# Departament d´Economia Aplicada

Document de treball

CO$_2$ emissions of the construction sector in Spain during the real estate boom: input–output subsystem analysis and decomposition

Vicent Alcántara / Emilio Padilla

Universitat Autònoma de Barcelona

Facultat d´Economia i Empresa

20.03

Aquest document pertany al Departament d´Economia Aplicada

Data de publicació: **Juny 2020**

Departament d´Economia Aplicada

Edifici B

Campus de Bellaterra

08193 Bellaterra

Telèfon: 00 34 935 811 680

E.mail: d.econ.aplicada@uab.cat

https://www.uab.cat/departament/economia-aplicada/

# $CO_2$ emissions of the construction sector in Spain during the real estate boom: input–output subsystem analysis and decomposition

Vicent Alcántara and Emilio Padilla*

Department of Applied Economics, Universidad Autónoma de Barcelona, 08193 Campus de Bellaterra, Cerdanyola del Vallès, Spain.

E-mails: vicent.alcantara@uab.es; emilio.padilla@uab.es

*Corresponding author

**Abstract**

The construction sector has a special interest in the case of the Spanish economy, given its large economic dimension and environmental impact, particularly during the real estate boom prior to the last economic crisis that started in 2008. We study the $CO_2$ emissions of construction activities in 2007, at the height of the construction boom, in the context of the productive structure of Spain. For this, we use an input–output subsystem method, which allows us to study the productive structure of the subsystem's activities, taking into account its links with the rest of the sectors. The decomposition of total emissions in four explanatory components allows us to make a classification of the different sectors according to the type of relationships that are established between the subsystem and the rest of the economy. We derive some implications for environmental policy from the analysis of these interrelations.

***Keywords:*** *$CO_2$ emissions; construction sector; input–output subsystem; productive structure; real estate boom.*

**JEL codes:** C67, L74, Q54.

## 1. Introduction

Spain experienced high rates of economic growth and job creation in the decade prior to the last economic crisis that started in 2008. One of the differential facts of this growth, in relation to other European countries and the OECD, was the importance that the construction sector had on it. In fact, the structure of the Spanish economy is characterized by a significantly higher weight of the construction sector (and auxiliary industries) compared with other industrialized countries (Naredo, 2004). Until the economic crisis broke out, the sector absorbed a large amount of resources (labour and capital), so that job creation and growth had an important dependence on the performance of this sector, although the majority of jobs generated were in the low salary band. There are several factors that can explain this greater importance of the construction sector in the case of Spain, such as the entry of four million immigrants in the years prior to the crisis, the demand for second homes by European Union citizens, as well as the fact that Spain's economy had less mature development than other European countries in terms of, for example, infrastructures (Bielsa and Duarte, 2011). However, speculative activity also had an important role in the size of the sector in Spain, with a strong demand motivated by the expectation of rising prices and low interest rates (Ahearne et al., 2005; Bielsa and Duarte, 2011). The economic crisis had an important impact on the sector, and other sectors of the Spanish economy were not able to replace the previous dynamism of the construction sector to absorb the generated unemployment. The other side of the importance of the construction sector in Spain was its impact on the environment. As an example, a material flow analysis for the Spanish economy shows how the growth in the use of materials experienced between 1980 and 2004 was largely due to the influence of the construction sector (González-Martínez et al., 2010). Moreover, Gutiérrez et al. (2011) found that the construction sector explained to a great extent the greater increase in energy consumption and $CO_2$ emissions in Spain with respect to the European Union between 1990 and 2007, which can be largely explained by the real estate boom. Only the economic crisis allowed a reduction in the strong environmental impact of construction, but as the economy recovers in recent years and interest rates remain low, there has been a certain recovery of construction with regard to the generation of employment and economic growth on one side and environmental pressures on the other.

The importance of the construction sector in the Spanish productive structure has been analysed previously from an input–output perspective, through a subsystem analysis, by Bielsa and Duarte (2011), who compare the sector with other countries, highlighting its larger size in the Spanish case and a certain 'deformation' of the Spanish economy in this sense. However, there are not many contributions which make a specific analysis of the environmental impacts of the construction sector, taking into account the intersectoral relationships. Among those, we can highlight the research by Acquaye and Duffy (2010), who perform an input–output analysis to analyse the $CO_2$ emissions of the construction sector in Ireland; Toller et al. (2011) who analyse the energy consumption and environmental pressures generated by the Swedish building and real estate management sector; Chang et al. (2016) who analyse the embodied atmospheric emissions and water footprints of buildings in China using a disaggregated input–output model of the life cycle inventory; Zhang and Wang (2016a; 2016b) who apply an input–output life-cycle assessment model to estimate the emissions embodied in the building industry in China; and Zafrilla et al. (2019), whose recent study applies this same methodology, complemented with the computation of the emissions induced through sectoral income expenditure, to quantify an extended carbon footprint of the construction sector in Spain. This last paper highlights the particular importance of the emissions induced by the construction sector to the other sectors in Spain.

We propose the use of an input–output subsystem analysis to achieve a better understanding of the intersectoral relationships and the impacts generated throughout the different sectors of the economy to satisfy the demand of the construction sector. In our work, we intend to contribute to the literature on the impacts of the construction sector through an analysis of its impact on $CO_2$ emissions during the real estate boom in Spain. Additionally, the use of our input–output subsystem method allows the study of the environmental pressures generated by the construction sector, considering in detail the different sorts of relationships that it establishes with the other productive sectors of the economy. We decompose total emissions into different explanatory components in order to classify the sectors according to their type of relationship with the construction sector in terms of emissions. This analysis provides a detailed picture of the role played by the different sectors in the emissions caused by construction sector demand and facilitates the extraction of different implications in terms of policy.

Next, in Section 2, we detail the method used in the analysis. Section 3 presents the data and the results of our analysis for the Spanish economy and its construction sector. Section 4 presents our conclusions.

## 2. Methodological approach

The subsystems notion was introduced by Sraffa (1960). The concept of a subsystem is relatively simple. As Sraffa (1960, p. 89) pointed out, if we consider a system of industries in which each one produces a different commodity (as occurs in an input–output table), 'such a system can be subdivided into as many parts as there are commodities in its net product, in such a way that each part forms a smaller self-replacing system the net product of which consists of only one kind of commodity. These parts we shall call *subsystems*'.

A subsystem allows us to see the particular productive structure of each of the industries that make up the economic system, without de-linking the sector under analysis from the rest of the system. A subsystems analysis can be done both from the perspective of a single sector or of a set of sectors. The application of subsystems, as we understand them here, was initially developed by Harcourt and Massaro (1964) and Pasinetti (1977). In our research, we will continue along the lines drawn by these authors.

From an environmental perspective, Alcántara (1995) developed the analysis of pollution-generating subsystems in a widely disaggregated manner, which allows us to study the polluting interconnections that take place in a productive system to obtain the final demand of any sector. Sánchez-Chóliz and Duarte (2003) complemented this analysis and applied the previous methodology, based on Pasinetti (1977), to the pollution of water by economic activity in the Spanish region of Aragon. These authors obtained five measurement indices corresponding to each productive branch and each type of pollution. Alcántara and Padilla (2009) developed an application to analyse the $CO_2$ emissions of the service sector in Spain. Navarro and Alcántara (2010) applied this type of analysis to the methane emissions of the agro-industry subsystem of the Spanish region of Catalonia. Piaggio et al. (2015) applied it to the service sector and $CO_2$ emissions in Uruguay. Llop and Tol (2012) addressed the analysis of greenhouse gas emissions in Ireland, applying the subsystems method from the perspective of all productive branches. Alcántara et al. (2017) analysed the $NO_X$ emissions of the Spanish economy considering each sector as a subsystem. A complementary application of a subsystem analysis was implemented by Fritz et al. (1998) to analyse the pressure of non-polluting sectors on polluting sectors in the Chicago region.

Consider the following matrix product,

(1) $(\mathbf{I}-\mathbf{A})^{-1}\hat{\mathbf{y}}$

in which ($\mathbf{I}$ – $\mathbf{A}$)$^{-1}$ is the Leontief inverse and $\hat{\mathbf{y}}$ is the final demand vector or net output formulated in diagonal matrix form.[1]

This product determines a set of $\mathbf{x}^{(i)}$ vectors that express the amount of vertically integrated output that all sectors have to produce to obtain the final demand of the *i-th* sector, in such a way that

(2) $\sum_i \mathbf{x}^{(i)} = \mathbf{x}$

reproduces the total output of the economy.

Thus, the subsystem generating the final production of the *i-th* sector is given by:

(3) $\mathbf{A}\mathbf{x}^{(i)} + \mathbf{y}^{(i)} = \mathbf{x}^{(i)}$

where $\mathbf{y}^{(i)}$ is a vector whose elements are zeros except the element *i* which shows the final demand of sector *i*. This equation decomposes the vertically integrated production of the system linked to sector *i* in two parts: the part related to the means of production and the net production or final demand of the subsystem.

Notice that equation (3) could have been written as follows, which shows more clearly the idea of vertical integration:

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

[1] In the present work, vectors are defined as column vectors and their transformation into a row vector is expressed with ('). Likewise, the sign (^) is used for the diagonalization of a vector: that is, its statement as a diagonal matrix.

The construction of a pollution-generating subsystem, in our case $CO_2$ emissions, is now immediate.

Let $\mathbf{e}$ be the vector of emissions whose characteristic element shows direct sector emission. Then, the coefficients of direct emission per unit of output would be given by the expression:

(5) $\mathbf{c} = \hat{\mathbf{x}}^{-1}\mathbf{e}$

Pre-multiplying equation (3) by vector $\mathbf{c}$ diagonalised, we obtain

(6) $\hat{\mathbf{c}}\mathbf{A}\mathbf{x}^{(i)} + \hat{\mathbf{c}}\mathbf{y}^{(i)} = \hat{\mathbf{c}}\mathbf{x}^{(i)} = \mathbf{e}^{(i)}$

in which $\mathbf{e}^{(i)}$ denotes the total emissions directly and indirectly generated by the different sectors of the economy to make possible the net output of sector $i$. This reflects the vertically integrated emissions that the production of the final demand of sector $i$ requires. It also shows, in turn, the emissions generated to obtain its productive inputs (the first term of the left-hand side) and the gases emitted directly by the sector to obtain its net output (the second term of the left-hand side) that we will denote as the *scale component*.

Consider now $i = s$, the sector on which we have built the polluting subsystem given in equation (6). The emissions generated to obtain the productive inputs of the subsystem can be perfectly attributable to each one of the intersectoral transactions carried out to obtain such inputs. Indeed, the diagonalisation of $\mathbf{x}^{(s)}$ in the first component of equation (6), leads to

(7) $\mathbf{E}^{s} = \hat{\mathbf{c}}\mathbf{A}\hat{\mathbf{x}}^{s}$

in which $\mathbf{E}^{s}$ is a matrix that shows the intersectoral distribution of the vertically integrated emissions generated by the sector $s$ to obtain its net output. In order to make clear the information contained in the matrix $\mathbf{E}^{s}$, we can write it in a non-compact form:

$$
(8) \qquad \mathbf{E}^s = \begin{pmatrix}
e_{11}^s & e_{12}^s & \cdots & e_{1i}^s & \cdots & e_{1s}^s & \cdots & e_{1n}^s \\
e_{21}^s & e_{22}^s & \cdots & e_{2i}^s & \cdots & e_{2s}^s & \cdots & e_{2n}^s \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\
e_{i1}^s & e_{i2}^s & \cdots & e_{ii}^s & \cdots & e_{is}^s & \cdots & e_{in}^s \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\
e_{s1}^s & e_{s2}^s & \cdots & e_{si}^s & \cdots & e_{ss}^s & \cdots & e_{sn}^s \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\
e_{n1}^s & e_{n2}^s & \cdots & e_{ni}^s & \cdots & e_{ns}^s & \cdots & e_{nn}^s
\end{pmatrix}
$$

Actually, this matrix is the adjacency matrix of a valued graph from which relevant information on the productive structure of the sector under analysis can be obtained, contextualized by the productive framework of the entire economy. We will see this below in its application for the case of Spain.

The characteristic element of this matrix, $e_{ij}^s$, denotes the total (direct and indirect) emissions generated by sector $i$ in the process to obtain its production oriented to sector $j$ with the end goal of making possible the net output of sector $s$. Note that the elements of the main diagonal show the own production of each sector necessary in the process of obtaining its production, whose final destination, direct and indirect, will be sector $s$.[2] In the case of sector $s$, the elements $e_{sj,s \neq j}^s$ show the emission volume, vertically integrated, linked to the provision of inputs from sector $s$ to sector $j$. The sum of these elements constitutes what we call the *sales component*—that is, the volume of emissions generated by the sector $s$ associated with its sales to other sectors. If we dispense with the main diagonal and the row corresponding with sector $s$, the sum of the rest of the elements of the matrix $\mathbf{E}^s$ is the *spillover component* generated by the final demand of the sector of the subsystem. The element $e_{ss}^s$ indicates the impact of obtaining the inputs of the same sector used to meet its final demand as well as the feedback that its sales to other sectors have on it. We denote this element of the matrix as the *internal component*.

The sum by rows of this matrix constitutes the total emissions directly and indirectly generated by the different sectors of the economy to make possible the net output of the

[2] These self-consumptions can be relatively important, taking into account the productive structure of the different sectors.

sector *s*. Adding to this amount the second term of the left side of the expression (6), for *s* we get the vector $\mathbf{e}^{(s)}$ which, as we have pointed out, denotes the total emissions directly and indirectly generated by the different sectors of the economy to make possible the net output of sector *s*, including the sector itself. In the same way, the sum by columns of the matrix shows the emissions that each one of the sectors pulls from the different sectors.

Therefore, the total emissions of the subsystem can be decomposed as follows:

(9) $$\text{Total emission} = \sum_i e_i^s = \underbrace{e_{ss}^s}_{\text{Internal component}} + \underbrace{\sum_{j,s\neq j} e_{sj}^s,}_{\text{Sales component}} + \underbrace{\sum_{i,i\neq s} e_{ij}^s}_{\text{Spillover component}} + \underbrace{\hat{\mathbf{c}}\mathbf{y}^{(s)}}_{\text{Scale component}}$$

## 3. Data and results: the construction sector in the framework of the Spanish economy

The data for our analysis was taken from the World Input–Output Database (WIOD) (Timmer et al., 2012). The WIOD (November 2016 Release) offers national input–output matrixes and covers 28 EU countries and 15 other major countries in the world for the period from 2000 to 2014, disaggregated into 56 sectors at basic prices (current US$). The sectors were classified according to the International Standard Industrial Classification, Revision 4 (ISIC Rev. 4). The pollution vectors were built with environmental data from EUROSTAT.

### *3.1. An aggregated perspective*

From the computation of equations (4) to (7), we obtained the information in Table 1.

## Table 1. Data and $CO_2$ emissions of the construction subsystem

| | Code | Emission coefficient kt/M US$ | Vertically integrated production M US$ | Vertically integrated emission $CO_2$ (kt) | Matrix **E** rows' sum $CO_2$ (kt) | Matrix **E** columns' sum $CO_2$ (kt) |
|---|---|---|---|---|---|---|
| Agriculture | c1 | 0.1671 | 913.6 | 152.6 | 152.6 | 48.0 |
| Mining and Quarrying | c2 | 0.1701 | 3,371.4 | 573.4 | 573.4 | 486.3 |
| Food, Beverages and Tobacco | c3 | 0.0468 | 904.0 | 42.3 | 42.3 | 82.7 |
| Textiles and Textile Products | c4 | 0.0891 | 592.0 | 52.8 | 52.8 | 38.3 |
| Leather, Leather and Footwear | c5 | 0.0309 | 16.9 | 0.5 | 0.5 | 0.9 |
| Wood and Products of Wood and Cork | c6 | 0.0485 | 4,641.6 | 225.0 | 225.0 | 341.1 |
| Pulp, Paper, Printing and Publishing | c7 | 0.0810 | 2,517.0 | 203.9 | 203.9 | 219.4 |
| Coke, Refined Petroleum and Nuclear Fuel | c8 | 0.4208 | 1,626.2 | 684.2 | 684.2 | 73.4 |
| Chemicals and Chemical Products | c9 | 0.1315 | 2,030.9 | 267.0 | 267.0 | 188.2 |
| Rubber and Plastics | c10 | 0.0240 | 2,972.1 | 71.3 | 71.3 | 257.5 |
| Other Non-Metallic Mineral | c11 | 0.9752 | 29,174.7 | 28,450.3 | 28,450.3 | 6,289.6 |
| Basic Metals and Fabricated Metal | c12 | 0.1249 | 24,211.0 | 3,024.2 | 3,024.2 | 2,043.5 |
| Machinery, Nec | c13 | 0.0170 | 4,347.5 | 73.8 | 73.8 | 259.8 |
| Electrical and Optical Equipment | c14 | 0.0062 | 5,962.6 | 36.7 | 36.7 | 326.2 |
| Transport Equipment | c15 | 0.0193 | 1,052.8 | 20.3 | 20.3 | 49.2 |
| Manufacturing, Nec; Recycling | c16 | 0.0178 | 3,899.2 | 69.5 | 69.5 | 211.8 |
| Electricity, Gas and Water Supply | c17 | 1.3573 | 7,020.3 | 9,528.8 | 9,528.8 | 2,126.8 |
| Construction | c18 | 0.0130 | 384,153.4 | 4,978.8 | 1,628.5 | 31,982.4 |
| Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel | c19 | 0.0633 | 5,272.0 | 333.6 | 333.6 | 238.4 |
| Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles | c20 | 0.0199 | 9,440.3 | 187.7 | 187.7 | 652.8 |
| Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods | c21 | 0.0141 | 8,866.1 | 125.0 | 125.0 | 560.1 |
| Hotels and Restaurants | c22 | 0.0032 | 1,353.1 | 4.3 | 4.3 | 39.0 |
| Inland Transport | c23 | 0.3725 | 5,842.4 | 2,176.5 | 2,176.5 | 328.5 |
| Water Transport | c24 | 0.7846 | 181.3 | 142.3 | 142.3 | 12.9 |
| Air Transport | c25 | 0.5404 | 235.2 | 127.1 | 127.1 | 11.9 |
| Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies | c26 | 0.0116 | 5,100.2 | 59.0 | 59.0 | 494.9 |
| Post and Telecommunications | c27 | 0.0045 | 4,203.2 | 19.0 | 19.0 | 243.3 |
| Financial Intermediation | c28 | 0.0037 | 8,134.0 | 29.9 | 29.9 | 98.8 |
| Real Estate Activities | c29 | 0.0005 | 6,423.0 | 3.1 | 3.1 | 58.5 |
| Renting of M&Eq and Other Business Activities | c30 | 0.0012 | 18,177.5 | 22.0 | 22.0 | 480.0 |
| Public Admin and Defence; Compulsory Social Security | c31 | 0.0050 | 1,099.9 | 5.5 | 5.5 | 53.3 |
| Education | c32 | 0.0005 | 406.3 | 0.2 | 0.2 | 9.3 |
| Health and Social Work | c33 | 0.0098 | 629.3 | 6.2 | 6.2 | 16.2 |
| Other Community, Social and Personal Services | c34 | 0.0259 | 2,053.0 | 53.3 | 53.3 | 76.8 |
| Total | | | 556,824.0 | 51,750.1 | 48,399.8 | 48,399.8 |

Note: direct emissions to obtain the net output of the construction subsystem amounted to 3,350.3 kt.

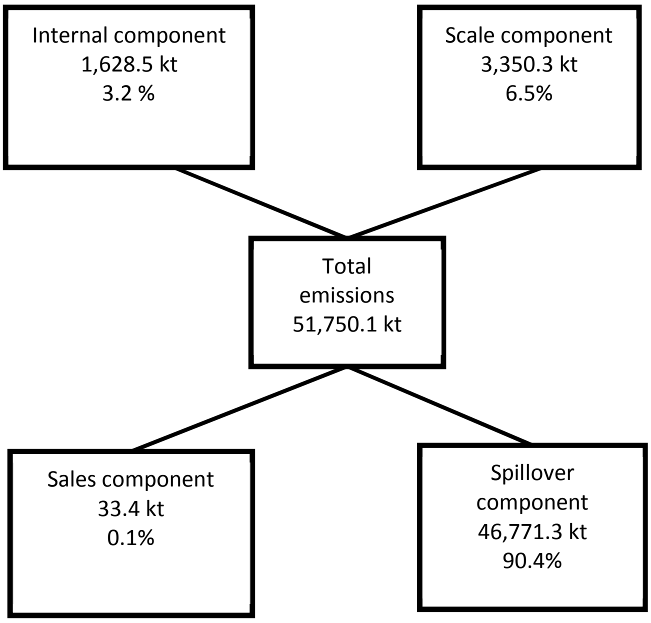
Source: prepared by the authors with WIOD (2016) data.

Notice that the only difference between expressions (6) (vertically integrated emission) and (7) (matrix **E** row's sum) appears in construction when the scale component only attributable to this sector is subtracted.

Total (direct and indirect) emissions to obtain the net production of the construction sector in the Spanish economy for the year 2007 amounted to 51,750kt. If we take into account that the total emissions of the Spanish economic system measured 365,388.9kt, the sector represented 14.2% of such emissions. If we now compare this with the emissions linked to intermediate transactions, which for the Spanish economy amounted to 287,621.8kt, given that the emissions of final consumption of households were 77,767.12kt, total emissions of the construction sector amounted to a percentage of 18%—almost a fifth of the emissions linked to the productive activity of the country. To calibrate the importance of this emission volume, we have computed the vertically integrated emissions of the road transport sector (which exclude private transport which is computed as part of household consumption). The direct and indirect emissions of this sector amounted to 12,275.5kt. That is to say, the total emissions of the construction sector were four times higher than those of road transport as a productive sector.

Note that the emission coefficient of the construction sector is very low. Therefore, the emissions directly generated in obtaining its final demand, *scale component*, only amount to 3,350.3kt, 6.5% of its total emissions, as shown by Figure 1 and obtained from matrix $\mathbf{E}^{s}$. The *internal component* represents 3.2% of total emissions and, the *sales component* a negligible 0.1%. In short, the emissions of the sector related to obtaining its net output comprise only 9.7% of the total, direct and indirect, emissions.

**Figure 1. Decomposition of total $CO_2$ emissions in four components**




Therefore, the remaining 90.4% corresponds to what we have called the *spillover component*. This shows the clear character of the sector as driver or inducer of emissions from other sectors.

Analysing the last two columns of Table 1, the sum by rows of the matrix **E** can be interpreted as the emissions from a forward perspective, while its sum by columns would be a backward point of view. We find a high concentration of emissions in a small number of sectors.

We will now perform an analysis to understand the role played by, as well as the linkages of, the most relevant sectors within the framework of the construction subsystem in the Spanish economy. For this, we will approach the analysis from the simple analytical proposal of matrix **E**.

*3.2. A disaggregated view of emissions*

We have previously pointed out that the matrix **E** could be interpreted as the adjacency matrix of a valued graph from which relevant information can be obtained. However, the matrix obtained gives rise to a compact graph with a large number of irrelevant intersectoral relations—elements of matrix **E**—that can obscure the perception of the important relationships. In order to have a more intelligible empirical framework, we proceeded to reduce the matrix in a double sense: by eliminating the irrelevant intersectoral linkages and the sectors that, from the previous eliminations, have no importance. For this, we proceeded as follows. Based on the elimination of the minimum transaction, we eliminated the successive minimums until reaching a level of emissions that amounted to at least 85% of them. Once this threshold was reached, we proceeded to eliminate those sectors whose sum of transactions, both of row and corresponding column, was equal to zero. That is, if $\sum_i e_{ij}^s = \sum_j e_{ij}^s = 0$, sector *i* was removed from matrix **E**, giving rise to a reduced matrix that almost collected the total emissions linked to the intermediate transactions of our subsystem.

After applying the procedure described above, the reduced matrix obtained amounted to 85.6% of such emissions, while of the thirty-four original sectors, only nine remained. The matrix obtained was reduced into blocks and is shown in Table 2.

**Table 2. Matrix E reduced (kt $CO_2$)**

| | | c18 | c11 | c12 | c26 | c2 | c20 | c21 | c23 | c17 | Total rows |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Construction | c18 | 1,595.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1,595.1 |
| Other Non-Metallic Mineral | c11 | 25,021.2 | 2,970.4 | 134.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 28,125.7 |
| Basic Metals and Fabricated Metal | c12 | 1,928.3 | 116.8 | 602.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2,647.1 |
| Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies | c26 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Mining and Quarrying | c2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles | c20 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods | c21 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Inland Transport | c23 | 345.2 | 593.3 | 0.0 | 318.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1,256.9 |
| Electricity, Gas and Water Supply | c17 | 1,606.2 | 2,063.0 | 920.7 | 0.0 | 319.5 | 325.5 | 472.1 | 115.7 | 1,994.2 | 7,816.9 |
| Total columns | | 30,496.0 | 5,743.6 | 1,656.8 | 318.4 | 319.5 | 325.5 | 472.1 | 115.7 | 1,994.2 | 41,441.7 |

Source: Prepared by the authors with WIOD (2016) data.

The matrix in Table 2 shows that only a set of sectors have interrelationships in both directions. That is, their emissions are pulled by the construction sector (c18), but they also pull an important amount of emissions from other sectors relevant to explaining total emissions of construction (such as electricity, gas and water (c17)). These sectors are other non-metallic minerals (c11) and basic metals (c12). In addition, there is a set of sectors that generate indirect emissions through their consumption of inputs for their production for the subsystem. These sectors are the same construction sector (c18) (because it requires inputs from the same sector), other supporting transport (c26), mining and quarrying (c2), wholesale trade (c20), and retail trade (c21). In this reduced matrix, the sectors electricity, gas and water (c17) and, to a lesser extent, inland transport (c23), appear as the ‘sources’ of emissions. That is, their emissions flow to the other productive branches in the matrix and no other sector generates a relevant amount of emissions for them; in the case of electricity, gas and water (c17), its emissions flow to all other productive branches in the matrix. Figure 2 shows the interrelationships between the construction sector and the other sectors of the Spanish economy in 2007.

**Figure 2. Main subsystem interactions**

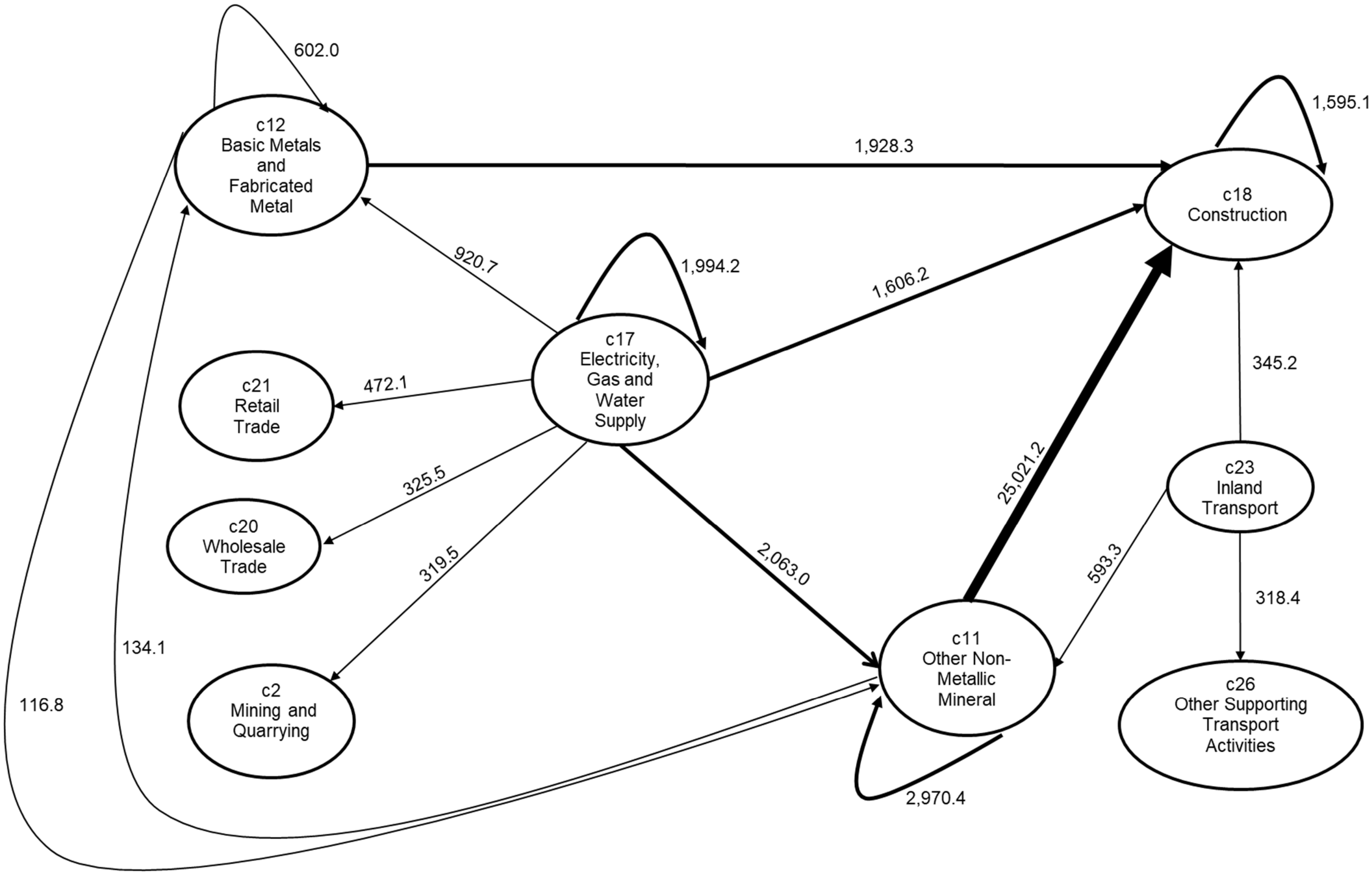


Figure 2 allows us to see clearly the relationships of the different sectors with the construction sector. The importance of the sector other non-metallic minerals (c11) stands out from the rest because it amounts to more than 50% of the emissions considered. Moreover, this sector is clearly related with other sectors that are also relevant for their transactions with the construction sector. Particularly, this sector is also connected with the other most important sector for its emissions, basic metals and fabricated metal (c12). In the middle of the figure, we find the sector electricity, gas and water (c17), with important transactions with most of the sectors that are relevant for the subsystem emissions, so that it appears clearly to be a very relevant sector for the different components of the subsystem. Previous works, such as that by Piaggio et al. (2014), who analysed the greenhouse emissions and the productive structure of Uruguay, also highlight the relevance of the construction sector for its indirect emissions generated by pulling the sector of other non-metallic mineral products to pollute, which, in turn, demands inputs from direct polluter sectors (such as electricity power generation activities). That is, they found an intersectoral connection similar to the one that we have found in our analysis. However, in the case of Spain, the relative relevance of these emissions and their magnitude constitutes a particular case which deserves special attention. In the analysis of Piaggio et al. (2014) for Uruguay, the building sector amounted to 7% of greenhouse gases, much below the percentages that we have found for the Spanish economy during the real estate boom as indicated above.

Besides the policies oriented to reducing the direct emissions of the electricity, gas, and water supply sector—that is, energy policies oriented to reduce the contribution of more polluting fossil fuels to the energy mix—, there are other policies that, according to our results, may be effective for controlling construction subsystem emissions. The huge requirements of inputs and the high associated emissions indicate the relevance of the housing market and construction activities for $CO_2$ mitigation policies. Measures such as the promotion of the purchase and improvement of secondhand houses, instead of the construction of new ones, may help to reduce the subsystem's emissions by reducing the requirement of inputs from both the sectors of basic metals and fabricated metal (c12) and electricity, gas, and water (c17). An obvious measure in the Spanish case is the promotion of rental housing as an alternative to buying (and building) new houses, because the percentage of people living in rented houses is still much below the European Union average (22.9% in Spain versus 30.7% in the EU-28 in 2017 according to Eurostat, 2017), while there is also an significant amount of uninhabited houses. Other interesting measures that could be implemented in the construction sector could be the requirement to provide information on emission content of materials by the abovementioned materials supplier sectors, or policies encouraging substitution for low-emission materials (Acquaye and Duffy, 2010; Piaggio et al., 2014). Sector policies in the EU and Spain have mainly focused on reducing energy consumption in buildings, such as the Spanish 2017–2020 National Energy Efficiency Action Plan (METDA, 2017) or the European Action Plan for Energy Efficiency (European Commission, 2009). These are important policies, though our analysis highlights the relevance of complementing them with adequate policies oriented to reducing the emissions associated with the construction sector in the Spanish productive structure and, particularly, the emissions pulled from other sectors.

## 4. Conclusions

We have analysed the emissions of the construction sector in Spain, which holds particular interest given its large economic dimension and environmental impact. The size of this sector was particularly large during the real estate boom prior to the economic crisis. While the crisis involved an important decline of the share of this sector in the Spanish productive structure, later recovery has been accompanied by the sector's recuperation. Therefore, the analysis of the sector and its environmental pressures has become a highly relevant issue both to assess its impact as well as to provide the appropriate policy recommendations to reduce the undesired environmental effects associated with this activity.

We analysed the $CO_2$ emissions of construction activities in 2007, the year before the economic crisis, in the context of the productive structure of Spain. For this purpose, we developed an input–output subsystem method. This technique allowed us to study the productive structure of the construction subsystem, taking into account in detail its links with the rest of the productive system. The decomposition of the total emissions in four explanatory components allowed us to make a classification of the different sectors according to the type of relationships that are established between them and the construction sector in terms of emissions. The information provided by our research complements previous analyses on the sector for the case of Spain by providing a more detailed analysis of the type of interactions of the sector with other sectors. The results confirm the great importance of the 'spillover component'—that is, construction is an important inducer of the emissions from other sectors of the economy. Our analysis provides a detailed study of the subsystem interactions, indicating the specific importance of the emissions induced in sectors such as other non-metallic mineral and basic metals and fabricated metal, which also pull emissions from other sectors that are important for the subsystem. It also highlights the relevance of inland transport and, particularly, electricity, gas, and water supply which are induced both by the construction sector and by the abovementioned suppliers of the construction sector. Some implications in terms of policy have been discussed, such as the promotion of rental housing, secondhand houses, reducing the number of uninhabited houses, or the provision of polluting information by the main polluting suppliers of the sector, which should complement the usual way of approaching the sector through technical requirements on the functioning of buildings. Given the difficulties shown by the Spanish economy in changing its productive structure, the application of these types of measures becomes particularly relevant in order to contribute to accomplishing its objective of reducing $CO_2$ emissions.

## Acknowledgements

This work was supported by the Spanish Ministry of Science, Innovation and Universities and ERDF (grant number: RTI2018-095484-B-I00).

## References

Acquaye, A.A., Duffy, A.P. (2010) "Input–output analysis of Irish construction sector greenhouse gas emissions", *Building and Environment* 45 (3), 784–791.

Ahearne, A. G., Ammer, J., Doyle, B. M., Kole, L. S., Martin, R. F. (2005) “House Prices and Monetary Policy: A Cross-Country Study”, International Finance Discussion Papers, n. 841, Board of Governors of the Federal Reserve System.

Alcántara, V. (1995) *Economía y contaminación atmosférica: hacia un nuevo enfoque desde el análisis input–output*. PhD Thesis, Univ. de Barcelona.

Alcántara, V., 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.

Alcántara, V., Padilla, E., Piaggio, M. (2017) “Nitrogen oxide emissions and productive structure in Spain: an input–output perspective”, *Journal of Cleaner Production* 141, 420–428.

Basart i Muñoz, J.M. (1994) *Grafs: Fonaments i Algorismes*. Servei de Publicacions, Univ. Autònoma de Barcelona. Bellaterra (Cerdanyola del Vallès), Spain.

Berman, A., Plemons, R.J. (1979) *Non Negative Matrices in the Mathematical Sciences*. Academic Press, Inc. New York.

Bielsa, J., Duarte, R. (2011) “Size and linkages of the Spanish construction industry: key sector or deformation of the economy”, *Cambridge Journal of Economics* 35, 317–334.

Chang, Y., Huang, Z., Ries, R.J., Masanet, E. (2016) “The embodied air pollutant emissions and water footprints of buildings in China: a quantification using disaggregated input–output life cycle inventory model”, *Journal of Cleaner Production* 113, 274–284.

European Commission (2009) Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009. Available at: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0063:0087:en:PDF

EUROSTAT (2017) EU-SILC survey. Available at: https://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do (accessed on 9/01/2020).

Fritz, O.M., Sonis, M., Hewings, G.J.D. (1998) “A Miyazawa analysis of interactions between polluting and non-polluting sectors”, *Structural Change and Economics Dynamics* 9, 289–305.

González-Martínez, A.C., Cañellas-Boltà, S., Puig-Ventosa, I., Russi, D., Sendra-Sala, C., Sojo-Benítez, A. (2010) “El flujo de materiales y el desarrollo económico en España: un análisis sobre desmaterialización (1980–2004)”, *Revista Iberoamericana de Economía Ecológica* 14, 33–51.

Gutiérrez, L.F., Marrero, G.A., Puch, L.A. (2011): “Los efectos medioambientales del boom y el parón inmobiliario”, *Economía Industrial* 379, 145–158.

Harcourt, G.C., Massaro, V.G. (1964) “A note on Mr. Sraffa's subsystems”, *The Economic Journal* 74, 715–722.

Llop, M., Tol, R.S.J. (2012) “Decomposition of sectoral greenhouse gas emissions: a subsystem input-output model for the Republic of Ireland”, *Journal of Environmental Planning and Management* 56 (9), 1316–1331.

Ministry of Energy, Tourism and Digital Agenda (METDA) (2017) 2017–2020 National Energy Efficiency Action Plan. Available at: https://ec.europa.eu/energy/sites/ener/files/documents/es_neeap_2017_en.pdf

Naredo, J.M. (2004). “Perspectivas de la vivienda”, *Información Comercial Española* 815, 143–154.

Navarro, F., Alcántara, V. (2010). “Las emisiones de metano ($CH_4$) en el subsistema agroalimentario catalán: un análisis input-output alternative”, *Economía Agraria y Recursos Naturales* 10 (2), 25–39.

Pasinetti, L.L. (1977). *Contributi alla Teoria della Produzione Congiunta.* Ilmulino, Bologna.

Piaggio, M., Alcántara, V., Padilla, E. (2014) “Greenhouse gas emissions and economic structure in Uruguay”, *Economic Systems Research* 26 (2), 155–176.

Sánchez Chóliz, J., 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.

Timmer, M., A.A. Erumban, J. Francois, A. Genty, R. Gouma, B. Los, F. Neuwahl, O. Pindyuk, J. Poeschl, J.M. Rueda-Cantuche, R. Stehrer, G. Streicher, U. Temurshoev, Villanueva, A., de Vries, G.J. (2012) The World Input–Output Database (WIOD): Contents, sources and methods, WIOD, Background document available at www.wiod.org.

Toller, S., Wadeskog, A., Finnveden, G., Malmqvist, T., Carlsson, A. (2011) “Energy use and environmental impacts of the Swedish building and real estate management sector”, *Journal of Industrial Ecology* 15(3), 394–404.

Zafrilla, J., López, L.A. (2017) “Booming and Stagnation of Spanish Construction Sector Through the Extended Carbon Footprint Concept”. In: Muthu, S. (Ed.) *Environmental Carbon Footprints. Industrial Cases*. Elsevier, Butterworth-Heinemann.

Zhang, X., Wang, F., (2016a) “Hybrid input–output analysis for life-cycle energy consumption and carbon emissions of China’s building sector”, *Building and Environment* 104, 188–197.

Zhang, X., Wang, F., (2016b) “Assessment of embodied carbon emissions for building construction in China: comparative case studies using alternative methods”, ·*Energy and Buildings* 130, 330–340.

# Últims documents de treball publicats

| Núm | Títol | Autor | Data |
|---|---|---|---|
| 20.03 | $CO_2$ emissions of the construction sector in Spain during the real estate boom: input-output subsystem analysis and decomposition | Vicent Alcántara/ Emilio Padilla | Juny 2020 |
| 20.02 | The Direct Rebound Effect of Electricity Energy Services in Spanish Households: Evidence from Error Correction Model and System GMM estimates | Martín Bordón / Jaume Freire / Emilio Padilla | Maig 2020 |
| 20.01 | Subsidizing Innovation Over the Business Cycle | Isabel Busom / Jorge-Andrés Vélez-Ospina | Març 2020 |
| 19.07 | África Subsahariana: ¿Del afropesimismo a la transformación económica? | Artur Colom Jaén | Novembre 2019 |
| 19.06 | Identification of relevant sectors in CO2 emissions in Ecuador through input-output analysis | Edwin Buenaño / Emilio Padilla and Vicent Alcántara | Setembre 2019 |
| 19.05 | Driving forces of CO2 emissions and energy intensity in Colombia | Lourdes Isabel Patiño / Vicent Alcàntara and Emilio Padilla | Setembre 2019 |
| 19.04 | The relation of GDP per capita with energy and CO2 emissions in Colombia | Lourdes Isabel Patiño / Vicent Alcàntara and Emilio Padilla and Josep Lluís Raymond | Setembre 2019 |
| 19.03 | Cruise activity and pollution: the case of Barcelona | Jordi Perdiguero / Alex Sanz | Juliol 2019 |
| 19.02 | Transportation and storage sector and greenhouse gas emissions: and input-output subsystem comparison from supply and demand side perspectives | Lidia Andrés / Emilio Padilla and Vicent Alcántara | Juliol 2019 |
| 19.01 | Selection and educational attainment: Why some childrens are left behind? Evidence from a middle-income country | Luciana Méndez-Errico / Xavier Ramos | Gener 2019 |
| 18.03 | Equality of opportunity in four measures of well-being | Daniel Gerszon Mahler / Xavier Ramos | Desembre 2018 |
| 18.02 | Higher Education and economic development: can public funding restrain the returns from tertiary education? | Paola Azar Dufrechou | Gener 2018 |
| 18.01 | Electoral politics and the diffusion of primary schooling: evidence from Uruguay, 1914-1954 | Paola Azar Dufrechou | Gener 2018 |
| 17.04 | Defence Spending, Institutional Environment and Economic Growth: Case of NATO | Natalia Utrero-González / Jana Hromcová and José F. Callado-Muñoz | Juliol 2017 |
| 17.03 | Pro-environmental behavior: On the interplay of intrinsic motivations and external conditions | Mariateresa Silvi and Emilio Padilla | Abril 2017 |

| | | | |
|---|---|---|---|
| 17.02 | Driving Factors of GHG emissions in EU transport activity | Lidia Andrés and Emilio Padilla | Març 2017 |
| 17.01 | Innovation, public Support and productivity in Colombia | Isabel Busom / Jorge-Andrés Vélez-Ospina | Gener 2017 |