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Linear General Equilibrium Model of Energy Demand and CO_2 Emissions Generated By the Andalusian Productive System

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ABSTRACT

In this study we apply a multiplier decomposition methodology of a linear general equilibrium model based on the regional social accounting matrix to the Andalusian economy. The aim of this methodology is to separate the size of the different effects in terms of energy expenditure and total emissions generated by the whole productive system to satisfy the final demand of each branch of the Andalusian economy and the direct emissions generated to produce energy for each subsystem.

Keywords: CO_2 Emissions, Social Accounting, Linear General, Multiplier Decomposition Methodology

1. INTRODUCTION

The use of energy commodities by productive activities is the key cause of greenhouse gases. Many studies conducted over recent decades have addressed this question in response to the growing awareness of the need to stop climate change.

In Andalusia, productive activities generate 90% of the region's total emissions, where emissions generated per unit of energy consumed are greater than the emissions generated for final consumption. This is attributable to the large price discrimination within this sector. As the emissions generated by the productive system have the biggest share in total emissions, this is priority target for the adoption of measures with a view to achieving the emission targets established in the Kyoto Protocol.

For this reason, this study focuses on analysing the emissions generated by the Andalusian productive system. The productive system is divided into several subsystems in order to establish the responsibilities of each one for satisfying the final demands for production for a more detailed analysis of the subsystems in the input-output framework, see (Sraffa, 1960; Heimler, 1991; Sanchez-Choliz and Duarte, 2003). The accounting multipliers calculated for each subsystem are disaggregated into four partial effects that we can use to decompose total emissions. The statistical information used to specify the SAM model parameters is the 2000 Andalusian social accounting matrix (SAMAND00) at basic prices and vector C of CO_2 emissions.

The study is structured as follows. In the next section we describe the methodology used to decompose sectoral production into different effects. Later we extend this methodology by mapping production to CO_2 emissions. In the next section, we apply the methodology to the Andalusian productive system. Finally, we state the conclusions and discuss the constraints and possible extensions of the model.

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2. LINEAR SAM MODEL-BASED MULTIPLIER DECOMPOSITION

In this section, we present an additive accounting multiplier decomposition methodology Multiplicative accounting multipliers (Polo *et al*., 1990) are another means of decomposition that is equally capable of disaggregating an economy's revenue generation process based on the SAMAND00. This methodology can disaggregate the output of the subsystems (i.e., groupings of productive sectors) into different effects. Based on a classification of institutions as n endogenous and m exogenous, the revenue of the endogenous institutions satisfies Equation 1:

$$y_n = A_{nn}y_n + A_{nm}y_m = A_{nn}y_n + d_n \quad (1)$$

where, y_n and y_m denote the vector of the revenue of the endogenous and exogenous institutions, respectively; A_{nn} and A_{nm} are two n×n and n×m matrices defined by the coefficients of the expenditure of the endogenous and exogenous institutions, respectively, destined for the endogenous institutions; and $d_n = A_{nm}y_m$ is the vector of the exogenous revenue destined for the endogenous institutions. As in the Leontief model, the revenue of the endogenous institutions can be obtained as Equation 2:

$$y_n = (I - A_{nn})^{-1} d_n = M_n y_{dn} \quad (2)$$

where, M is the generalized multiplier matrix. Substituting (2) into (1), we get:

$$y_n = A_{nn}M_n y_n + d_n \quad (3)$$

Following Alcantara and Padilla (2008) Whereas Alcantara and Padilla (2007) analyse the services subsystem, we extend the analysis to the other subsystems making up the Andalusian productive system, if we denote the subsystem of endogenous accounts under analysis by s and the complementary subset by r and partition the expenditure and multiplier matrices Equation 4a and 4b:

$$A_{nn} = \begin{pmatrix} A_{ss} & A_{sr} \\ A_{rs} & A_{rr} \end{pmatrix} = \begin{pmatrix} A_{ss} & 0 \\ 0 & A_{rr} \end{pmatrix} + \begin{pmatrix} 0 & A_{sr} \\ A_{rs} & 0 \end{pmatrix} \quad (4a)$$

$$M_n = \begin{pmatrix} M_{ss} & M_{sr} \\ M_{rs} & M_{rr} \end{pmatrix} \quad (4b)$$

Equation (3) can be written as Equation 5:

$$\begin{pmatrix} y_s \\ y_R \end{pmatrix} = \left[\begin{pmatrix} A_{ss} & 0 \\ 0 & A_{rr} \end{pmatrix} + \begin{pmatrix} 0 & A_{sr} \\ A_{rs} & 0 \end{pmatrix} \right] \begin{pmatrix} M_{ss} & M_{sr} \\ M_{rs} & M_{rr} \end{pmatrix} \begin{pmatrix} d_s \\ d_r \end{pmatrix} + \begin{pmatrix} d_s \\ d_r \end{pmatrix} \quad (5)$$

where, y_s and y_r are the column vectors of the accounts that subsystem S includes or excludes, respectively and d_s and d_r are the vectors of exogenous revenue destined for subsystem s or the complementary subsystem r, respectively. Supposing that exogenous revenue destined for the complementary subsystem r is zero, $d_r = 0$, we get the following system of Equation 6:

$$\begin{aligned} y_s &= A_{ss}M_{ss}d_s + A_{sr}M_{rs}d_s + d_s \\ y_r &= A_{rr}M_{rs}d_s + A_{rs}M_{ss}d_s \end{aligned} \quad (6)$$

This system provides the revenue of the institutions when the demand destined for the complementary subsystem is zero. The revenue of the institutions included in subsystem *s* is decomposed into three summands:

- $A_{ss}M_{ss}d_s$ represents the revenue generated within the subsystem s itself when it receives exogenous revenue d_s. It is called own effect and denoted y_s^{OE}
- $A_{sr}M_{rs}d_s$ represents revenue generated in subsystem *s* due to the increase in revenue generated in the complementary subsystem r to satisfy the exogenous demand d_s. It is called the feedback effect and is denoted y_s^{FBE}
- d_s represents the direct revenue of subsystem *s* when the exogenous revenue is d_s. It is called the scale effect (SCE) and is denoted y_s^{SCE}

The second Equation (5) provides the revenue generated in the complementary subsystem r when the exogenous revenue is d_s. The second term, $A_{sr}M_{ss}d_s$, represents the revenue induced in the complementary subsystem r by the revenue generated in the institutions s; and the first term, $A_{rr}M_{rs}d_s$, reflects the revenue induced in subsystem r by the generation of revenue in its institutions induced by the exogenous revenue destined for the institutions in s. It is called the spill-over effect and is denoted y_r^{SOE} .

3. AN ESTIMATE OF SECTOR CO_2 EMISSIONS

To link the above analysis with CO_2 emissions, we need a vector that converts the monetary units of the model into emission units. To do this, we use the vector c_e of emissions per unit of each energy commodity used (**Table 11**). Multiplying this vector by the submatrix A^E_{nn}, we get a vector of unit emissions for each institution Equation 7:

$$c_n = c' A^E_{nn} \quad (7)$$

where, c is the transpose of the vector. By dividing this vector into two, one for the institutions in subsystem r, c_r and another for subsystem *s*, we get a breakdown of total CO_2 emissions Equation 8:

$$E^T = c'_s y_s + c'_r y_r \quad (8)$$

Generated to satisfy the vector of final demand d_s by the four above-mentioned effects:

Emissions associated with the own effect Equation 9:

$$E^{OE} = c'_s y^{OE}_s = c'_s A_{ss} M_{ss} d_s \quad (9)$$

Emissions associated with the feedback effect Equation 10:

$$E^{FBE} = c'_s y^{FBE}_s = c'_s A_{sr} M_{rss} d_s \quad (10)$$

Emissions associated with the scale effect Equation 11:

$$y^{SCE}_s = c'_s d_s \quad (11)$$

Emissions associated with the spill-over effect Equation 12:

$$E^{SOE}_s = c'_r y_r = c'_r \left(A_{rr} M_{rs} d_s + A_{rs} M_{ss} d_s \right) \quad (12)$$

To get the emissions by branches, we have to diagonalize vector d ($\hat{d}$), whereby, for scale effect emissions, we get the vector $em_S{}^{SCE}$ (1×s) Equation 13:

$$em_S{}^{'SCE} = c_S{}'\cdot,\hat{d}_S \quad (13)$$

where, these are the emissions generated by each branch of subsystem *s* to produce the units destined to satisfy its final demand.

We get the spill-over effect in terms of emissions by calculating the vector $em_S{}^{SOE}$ (1×R) Equation 14:

$$em_S{}^{'SOE} = c_r{}'\cdot \left(A_{rr}\cdot M_{rs} + A_{rs}\cdot M_{ss}\right) \cdot\hat{d}_S \quad (14)$$

This vector is composed of emissions generated by the other productive branches to produce what each branch of subsystem s demands to be able to satisfy its final demand.

To get the emissions generated by the production of the analysed subsystem destined to meet the needs of each subsystem branch for own inputs to satisfy its final demand (emissions due to the own effect), we calculate the vector $em_S{}^{OE}$ (1×s) Equation 15:

$$em_S{}^{'OE} = c_S{}'\cdot A_{SS}\cdot M_{SS}\cdot\hat{d}_S \quad (15)$$

In this case, the results suggest that the final demand of each branch of the subsystem has a pull effect on the emissions that it generates.

Similarly, we calculate the emissions due to the feedback effect Equation 16:

$$em_S{}^{'FBE} = c_S{}'\cdot A_{sr}\cdot M_{rs}\cdot\hat{d}_S, \quad (16)$$

where, each element of this vector represents the emissions generated by the subsystem as a whole to produce what the other branches belonging to *r* need to be able to produce what each branch of subsystem *s* demands to satisfy its final demand.

Therefore, the total effect (EM_{TE}) in terms of emissions directly or indirectly generated to satisfy the final demand of subsystem *s* would be Equation 17:

$$EM_{TE} = EM_{SCE} + EM_{OEP} + EM_{FBE} + EM_{SOE} \quad (17)$$

and the total effect in terms of emissions due to the final demand of each branch of *s* would be the vector $em_S{}^{TE}$ (1×s) Equation 18:

$$em_S{}^{TE} = em_S{}^{SCE} + em_S{}^{OE} + em_S{}^{FBE} + em_S{}^{SOE}. \quad (18)$$

Moreover, we can use Equation (5) again, this time making the vector D_S zero, to get the sales made by subsystem s to the other sectors to enable them to satisfy their own final demands. Following the same procedure as above, we would get for the other branches Note that this equation reflects the spill-over effect for branches of r in the same way as (9) does for the branches of s Equation 19:

$$A_{ss}\cdot M_{sr}\cdot d_r + A_{sr}\cdot M_{rr}\cdot d_r + 0 = Y^r{}_S \quad (19)$$

If we multiply this expression by the vector of emissions, we will have the emissions generated by sales to other sectors to satisfy their demand, which we will denote Sales Effect (SE) Equation 20:

$$EM_{SE} = c_S' \cdot Y^r{}_S \quad (20)$$

and the emissions for each branch of the subsystem by sales to other sectors would be Equation 21:

$$em_S{}^{'SE} = c_S' \cdot \hat{Y}^r_S \quad (21)$$

In a SAM analysis such as this, the emissions due to the sales effect account for the influence of the endogenized accounts, as we will see later. This means that these emissions are closer than in the input-output model to the direct emissions, called EM_{DE}, generated by each productive subsystem. We calculate EM_{DE} by multiplying the unit emissions generated per unit produced by each subsystem by subsystem production Equation 22:

$$EM_{DE} = c_S' \cdot Y_S \quad (22)$$

4. RESULTS AND DISCUSSION

In accordance with the Stern Review classification Stern (2007), we divide the Andalusian productive system into six groups, called subsystems, shown in **Table 1**, alongside their SAMAND00 (**Table 12**) for Andalusian SAMAND00 accounts and input-output (MIOAND00) framework equivalences for the year 2000 equivalences.

In the following, we apply the multiplier decomposition methodology outlined to the SAMAND00 using a SAM model (**Table 10**) shows the results of applying the multiplier decomposition methodology to the SAMAND00 input-output model, that is, without endogenizing labour, capital and consumption (considering the labour (29), capital (30) and consumption (31) accounts as endogenous) for each subsystem. This outputs the production of each subsystem destined to satisfy the final demand of each subsystem branch divided into the different effects forming what we term the total effect.

We transform these results into CO_2 emissions as explained before. This way, as shown in **Table 2** below, we get the emissions generated to satisfy the final demand of each subsystem.

Table 1. Productive subsystems of the andalusian economy

	SAMAND00 account equivalence
Subsystem 1: Primary	1, 2 and 3
Subsystem 2: Energy	4, 5, 7, 8 and 9
Subsystem 3: Industry	6, 10 to 21
Subsystem 4: Construction	22
Subsystem 5: Transport and communications	25
Subsystem 6: Services	23, 24, 26, 27 and 28

Source: Own elaboration

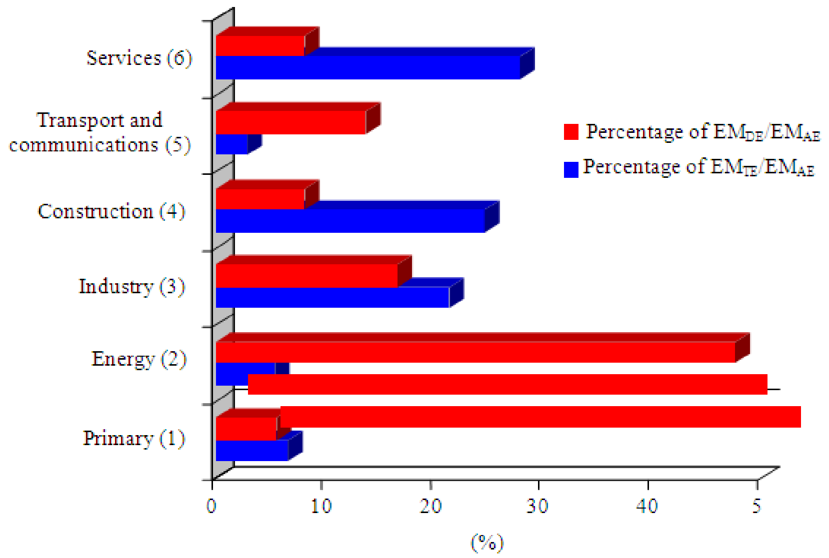

Fig. 1. Direct and total emissions of the Andalusian economy's productive subsystems over sectoral emissions (%)

Table 2. Total and direct CO_2 emissions generated by the Andalusian productive system (2000) based on the SAM* model

	Primary (1)	Energy (2)	Industry (3)	Construction (4)	Transport and communications (5)	Services (6)
EM_{OE}	83.63	343.8	979.67	699.48	157.09	199.37
EM_{FBE}	48.88	92.62	213.77	55.8	40.1	633.06
EM_{SCE}	747.93	1,602.16	2,220.26	2,195.57	588.32	763.9
EM_{SOE}	1,907.35	190.73	5,534.27	7,325.98	430.86	10,036.88
EM_{TE}	2,787.80	2,229.31	8,947.97	10,276.83	1,216.37	11,633.21
$\%EM_{TE}/EM_{AE}$**	6.70%	5.36%	21.50%	24.69%	2.92%	27.95%
EM_{SE}	1,468.26	17,758.76	3,526.15	471.9	4,957.05	1,768.12
EM_{DE}	2,348.71	19,797.34	6,939.84	3,422.75	5,742.56	3,364.45
$\%EM_{DE}/EM_{AE}$**	5.64%	47.57%	16.68%	8.22%	13.80%	8.08%

(*) Stated in kilotonnes (kt) of CO_2.
(**) Andalusian Economy Sectoral Emissions (EMAE): 41,616
Source: Own elaboration.

Table 3. Total and direct unit emissions of the andalusian productive system

	Primary (1)	Energy (2)	Industry (3)	Construction (4)	Transport and communications (5)	Services (6)
EM_{TE}/D	0.725	0.896	0.493	0.727	0.949	0.513
EM_{DE}/Y_d*	0.241	2.226	0.211	0.155	0.537	0.045

* Yd: Domestic production; **Source:** Own elaboration

Table 4. CO_2 emissions by branches of the primary subsystem

	EM_{OE}	EM_{FBE}	EM_{SCE}	EM_{SOE}	EM_{TE}	EM_{SE}	EM_{DE}
Arable farming	68.0	37.7	681.8	1,684.0	2,471.4	1,144.4	1,944.3
Livestock farming	15.6	10.7	43.3	205.8	275.4	132.0	181.3
Fishery	0.1	0.5	22.8	17.5	41.0	191.9	223.1
TOTAL SUBSYSTEM 1	83.6	48.9	747.9	1,907.4	2,787.8	1,468.3	2,348.7

Source: Own elaboration

Table 5. CO_2 emissions by branches of the energy subsystem

	EM_{OE}	EM_{FBE}	EM_{SCE}	EM_{SOE}	EM_{TE}	EM_{SE}	EM_{DE}
Coal	7.6	5.2	106.1	8.0	126.9	334.4	458.4
Oil and natural gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oil refinery	244.6	76.6	1,074.0	164.7	1,559.9	1,845.8	3,004.8
Electricity	73.6	7.3	412.7	11.8	505.5	15,513.3	16,258.4
Gas	18.0	3.5	9.3	6.2	37.1	65.3	75.8
TOTAL SUBSYSTEM 2	343.8	92.6	1,602.2	190.7	2,229.3	17,758.8	19,797.3

Source: Own elaboration

Table 2 shows the different effects in EM_{TE} for each subsystem as a whole. The results are disaggregated by branches (**Table 4-9**) and containing the emissions due to the own effect (EM_{OE}), that is, emissions generated by subsystem s to produce what the subsystem itself requires to satisfy its final demand.

This is followed by the feedback effect (EM_{FBE}), that is, emissions generated by subsystem s to produce what it needs to sell to other sectors for them to produce what subsystem s demands from them to satisfy its final demand. The next row shows the scale effect (EM_{SCE}), which are the emissions generated by the subsystem s to produce what it is to sell directly to its final demand and finally, we have the spill-over effect (EM_{SOE}), that is, the emissions generated by the other sectors to produce what subsystem s demands from them to be able to satisfy its final demand.

Then come the emissions due to sales made by each subsystem to the other sectors r (EM_{SE}) in order to satisfy the final demands of r and finally, the emissions generated directly by the production of each subsystem, which we call the direct effect (EM_{DE}).

Finally, **Table 2** lists both the EM_{TE} and the EM_{DE} for each subsystem, as a ratio of total sectoral emissions (which we call EM_{AE}) of the Andalusian economy.

Table 6. CO_2 emissions by branches of the industry subsystem

	EM_{OE}	EM_{FBE}	EM_{SCE}	EM_{SOE}	EM_{TE}	EM_{SE}	EM_{DE}
Other extractive	5.8	1.3	59.7	64.0	130.8	316.8	539.3
Water	0.0	0.0	0.0	0.0	0.0	11.7	13.6
Food	126.4	129.9	177.1	2,357.6	2,791.0	258.5	498.0
Textile and leather	10.9	3.8	7.0	107.9	129.5	21.4	32.9
Wood working	13.2	3.5	20.2	92.3	129.1	89.9	139.4
Chemical industry	202.6	17.7	1,067.9	924.3	2,212.5	1,479.1	3,061.8
Mining and iron and steel	234.1	18.7	680.3	734.4	1,667.5	350.5	1,312.2
Metal working	89.1	5.0	21.1	158.6	273.8	65.7	99.2
Machinery	49.8	7.7	15.6	204.1	277.2	30.3	53.5
Vehicle	37.8	2.9	6.5	99.6	146.8	9.0	17.2
Building materials	43.9	5.0	115.0	234.1	398.1	822.1	1,022.7
Transport	62.5	6.5	21.2	175.1	265.2	11.6	43.4
Other manufacturing	103.6	11.9	28.7	382.2	526.5	59.7	106.5
TOTAL SUBSYSTEM 3	979.7	213.8	2,220.3	5,534.3	8,948.0	3,526.1	6,939.8

Source: Own elaboration

Table 7. CO_2 emissions by branches of the construction subsystem

	EM_{OE}	EM_{FBE}	EM_{SCE}	EM_{SOE}	EM_{TE}	EM_{SE}	EM_{DE}
Construction	699.5	55.8	2,195.6	7,326.0	10,276.8	471.9	3,422.8
TOTAL SUBSYSTEM 4	699.5	55.8	2,195.6	7,326.0	10,276.8	471.9	3,422.8

Source: Own elaboration

These ratios are also illustrated as percentages in **Fig. 1** to give a clearer and fuller picture of the results and make the detailed analysis that follows easier to understand and follow.

As **Fig. 1 and Table 2** show, the results split the subsystems into two groups. On the one hand, we have subsystems 1, 3, 4 and 6, which have higher EM_{TE} than EM_{DE}, whereas the opposite applies to subsystems 2 and 5.

Starting with the first of these groups, the primary (1), industry (3), construction (4) and services (6) subsystems are sectors that have a pull effect on emissions generated by the economy, that is, they generate high indirect emissions to satisfy their final demand. Consequently, their EM_{TE} are greater than the emissions that are generated directly by sector production (EM_{DE}). Generally speaking, a characteristic of these subsystems is that they have high EM_{SOE} and low EM_{SE}.

The services (6) subsystem, whose EM_{SOE} account for 24.12% of total Andalusian productive system emissions, ranks top of this group, due to the emissions generated by production in other sectors and required by the services subsystem to satisfy its own final demand. It is this that explains the services subsystem's high level of EM_{TE}, accounting for over a quarter of the emissions of all the productive activities.

These results reflect the sizeable pull effect of this sector, not usually considered as a major polluter, on emissions generated by the Andalusian economy Alcantara and Padilla (2008).

On the other hand, EM_{SE} are the second ranked emissions in this sector, albeit well below EM_{SOE}. This is because they contain sales for private consumption. For this reason, EM_{SCE} are lower than in the input-output model (**Table 10**), where they rank second for this subsystem and although again considerably lower than EM_{SOE}, are relatively high compared with the other subsystems.

Finally, this sector has strikingly high EM_{FBE} levels compared with the other subsystems, once again showing how important the services sector is within the Andalusian economy because of its high interdependencies with the other subsystems.

Looking at the results by branches we have conducted a study of whole subsystems rather than a branch-by-branch analysis. For this reason, the results stated by branches refer to emissions generated to satisfy the final demand of the subsystem to which they belong. For a branch-by-branch analysis, the own effect has to be split into two (an intra-branch effect and an inter-branch effect), Alcantara and Padilla (2008). We find that the services not for sale sector (28) ranks top within this subsystem. This sector has the highest level of EM_{TE} at about 20% of the total emissions of the productive activities, primarily due to EM_{SOE}. Another noteworthy point is that the trade (24) branch, except fuel trade (23), behaves differently within this subsystem, as it accounts for over 50% of the subsystem's EM_{DE}, whereas EM_{TE} are relatively small.

Table 8. CO_2 emissions by branches of the transport and communications subsystem

	EM_{OE}	EM_{FBE}	EM_{SCE}	EM_{SOE}	EM_{TE}	EM_{SE}	EM_{DE}
Transport and communications	157.1	40.1	588.3	430.9	1,216.4	4,957.0	5,742.6
TOTAL SUBSYSTEM 5	157.1	40.1	588.3	430.9	1,216.4	4,957.0	5,742.6

Source: Own elaboration

Table 9. CO_2 emissions by branches of the services subsystem

	EM_{OE}	EM_{FBE}	EM_{SCE}	EM_{SOE}	EM_{TE}	EM_{SE}	EM_{DE}
Fuel trade	4.2	8.4	19.6	161.9	194.0	48.3	86.9
Other trade	13.0	28.6	77.2	555.1	674.0	1,170.5	1,773.6
Other services	37.8	77.2	73.2	1,235.9	1,424.1	208.3	394.9
Services for sale	19.6	70.6	67.4	1,035.7	1,193.3	334.4	572.9
Services not for sale	124.8	448.2	526.6	7,048.3	8,147.8	6.6	536.2
TOTAL SUBSYSTEM 6	199.4	633.1	763.9	10,036.9	11,633.2	1,768.1	3,364.4

Source: Own elaboration

Table 10. Total and direct CO_2 emissions generated by the Andalusian productive system (2000) based on the input-output model*

	Subsystem 1	Subsystem 2	Subsystem 3	Subsystem 4	Subsystem 5	Subsystem 6
EM_{OE}	100.51	1,236.04	1,297.83	709.47	530.44	383.15
EM_{FBE}	10.09	50.46	161.53	11.68	25.02	40.77
EM_{SCE}	1,047.09	6,468.38	2,844.60	2,271.82	2,097.01	2,705.38
EM_{SOE}	1,003.34	167,74	4,996.05	3,744.22	550.54	9,162.52
EM_{TE}	2,161.03	7,922.63	9,300.01	6,737.19	3,203.00	12,291.81
$\%EM_{TE}/EM_{AE}$**	5.19	19.04	22.35	16.19	7.7	29.54
EM_{SE}	1,191.02	12,042.46	2,635.88	429.78	3,090.10	235.16
EM_{DE}	2,348.71	19,797.34	6,939.84	3,422.75	5,742.56	3,364.45
$\%EM_{DE}/EM_{AE}$**	5.64	47.57	16.68	8.23	13.8	8.08

(*) Stated in kilotonnes (kt) of CO_2.
(**) Andalusian economy sectoral emissions (EM_{AE}): 42,616.
Source: Own elaboration

Table 11. Vector *C* of emissions per unit of energy commodity used (kt CO_2/ 1000€)

	Coal	Oil	Refinery	Electricity	Gas
Intermediate Demand	46.40	0.00	8.08	0.00	7.25
Final Demand	27.98	0.00	4.65	0.00	3.26

Source: Own elaboration based on Manresa and Sancho (2004)

Comparing the results for this subsystem, we find that although there are some differences between the two models, they both show that the services subsystem has a sizeable pull effect on the emissions of the other branches.

Note firstly that there is big a difference between the two models as regards both EM_{SOE} and consequently, EM_{TE}. Another striking point is that the emissions due to the spill-over effect in the services for sale sector (27) and especially, the services not for sale sector (28) are greater in the SAM model.

These differences again highlight the fact that SAM models account for relationships not captured by input-output models.

Ranking second in terms of emissions in this first group is the construction subsystem (4). This subsystem behaves similarly to the services subsystem and its EM_{SOE} are again high, due to this sector's massive demands for energy and industrial inputs. In this case, there is no need to analyse this sector by branches, as it is composed of a single SAMAND00 account (22).

Although this subsystem's direct emissions are under 9%, this is a relatively high value considering that it is a single SAMAND00 account. Another noteworthy point is the high level of EM_{TE} of construction in Andalusia, which accounts for nearly 25% of the emissions of the whole productive system, even though it is a single account and ranks above other subsystems like industry (3).

Table 12. Sectoral structure of SAMAND00 and MIOAND00 equivalences

SAMAND00	MIOAND00
1. Arable farming	1 to 3
2. Livestock framing	4 and 5
3. Fishery, fish farming and related activities	6
4. Energy extractive	7
5. Other extractive	8 and 9
6. Oil refinery and nuclear waste treatment	26
7. Electrical energy production and distribution	46
8. Gas, water vapour and hot water production	47
9. Water collection, treatment and distribution	48
10. Food	10 to 19
11. Textile and leather	20 to 22
12. Wood working	23 and 24
13. Chemicals	27 and 28
14. Mining and iron and steel	33
15. Metal working	34
16. Machinery	35 to 39
17. Vehicles	40
18. Building materials	30 to 32
19. Transport	41 and 42
20. Other manufacturing	25, 29, 43 to 45
21. Construction	49 and 50
22. Vehicle and fuel trade	51
23. Other trade	52 to 56
24. Transport and communications	57 to 60
25. Other services	61 to 63, 66 to 71, 73, 83 and 84
26. Services for sale	64, 65, 72, 76, 78, 80, 81, 85 and 86
27. Services not for sale	74, 75, 77, 79 and 82

Source: Own elaboration based on MIOAND00 (Andalusian Statistical Office)

Comparing these results with the input-output model outcomes, we find that this subsystem ranks fourth in terms of total emissions, because it has lower EM_{SOE}, although, as applies to other subsystems, the findings are similar and more pronounced in the SAM.

The next highest ranked subsystem in this group is industry (3). In this case, the differences between EM_{TE} (21.50%) and EM_{DE} (16.68%) are less, albeit significant in both cases. This was to be expected taking into account that this is the largest subsystem with a total of 13 branches. Again, the explanation is to be found in the EM_{SOE}, which account for over 60% of EM_{TE}.

Compared with the other subsystems, industry has the greatest EM_{SCE} and EM_{OE} of the Andalusian productive system and the second highest value for EM_{FBE}. The explanation is unquestionably that industrial inputs are very important for all productive systems, industry included, as well as for final demand, especially investment.

Finally, industry's high EM_{SE} account for the fact that the differences between its EM_{TE} and its EM_{DE} are less than for the services subsystem.

As regards the results by branches, the highest ranking sectors are the food (11), chemicals (14), mining and iron and steel (15) and building materials (19) industries, although they behave differently in terms of EM_{DE} and EM_{TE}. The chemicals sector (14) has the greatest EM_{DE} values, accounting for 7.36% of total sectoral emissions and ranking second in terms of EM_{TE}, after food (11). The other two branches whose production generates most direct emissions within this subsystem are mining and iron and steel (15) and building materials (19).

Looking at EM_{TE}, though, we find that the food industry (11) generates the highest values, with relatively low $EM_{DE,}$ but EM_{SOE} that account for just over 80% of its EM_{TE} and which are much higher than its EM_{DE}. It is followed by the chemicals (14) and mining and iron and steel (15) industries, whereas the building materials sector (19) has low EM_{TE} levels.

These results highlight the role played by the food industry in the Andalusian economy, where it is a key sector and therefore has a big influence on the pollutant emissions generated by the system.

The lowest ranking subsystem in this first group is the primary sector (1), which is the subsystem that generates the fewest emissions as a whole in terms of EM_{DE} and ranks fourth, with slightly higher EM_{TE}, above the energy (2) and transport (5) subsystems.

However, an analysis by shows up significant differences, as the agriculture sector (1) accounts for most of the subsystem emissions, with 80% of both direct and total emissions.

Finally, let us stress that the emissions generated by this subsystem also have a noteworthy EM_{SE} and EM_{SOE} component. This explains why there is so little difference between the total and direct emissions.

Focusing now on the second group, we have subsystems 2 and 5. In both, EM_{DE} are greater than EM_{TE}. This indicates that these are branches that absorb emissions from other sectors and are characterized by high emissions per sales to other sectors (EM_{SE}) and low values for emissions due to the spill-over effect (EM_{SOE}).

Starting with the top-ranking subsystem within this second group, we have the energy subsystem (2). In this case, the high emissions due to the own effect, scale effect and sales effect were to be expected. They are explained by the high use of energy commodities by both the productive system and final demand.

As **Table 2** shows, the emissions generated directly by the energy subsystem (2) in its production process (EM_{DE}) account for almost 50% of total emissions by productive activities, where this subsystem ranks well above the rest of the economy. This is explained primarily by the EM_{SE}. The value of EM_{SE} in this model amounts to almost 90% of this subsystem's direct emissions, as this sector absorbs all the emissions generated by the energy needs of all the other subsystems to satisfy their final demands.

Additionally, we find that the emissions due to the final demand of energy (EM_{TE}) account for 5.36% of sectoral emissions, of which just over 70% correspond to EM_{SCE}, that is, to output destined for the final demand of energy.

In relation to the branches of this subsystem, we find that the electricity sector ranks top, with direct emissions accounting for over 39% of the emissions generated by the productive activities. This is the branch of the Andalusian economy that releases most emissions into the atmosphere One of the reasons for electricity sector being the biggest polluter of the Andalusian economy is the use of a high percentage of coal production, this being the energy commodity that generates most emissions when consumed. This is explained by the high emissions generated by sales to other sectors (EM_{SE}, which account for 37% of total emissions in the Andalusian productive system).

However, the EM_{TE} of this branch account for just 1.2% of sectoral emissions. This is explained partly by the model, as we have endogenized private consumption, meaning that final demand (exogenous accounts) does not include consumption and therefore, the emissions due to the scale effect are less than we would get with an input-output model, as are emissions due to own effect, as the demand they have to satisfy is lower. The values of the other effects, especially the spill-over and feedback effects, are very low for the electricity branch.

In the case of coal, whose direct emissions amount to 1.10% of sectoral emissions and whose EM_{TE} are just under 0.3%, emissions generated by sales to other sectors are noteworthy, given that most of its production is destined for use as input for the energy branches, especially, the electricity sector, whereas its final uses have declined.

The EM_{TE} of the refinery branch (7), which accounts for direct emissions amounting to just over 7% of sectoral emissions, ranks top in terms of emissions generated by this subsystem. This shows just how important the final demand of this sector is in terms of emissions. This is likely to be due to exports (where 35% of the output of this sector is destined for this use), as sales to other sectors includes private transport In Andalusia's input-output framework for the year 2000 and therefore in the SAMAND00, private transport is allocated to the oil refinery row and the private consumption column. This explains its high value, which even outranks total emissions.

One of the most noteworthy results of the analysis of this subsystem is the low level of emissions of the gas branch (9), accounting for less than 0.2% of total sectoral emissions in both cases (EM_{TE} and EM_{DE}), where the values for emissions due to the own effect and to the sales effect are the most significant.

Finally, another interesting point is that EM_{SOE} account, in all cases, for a very small percentage of sectoral emissions, as expected.

Continuing with the analysis of the second group, the second ranked subsystem after energy is transport and communications (5). The analysis of this subsystem is similar, as it is a sector of which both the productive activities and final demand make a lot of use. Its direct emissions are therefore greater than emissions due to the total effect and it has the second highest value for EM_{SE}, after the energy subsystem (2). This reflects how this sector absorbs emissions from the rest of the system.

Again, as in the case of construction, no analysis by branches is required, as this subsystem is composed of only one SAMAND00 account (25).

To complete this analysis, let us detail the results of this exercise presented in **Table 3**. **Table 3** shows the emissions due to both the total effect and the direct effect, weighted, in the first case, against the final demand of each subsystem branch and in the second, against the domestic output of each branch of the subsystem. The aim here is to fine tune the results, as, in some cases, they are due to a greater weight in the economy and in others, to sizeable price differences.

The values for EM_{TE}/D indicate the emissions generated by the system as a whole to be able to satisfy a unit of the system's final demand, whereas EM_{DE}/Y_d are emissions generated by the subsystem per unit output.

Here we find that the energy subsystem (2) ranks well above all the others in terms of direct emissions, whereas the highest value for total emissions generated by the system to satisfy one unit of final demand is for the transport and communications (5) subsystem. Also, comparing the two indicators for all the subsystems, we find that only in the case of subsystem 2 is the second indicator greater than the first. This indicates that this is the subsystem that absorbs most of the emissions generated in the system.

Noteworthy are the low emissions per unit of demand satisfied in the industry subsystem.

Additionally, whereas the services sector is ranked as the subsystem that has the greatest EM_{TE} in the analysis set out in **Table 2**, here we find that the emissions per unit of demand satisfied are the second lowest across the system, after the industry subsystem. Even so, we also find that there is a big difference between these emissions and emissions generated per unit of production in the services subsystem.

5. CONCLUSION

In this study we have developed a methodology that is useful for extending the information about CO_2 emissions by the productive sectors of the Andalusian economy, as, apart from identifying the emissions that each branch generates in its productive process, we are able to ascertain what indirect emissions (generated by other branches) are necessary to satisfy the final demand of each branch.

Thanks to the applied methodology, therefore, we can output the direct emissions generated by each subsystem and the total emissions, i.e., direct and indirect emissions, that are generated to satisfy the final demand of each subsystem. We can also separate these emissions into different effects.

Calculating these emissions can be helpful for detecting which branches and subsystems are the ones that release most emissions into the atmosphere and especially, which are the demands that have the biggest pull effect on emissions generated in the economy, plus which are the branches and subsystems most affected by these demands.

We have divided the subsystems into two groups depending on the results. The first, composed of the primary, energy, industry and construction subsystems, are characterized by high EM_{SOE} and low EM_{SE}. On the other hand, subsystems 2 and 5 are characterized by high EM_{SE} and lower EM_{SOE}.

The first group contains the sectors with a sizeable pull effect on emissions generated by the system, especially the services subsystem. The second group includes sectors that have a high absorption effect of emissions generated by the system.

In conclusion, the subsystems that have the highest levels of direct emissions are:

- The energy subsystem (2), accounting for 47.6% of total sectoral emissions. The highest ranked sector within this subsystem is electricity (8), accounting for 39% of EM_{AE}
- The industry subsystem (3), which generates 16.7% of sectoral emissions. The top ranked sector in this subsystem is chemicals (14)
- The transport and communications (5) subsystem, which accounts for 13.8% of sectoral emissions

These subsystems and branches therefore have a sizeable absorption effect of system emissions.

The highest ranking subsystems in terms of emissions due to the total effect are:

- The services subsystem (6), accounting for 27.95% of total sectoral emissions. Within this subsystem, the top-ranking branches are trade (24) in terms of direct emissions and above all, services not for sale (28) in terms of total emissions
- The construction subsystem (4), whose total emissions account for 25% of EM_{TE}
- The industry subsystem (3), which generates 21.5% of total sectoral emissions. The top-ranking branch within this subsystem is the food industry (10)

In this case, these are sectors that, as already mentioned, have a sizeable pull effect on system emissions.

As regards the differences in the results of applying this methodology to the SAM model, where we endogenize the labour (29), capital (30) and consumption (31) accounts and the input-output model, if we compare **Table 2** with **Table 10**, we see that the findings are similar, although more pronounced in the case of total emissions in the SAM model.

The key differences between the two models are that the scale effect does not include private consumption. This is reflected in the sales to other sectors effect and the spill-over effect, which includes emissions due to the endogenized accounts.

The results of this exercise are potentially useful for extending the, sometimes deficient, information about emissions, apart from providing guidance on policies for application in the future. Note, however, that the difference in emissions can, in some cases, be explained by the subsystems having a greater weight in the economy, as shown in **Table 3**, or by sizeable price differences, as in the case of the energy subsystem, which is known to apply sizeable price discrimination.

In this respect, an interesting extension of this research could be to take into account such price differences in both energy units and the final prices of the different branches.

Additionally, these analyses should to start to include renewable energies, which are gaining in importance in economic and environmental terms. For this to be possible, the input-output frameworks would have to separate these activities.

6. REFERENCES

Alcantara, V. and E. Padilla, 2007. Subsistemas Input-Output y contaminacion: Una aplicacion al Sector Servicios y las Emisiones de CO_2 en España. II Jornadas Españolas de Analisis Input-Output Zaragoza: Crecimiento, Demanda y Recursos naturales. Libro de Comunicaciones. Asociacion Hispanoamericana de Input-Output. Zaragoza.

Alcantara, V. and E. Padilla, 2008. Input-output subsystems and pollution: An application to the service sector and CO_2 emissions in Spain. Ecol. Econ., 68: 905-914. DOI: 10.1016/j.ecolecon.2008.07.010

Heimler, A., 1991. Linkages and vertical integration in the Chinese economy. Rev. Econ. Stat., 73: 261-267.

Manresa, A. and F. Sancho, 2004. Energy intensities and CO_2 emissions in catalonia: A SAM analysis. Int. J. Environ. Workplace Employment, 1: 91-106.

Polo, C., D. Roland-host and F. Sancho, 1990. Distribucion de la renta en un Modelo SAM de la economía española. Estadística Española, 32: 537-567.

Sanchez-Choliz, J. and R. Duarte, 2003. Analysing pollution by way of vertically integrated coefficients, with an application to the water sector in Aragon. Camb. J. Econ., 27: 433-448. DOI: 10.1093/cje/27.3.433

Sraffa, P., 1960. Production of Commodities by Means of Commodities. 1st Edn., CUP Archive, Cambridge, ISBN-10: 0521099692, pp: 98.

Stern, N.N.H., 2007. The Economics of Climate Change: The Stern Review. 1st Edn., Cambridge University Press, Cambridge, ISBN-10: 0521700809, pp: 692.