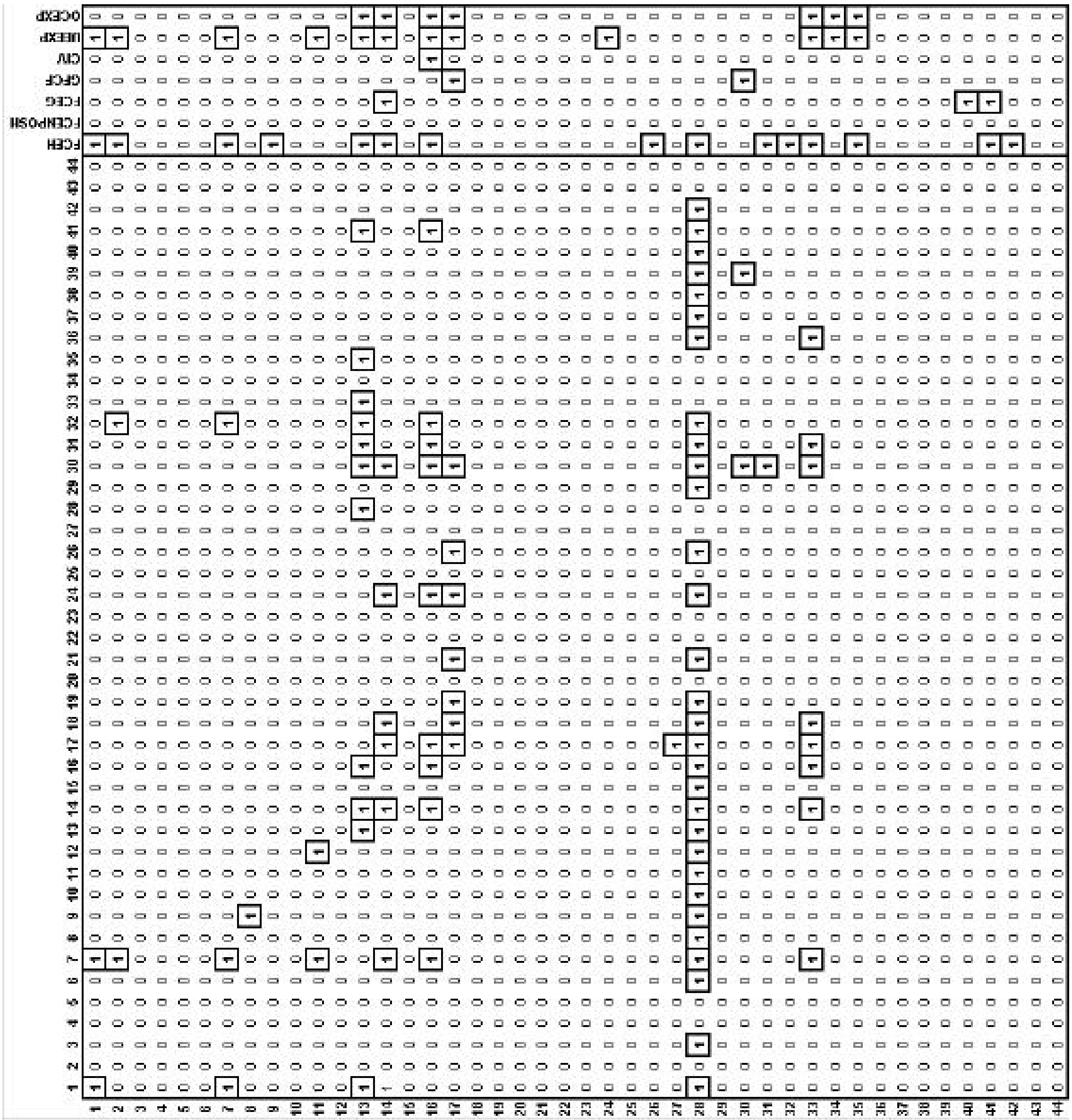
The interpretation of the coefficients has provided a picture of the sectors that should be considered when implementing effective emissions reduction measures. A filter has been applied to the coefficient matrix in order to identify the most important coefficients of the system a_{ij} and h_{ik} . Coefficients are "important" if their respective *ä* indicators (calculated according to (22) and (23)) are above 0.1[6].

The elements of the Boolean matrix W take the value 1 if the associated coefficients exceed the filter and 0 if they do not. Figure 1 shows the calculations.

Given an activity branch i causing impacts in other branches, the stretch of the route between activity branches i and l can be established if the w_{li} element of the binary matrix l equals 1 (meaning that the transaction represented by the a_{lj} coefficient is relevant). In addition, if there was a w_{jl} element equalling one, then a second "stretch" of the route would exist, extending between activity branches l and j. The $w_{i(n+k)}$ elements (final demand) are interpreted in the same manner.

[6] This limit is arbitrary but it has been chosen to highlight the most pollution-intensive linkages. Lower filters could also have been selected but, then, less emissions-intensive linkages would have been included.

Figure 1. Identification of the most relevant coefficients in terms of CO_2. TIOE-95

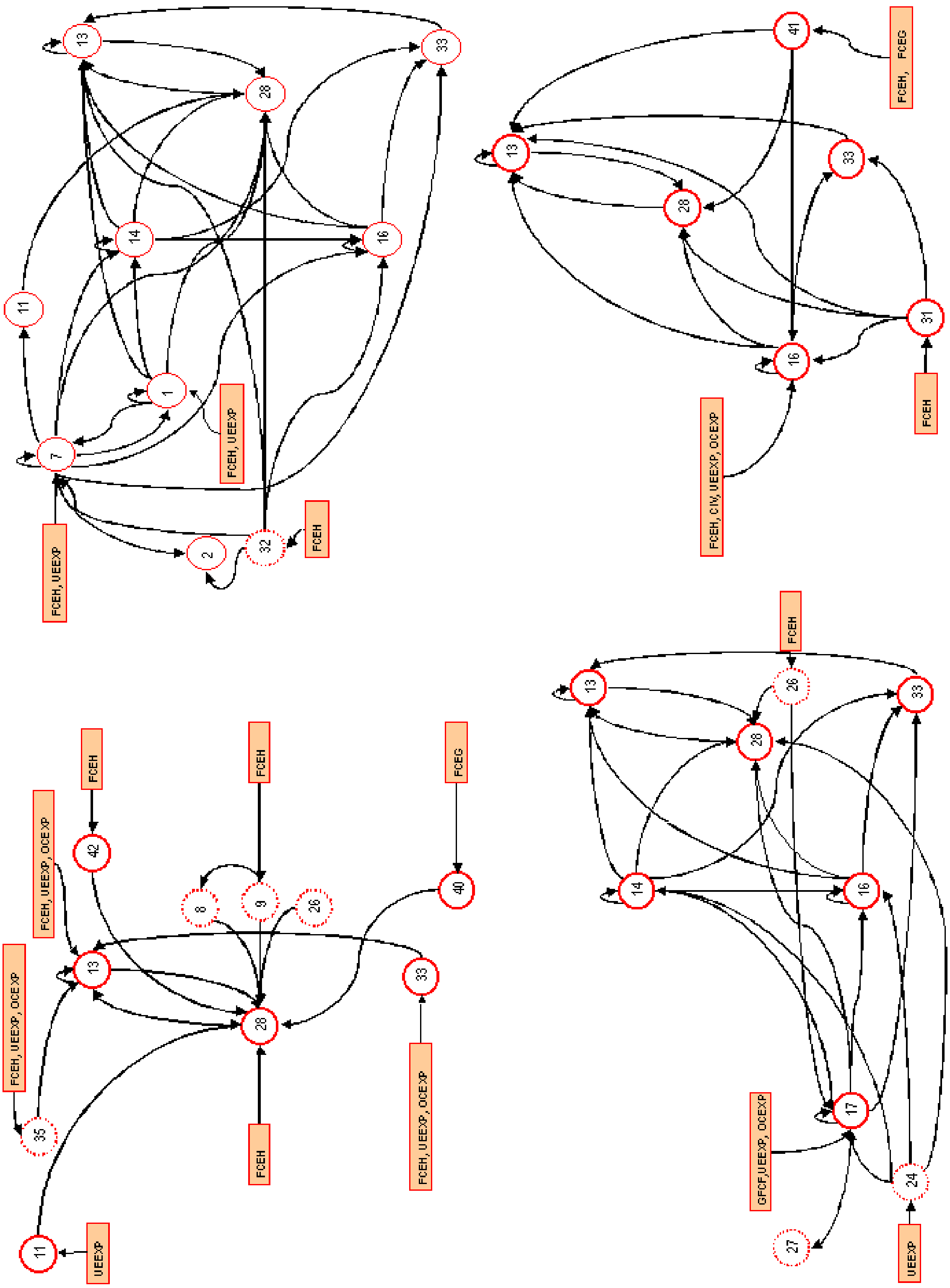


Source: Own elaboration.

The graphical representation of those "stretches" allows the tracing of the essential links between the different IOT activity branches. A less restrictive filter would reduce the number of stretches, increasing the complexity of the corresponding graph.

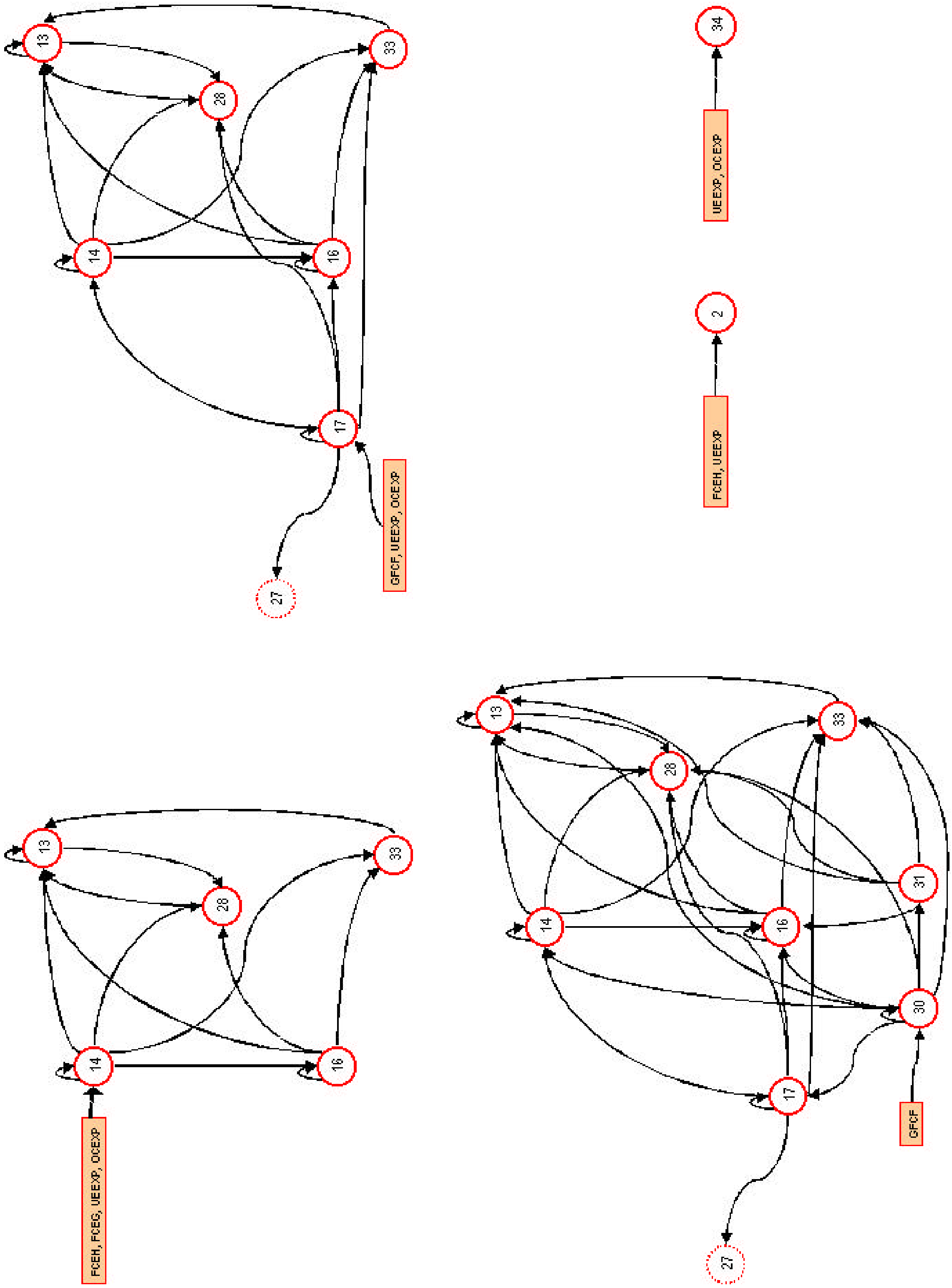
The identified productive routes spread the impact to important final demand coefficients through the production structure of the economy, leading to groups of CO_2 emitting activity branches. Figures 2 and 3 show the main groups.

Figure 2. Clusters of sectors relevant for CO_2 emissions (I). TIOE-95



Source: Own elaboration.

Figure 3. Clusters of sectors relevant for CO_2 emissions (II). TIOE-95



Source: Own elaboration.

Activity branches have forward and backward productive linkages with other sectors. The change in final demand aggregates of a sector may affect CO_2 emissions in other sectors. The first type of sectors are called "incidental", whereas the second type are called "influenced". Concerning the later, the following are worth mentioning: 28, 17, 13, 33 and 7. "Incidental" sectors are: 30, 31, 32 and 24. Several sectors are both "incidental" and "influenced" and some have loops within themselves. The rest of this section provides a discussion of these linkages.

- <u>Production and distribution of electricity and gas (28)</u>. The change in the final demand of other energy-consuming sectors (pulp and paper, public services and institutions, textile, shoe and wood industry) has an impact on electricity and gas demand and, thus, on CO_2 emissions.
- <u>Coke production, refining and nuclear fuels (13)</u>. This is also an "influenced sector", significantly linked to the terrestrial transport sector. Oil products account for 99% of energy consumption, making transport the second largest GHG emitting Spanish sector. Other major oil consuming sectors are electricity and coke production and the refining sector itself, which uses oil as an input.
- <u>Manufacturing of vehicles (24)</u>. This is an "incidental" sector. Changes in the demand for its products affect emissions in other sectors (metallurgy, chemical products and electricity).
- <u>Transport sector (33)</u>. This is mostly an influenced sector (only incidental in its relationship with the oil refining sector). An increase in the final demand of several sectors (particularly, metallurgy, chemical sector and non-metallic mineral products) causes a significant increase in transport emissions. Their intensive use of transportation is related to their production taking place in installations scattered all over the Spanish territory and to consumption of their products being also highly dispersed. Road transport is the transport modality experiencing the largest growth in the last 20 years. This increase in demand for mobility has outpaced the reductions in emissions per km caused by better vehicle energy efficiencies (i.e., the improvement in the intensive indicator is outpaced by the worsening of the extensive indicator). Today, the transport sector accounts for 36% of final energy consumption in Spain (and 22% of total GHG emissions. Due to the high growth rate of motorization, the increase of

infrastructure investments in high-capacity roads, the reduction of private road transport costs and the urban planning model followed it will be the largest contributor to GHG emissions in 2012 (Spanish government 2004).

- Non-metallic mineral products (16), metallurgy (17) and chemical (14) are both incidental and influenced sectors, producing intermediate products.
- Food and drinking industry and manufactured tobacco (7) also shows significant forward and backward linkages. By being mostly intermediate products, a change in the final demand of other sectors (hotel business, agriculture and the food industry itself) significantly changes the emissions of this sector. In turn, a change of its final demand affects other sectors providing intermediate products to the food and drinking industry[7].
- Agriculture and cattle raising (1). Basically an incidental sector (on electricity production, refining and the chemical sectors), it maintains a bi-directional relationship with the food industry (i.e., incidental and influenced).
- Hotel business (32). As a final demand sector, it is exclusively an incidental sector on the following sectors: electricity production, refining, fishing, food industry and non-metallic mineral products. The share of tourism on Spanish GDP being 13%, this sector has a very important place in the economy.
- Commercial (31), education, health and social services (41) and construction sectors (30) are also totally incidental sectors on refining and electricity generation, transport and other non-metallic mineral products.

A systemic perspective on intersectoral linkages regarding CO2 emissions is a first step to identify effective mitigation measures. However, the technoeconomic particularities of each sector should also be considered because the approach taken to "effectiveness" implicitly assumes that mitigating one ton of CO_2 in one sector requires the same level of effort than in others.

On the contrary, certain technoeconomic characteristics of the sectors (availability of mitigating technologies, costs of different technological options, product features, characteristics of the product markets...) make it more technically feasible to reduce in one sector than in another.

[7] Such as fishing, agriculture, pulp and paper (as a packaging material), chemical products, electricity, other non-metallic mineral products and transport The highly dispersed nature of food consumption and production activities entails an intensive use of transport to distribute the products.

5. CONCLUSIONS.

This paper proposes a methodology combining input-output tables and a sensitivity analysis of the intersectoral production structure to identify the systemic sources of CO_2 emissions on the production structure. It determines which economic transactions lead to the highest emissions levels and identifies those production linkages through which these emissions spread. This is deemed relevant to choose effective mitigation policies.

This approach has several advantages with respect to other methodologies. It extends the analysis to the final demand matrix and it allows to get the most important elements in terms of emissions and not in terms of production, which is usually the case. However, it is not an alternative but rather a complement to other approaches.

However, several limitations and caveats of this study are worth considering, suggesting directions for further research.

- Some of the limitations relate to the data used. First, final demand and technical coefficients have been calculated according to "internal" transactions, disregarding imports. We believe this provides a better reflection of the Spanish economic structure but caution should be taken when interpreting the results. A reduction of a coefficient might be a consequence of import substitution and not of a lower CO2 emissions innovation process.
- Second, 1995 data was used to achieve coherence between data on the Spanish productive structure and on CO_2 emissions. This is an important limitation because, although there has not been any major structural change in the Spanish economy since 1995, emissions-reductions technological changes have been adopted in some industrial sectors.
- Only data on CO_2 emissions have been used. Emissions of other GHG should be considered in further research.
- The policy relevance of this analysis is limited, since there is no estimate of the costs of emission reductions. The variation in costs linked to changes in the coefficients should be taken into account if cost-effectiveness is to be considered, which is crucial for deciding which sectors to tackle and what type

of mitigation measures to take. Further research should try to integrate the most emissions-intensive production routes with their associated abatement costs.

The empirical study shows the relevance of certain "key" sectors in the total Spanish CO_2 emissions. The results confirm that emissions in the energy, residential and transport sectors should be tackled if total emissions are to be significantly reduced. The paper points to the need for effective public policies to tackle both ends of the spectrum (final consumers and producers) with a mix of measures targeted at, both, behavioural and technological changes.

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Annex I. Description of activity branches (R-44)(1995).

	Activity branches*	CO_2 emissions (thousand tonnes)	Output (basic prices). M€
1	(A)- 01 y 02 Agriculture, cattle raising, hunting and forestry	8349	29255
2	(B)- Fishing	4361	1692
3	(C)- 10 Coal (all types)	248	1738
4	(C)- 11 y 12 oil, natural gas, uranium and thorium	258	169
5	(C)- 13 Metallic mineral extraction.	135	198
6	(C)- 14 Non-metallic mineral extraction.	181	1896
7	(D)- 15 y 16 Food, drinking and tobacco manufacturing	4333	56946
8	(D)- 17 Textile industry	1062	7667
9	(D)- 18 y 19 Leather, shoe, dressmaking and furrier	731	12649
10	(D)- 20 Wood and cork industry	798	5620
11	(D)- 21 Paper industry	2174	8342
12	(D)- 22 Publishing and graphic arts	348	8723
13	(D)- 23 Coke production, refining and nuclear fuels.	14907	8635
14	(D)- 24 Chemical industry	10769	22149
15	(D)- 25 Rubber and plastics	573	9534
16	(D)- 26 Other non-metallic mineral products	33634	14100
17	(D)- 27 Metallurgy	17114	13873
18	(D)- 28 Metallic product manufacturing	638	16694
19	(D)- 29 Mechanical machinery and equipment.	774	13124
20	(D)- 30 Office machinery and computer equipment.	60	1953
21	(D)- 31 Manufacturing of electronic material and equipment.	535	7142
22	(D)- 32 Manufacturing of electronic material.	0	3561
23	(D)- 33 Surgical-medical instruments	43	2109
24	(D)- 34 Manufacturing of motor vehicles	701	28600
25	(D)- 35 Manufacturing of other transport material	285	3938
26	(D)- 36 Furniture and other manufacturing industry	782	8415
27	(D)- 37 Recycling	273	375
28	(E)- 40 Production and distribution of electricity, gas and water steam.	70599	17384
29	(E)- 41 Water purification and distribution	439	2565
30	(F)- 45 Construction	2821	79154
31	(G)- 50-52 Commercial sector, vehicles sales and repairs	3824	74212
32	(H)- 55 Hotel business	1050	53546
33	(I)- 60 Terrestrial transport	8899	22321
34	(I)- 61 Sea transport	2580	1565
35	(I)- 62 Air transport	3217	3561
36	(I)- 63 Activities attached to transport	783	10861
37	(I)- 64 Post and telecommunications	111	11361
38	(J)- 65-67 Financial brokerage	263	32540
39	(K)- 70-74 Property developers and corporate services	399	86491
40	(L)- 75 Public administration and services	566	33161
41	(M)- 80 y 85 Education, health and social services.	1176	55202
42	(O)- 90-93 Other social activities and services.	1123	21083
43	Housework	0	4509
SIFMI	Financial brokerage indirectly measured (SIFMI)	0	0

**Numbers on the second column correspond to the CNAE classification.*