Solís, Alberto Franco; De Miguel Vélez, Francisco Javier

Conference Paper

Decomposition of sectoral water consumption: a subsystem SAM model for Extremadura, Spain

55th Congress of the European Regional Science Association: "World Renaissance: Changing roles for people and places", 25-28 August 2015, Lisbon, Portugal

Provided in Cooperation with:
European Regional Science Association (ERSA)

Suggested Citation: Solís, Alberto Franco; De Miguel Vélez, Francisco Javier (2015) : Decomposition of sectoral water consumption: a subsystem SAM model for Extremadura, Spain, 55th Congress of the European Regional Science Association: "World Renaissance: Changing roles for people and places", 25-28 August 2015, Lisbon, Portugal, European Regional Science Association (ERSA), Louvain-la-Neuve

This Version is available at:
https://hdl.handle.net/10419/124800

A DECOMPOSITION OF THE INTERSECTORAL AIR EMISSIONS AND WATER USE RELATIONSHIPS IN A REGIONAL ECONOMY.

Alberto Franco Solís[a,1], Fco. Javier De Miguel Vélez[b2]

[a,b] Department of Economics, University of Extremadura, Spain

ABSTRACT:

The analysis of environmental degradation by a subsystem **I**nput-**O**utput (I-O) approach provides detailed insight into the channels by which the environmental burdens are transmitted and generated within the production system. In this paper, the analysis is developed to the study of the **C**arbon **D**ioxide **eq**uivalent (CO_2-eq) emissions and water use certainly associated to each one of the production sectors defined in a **S**ocial **A**ccounting **M**atrix (SAM). In contrast with other studies, this paper applies the methodology to a regional economy in Spain, Extremadura. Hence, the application of the model to sub-national data may result in more localized and accurate findings. The results mainly confirm the importance of the productive linkages on the agri-food sectors as regards the CO_2-eq emissions and water use in the region. They also reveal the influence that the final demand of these sectors has on the environmental loads caused by the Extremadura economy. This study is potentially useful for extending the deficient regional information about the real causes leading to CO_2-eq emissions and water use, apart from providing guidance on effective policy measures aimed at the reduction of these environmental impacts.

Keywords: *subsystem input-output approach, input-output table, water resources, carbon dioxide equivalent, Extremadura.*

JEL classifications: C67, D58, Q43, Q51, R13, E16, Q25, R11.

1. Introduction.

World population is projected to grow from 7.2 billion today to 9.6 billion in 2050 according to **U**nited **N**ations (UN). Within this context, agriculture and livestock are recognized as playing a decisive role in meeting the future food needs of all humans. Nevertheless, because of their large interface with the environment, the question arises of how this can be achieved by sustainable means. According to the United Nations **F**ood and **A**griculture **O**rganization (FAO), the **G**reen**h**ouse **G**ases (GHG) emissions from agriculture, forestry and fisheries have nearly doubled over the past fifty years and could increase an

[1] Corresponding author. Tel.: +34 924 28 93 00
E-mail addresses: albertofranco@unex.es (A. Franco).
[2] The author acknowledges support from project ECO2013-41917-p (*Ministerio de Educación, Cultura y Deporte*).

additional 30 percent by 2050. In addition, with a percentage of emissions of 14.5 percent of human-induced GHG emissions per year, the livestock sector emerges as another significant contributor to climate change.

On the other hand, water demand is also largely influenced by population growth and macro-economic processes such as increasing consumption. As pointed out by UN, by 2050, global water demand is projected to increase by 55%, mainly due to growing demands from manufacturing, thermal electricity generation and domestic use. Feeding an increasing global population without compromising environmental integrity is thus one of the challenges that agriculture and livestock must deal with nowadays.

Nevertheless, by only reflecting the direct environmental effects[3] generated in each production sector, we obviate the fact that a large number of these effects are generated to facilitate the production of other sectors. The environmentally damaging character of a production sector should thus be also determined by reference to the purchases and sales that this sector makes in the economy (Sánchez-Chóliz, J. and Duarte, R., 2003). In this regard, I-O techniques allow us to distinguish the environmental effects generated by each production sector to obtain its required output and that demanded by other activities.

Specifically, the analysis of I-O subsystems provides a useful tool for studying the entire flow by which these environmental burdens are caused and transmitted throughout the production system. By isolating the relations of a specific sector or group of sectors, named as a subsystem, from the whole system, this methodology provides specific information about the production relations of each subsystem without modifying the main characteristics of the economic system to which it belongs (Llop and Tol, 2013). Hence, the environmental effects can be decomposed into different components depending on the origin and destination of the generated output.

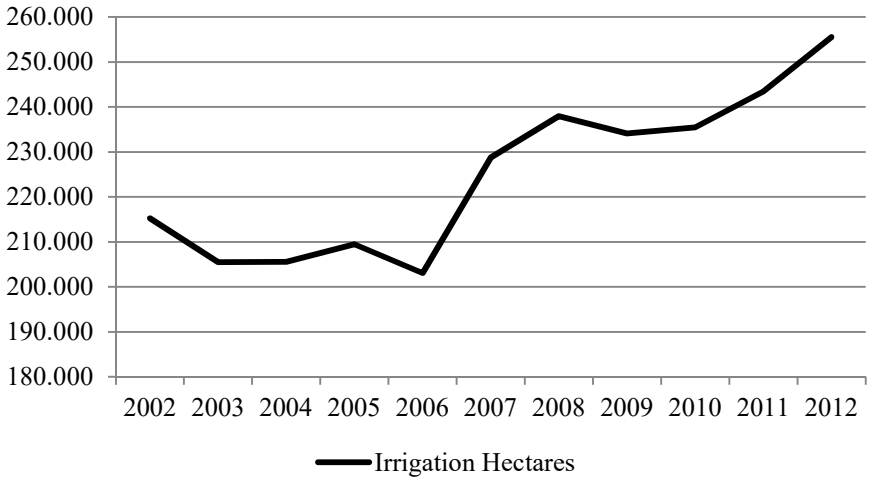
The first reference to I-O subsystems is by Sraffa (1960). Subsequently, the theory is further developed from the contributions of Pasinetti (1973, 1986, 1988), Deprez (1990), Scazzieri (1990), among others. More recently, Alcántara (1995) used the subsystems approach from an economic and environmental perspective. Sánchez-Chóliz and Duarte (2003) adopt this decomposition approach by using the Pasinetti vertical integration methodology in order to study the network of relations that link the economic sectors from the scope of water pollution. In a recent study, Alcántara and Padilla (2009) apply this methodology to the CO_2 emissions of the service subsystem in Spain. Other recent study analyzing service sector linkages and CO_2 emissions for the Spanish case is the one by Butnar and Llop (2011), which extended the study with structural decomposition. With a parallel approach, Cardenete and Fuentes (2012) provide a breakdown of CO_2 emissions for the energy and non-energy sectors of the Spanish economy using a subsystem representation within a SAM. Later, Llop and Tol (2013) treat each sector in the Irish economy as a subsystem for decomposing sectoral GHG emissions.

[3] Referred to those environmental effects caused by the production activity of a sector.

Our approach is based on the model proposal made by these last authors. Nevertheless, in our paper an I-O subsystem analysis is applied to study both the CO_2-eq emissions and the water use associated to the different production sectors of a regional economy. Although the actual different production situations, environmental impacts and possible intervention strategies calls for substantial further studies at a more localized level, so far scarce attention has been paid to the analysis of environmental-economic interdependencies in a sub-national economy. Hence, the development of a subsystem model applied to a regional economy represents a relevant contribution of this paper.

In Extremadura, a convergence objective NUTS II region located in the southwest of Spain, most of the regional GHG emissions and direct water use are generally associated with two activities: livestock and agriculture, respectively. Indeed, GHG emissions by agriculture and livestock contributed to the non-compliance of the GHG 15% growth permitted by the Kyoto Protocol during the 2008-2012 period compared to 1990 year. On the other hand, agriculture dominated water use with almost 96% of the resources in 2012. In addition, demand for irrigation water has increased as a consequence of the intensification of irrigated farmlands from 2002 to 2012 (See Figure 1). The relevance of these environmental loads, together with the important role of the agrarian sector on the regional economy of Extremadura (accounts for the 5.6% of the regional GDP in 2012), call for an in-depth analysis of the real causes leading to these impacts.

Figure 1. Evolution of irrigated farmlands in Extremadura (hectares).



Source: Self-made based on the Areas and Crop Yields Survey (ESYRCE in Spanish abbreviation), 2012.

This paper proposes a separated application of the subsystems I-O model to each production sector of Extremadura in their relationships with the CO_2-eq emissions and water use. Thereby, this approach will provide us with a better understanding on how the sectoral interrelations of each activity are involved in those environmental burdens generated in the region. That is, such analysis will allow us to exactly identify those sectors responsible for the highest amount of CO_2-eq emissions and water use. In addition, to reinforce the importance of the sectoral interdependencies effects on the environmental loads, we previously apply

an I-O model to calculate the emissions and water use generated to satisfy the final demand of each production sector. In this paper, following most of the existent related literature, these environmental impacts are referred to as *embodied*.

In meeting this objective, we have used as a database a Social Accounting Matrix expanded with Environmental Accounts of Extremadura for 2005 year (SAMEAEXT-05). The Environmental Accounts, specified in physical terms, illustrate the six GHG considered by the Kyoto Protocol (CO_2, CH_4, N_2O, HFC, SF_6) and the water use attributable to the production of the different sectors in the region.

The results in this paper may be extremely useful for the regional government's planning and future policies to lessen environmental burdens. Specially, bearing in mind that the scientific-technical and social priorities of the Fifth **R**esearch and **T**echnological **D**evelopment (RTD) Plan of Extremadura for the period 2014-2017 are oriented towards the development of research applied to strategic areas such as agriculture, food and natural resources. Besides, applying this methodology to data at a sub-national level may allow us to obtain accurate conclusions with regard to the interrelations between production sectors and its effects on the environment.

This paper is organized in four sections. After considering a background of the subsystem decomposition method, section 2 provides the details of the model applied. Along with the application of the subsystem method itself, the direct and embodied sectoral CO_2-eq emissions and water use on the economy are examined in section 3. Section 4 applies the subsystem methodology to the Spanish region of Extremadura and shows and discusses the results. The paper closes with some concluding remarks and policy recommendations.

2. Methodology

Consistent with the literature, the starting point in the application of the subsystems model is the decomposition of the *T* accounts of our SAM system into two categories: *m* endogenous and *n* exogenous. Given that our objective is to measure the amount of air pollution and water use associated with the activity of the different production sectors, these accounts have been considered as endogenous. Hence, the actual production of the endogenous accounts satisfies:

$$x_m = A_{mm}x_m + A_{mn}x_n = A_{mm}x_m + y_m \quad (1)$$

where x_n denote the vector of income of exogenous accounts; A_{mm} and A_{mn} stand for the *m x m* and *m x n* matrices with the technical coefficients of the Leontief model for the endogenous and exogenous accounts, respectively; and y_m is the vector of the exogenous demand directed to the endogenous accounts.

Following Alcántara and Padilla (2009), we denote the *m* endogenous accounts under analysis by two categories, *R* and *S*, and partition the equation (1) as follows:

$$\begin{pmatrix} x^R \\ x^S \end{pmatrix} = \begin{pmatrix} A_{RR} & A_{RS} \\ A_{SR} & A_{SS} \end{pmatrix} \begin{pmatrix} x^R \\ x^S \end{pmatrix} + \begin{pmatrix} y^R \\ y^S \end{pmatrix} \quad (2)$$

where the column vector $x_m = \begin{pmatrix} x^R \\ x^S \end{pmatrix}$ contains the vector of sectoral output in the economy, and the column vector $y_m = \begin{pmatrix} y^R \\ y^S \end{pmatrix}$ represents the exogenous final demand destined for the endogenous subsystem *R* and the complementary analyzed subsystem *S*. In accordance with the fundamental Leontief equation, $x_m = (I - A_{mm})^{-1} y_m$, and by designating B_{mm} as the Leontief inverse matrix $(m \times m)$, $B_{mm} = (I - A_{mm})^{-1}$, the expression (2) becomes:

$$\begin{pmatrix} x^R \\ x^S \end{pmatrix} = \begin{pmatrix} B_{RR} & B_{RS} \\ B_{SR} & B_{SS} \end{pmatrix} \begin{pmatrix} y^R \\ y^S \end{pmatrix} \quad (3)$$

Substituting equation (3) to equation (2), the subsystems I-O model is given by:

$$\begin{pmatrix} x^R \\ x^S \end{pmatrix} = \left[\begin{pmatrix} A_{RR} & A_{RS} \\ A_{SR} & A_{SS} \end{pmatrix} \right] \begin{pmatrix} B_{RR} & B_{RS} \\ B_{SR} & B_{SS} \end{pmatrix} \begin{pmatrix} y^R \\ y^S \end{pmatrix} + \begin{pmatrix} y^R \\ y^S \end{pmatrix} \quad (4)$$

Expression (4) contains the following two equations[4]:

$$x^R = A_{RR} B_{RR} y^R + A_{RR} B_{RS} y^S + A_{RS} B_{SR} y^R + A_{RS} B_{SS} y^S + y^R \quad (5)$$

$$x^S = A_{SS} B_{SR} y^R + A_{SS} B_{SS} y^S + A_{SR} B_{RR} y^R + A_{SR} B_{RS} y^S + y^S \quad (6)$$

The two equations in (5) and (6) show the production of the *R* and *S* subsystems, respectively. These proposed expressions of the subsystem I-O model are based on that developed by Llop and Tol (2013). As such, by following the approach addressed in that paper, let us assume that we are interested in analyzing the *S* subsystem. Hence, the production of *R* is decomposed into two summands. The first one, $A_{RR} B_{RS} y^S + A_{RS} B_{SS} y^S$ indicates the production generated in subsystem *R* to satisfy the final demand directed to the *S* subsystem demand, y^S. It is called *S external component* and denoted as EXC^S. The remaining elements in the first equation (5), $A_{RR} B_{RR} y^R + A_{RS} B_{SR} y^R + y^R$ indicate the production generated within the actual *R* subsystem required to cover its final demand[5].

[4] Differently to the related literature assuming the final demand of one subsystem is zero and, as such, its whole production is directed to the intermediate demand, expressions (5) and (6) captures all the final demand relations within the economic system.

[5] Notice that if we focus on the *S* subsystem, this part of the *R* production does not have any interest.

On the other hand, the equation (6) showing the output generated in the subsystem *S* is divided into 3 different components. The term $A_{SS}B_{SR}y^R + A_{SR}B_{RR}y^R$ represents the production induced in the subsystem *S* by the output generated in the *R* subsystem to satisfy the final demand of this last subsystem. This component is called *induced component* and denoted as $INDC^S$. The term $A_{SS}B_{SS}y^S + A_{SR}B_{RS}y^S$ is interpreted as an *internal component* (ITC^S) and shows the output generated within the actual subsystem *S* to cover its final demand. Finally, the last component, y^S, represents the final demand of subsystem *S* and can be interpreted as a *demand level component* and denoted as DC^S.

To link the above analysis with air emissions, we pre-multiply the previous components by the row vectors E^R and E^S of direct CO_2-eq emissions coefficients of the *R* and *S* production sectors. These vectors show the different CO_2-eq emissions as rows and sectors as columns. Following the same previous procedure, we use a row vector of water use per unit of output by the different sectors pertaining to each subsystem (W^R and W^S) to express the different components in terms of this natural resource. Thereby, we segregate the emissions and water use associated with the various components of the *S* subsystem as presented below:

2.1. External component

$$EXC^S{}_E = E^R(A_{RR}B_{RS} + A_{RS}B_{SS})y^S \qquad (7) \qquad EXC^S{}_W = W^R(A_{RR}B_{RS} + A_{RS}B_{SS})y^S \qquad (8)$$

Environmental damages computed from equations (7) and (8) refer to those CO_2-eq emissions and water use generated by the *R* subsystem to produce what each sector of the *S* subsystem requires to satisfy its final demand.

2.2. Induced component

$$INDC^S{}_E = E^S(A_{SS}B_{SR} + A_{SR}B_{RR})y^R \qquad (9) \qquad INDC^S{}_W = W^S(A_{SS}B_{SR} + A_{SR}B_{RR})y^R \qquad (10)$$

Equations (9) and (10) show the CO_2-eq emissions and water use associated with *S* subsystem to produce what each production sector of subsystem *R* demands to satisfy its own final demand.

2.3. Internal component

$$ITC^S{}_E = E^S(A_{SS}B_{SS} + A_{SR}B_{RS})y^S \qquad (11) \qquad ITC^S{}_W = W^S(A_{SS}B_{SS} + A_{SR}B_{RS})y^S \qquad (12)$$

Environmental damages computed from equations (11) and (12) are referring to those CO_2-eq emissions and water use generated by the output of the analyzed subsystem *s* to meet the needs of each sector of this subsystem for own inputs to cover its final demand.

2.4. Demand level component

$$DC^{S}{}_{E} = E^{S}y^{S} \quad (13) \qquad DC^{S}{}_{W} = W^{S}y^{S} \quad (14)$$

Finally, equations (13) and (14) measure the CO_2-eq emissions and the water use generated by the subsystem *S* to meet its final demand.

The sum of these four components referring to the CO_2-eq emissions and water use results in the total of these environmental burdens, $ET^{S}{}_{E}$ and $ET^{S}{}_{W}$ respectively, by the *S* subsystem:

$$ET^{S}{}_{E} = EXC^{S}{}_{E} + INDC^{S}{}_{E} + ITC^{S}{}_{E} + DC^{S}{}_{E} =$$

$$E^{R}(A_{RR}B_{RS} + A_{RS}B_{SS})y^{S} + E^{S}[(A_{SS}B_{SR} + A_{SR}B_{RR})y^{R} + (A_{SS}B_{SS} + A_{SR}B_{RS})y^{S} + y^{S}] \quad (15)$$

$$ET^{S}{}_{W} = EXC^{S}{}_{W} + INDC^{S}{}_{W} + ITC^{S}{}_{W} + DC^{S}{}_{W} =$$

$$W^{R}(A_{RR}B_{RS} + A_{RS}B_{SS})y^{S} + W^{S}[(A_{SS}B_{SR} + A_{SR}B_{RR})y^{R} + (A_{SS}B_{SS} + A_{SR}B_{RS})y^{S} + y^{S}] \quad (16)$$

which is partially explained by the final demand of the S subsystem (EXC^{S}, ITC^{S} and, finally, DC^{S}), and by the final demand of the *R* subsystem ($INDC^{S}$ or induced component). Following the same line of the work by Llop and Tol (2013), in this paper we treat each individual sector separately and, for each one, we apply the subsystems I-O model.

3. A general view of the environmental burdens by the Extremadura production and demand systems.

3.1. A direct environmental-economic analysis from the database used.

For the empirical applications in this paper, we use a Social Accounting Matrix and Environmental Accounts (SAMEA) for the Extremadura economy, with 2005 data. The sectoral classification of this tool maps 26 sectors that are considered as endogenous accounts in our model. This SAMEA also includes labor, capital, savings-investment, firms, households[6], public sector and foreign sector that, in turn, are treated as exogenous. With respect to the environmental information, the SAMEA originally includes data on the six GHG regulated by the Kyoto Protocol (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6) and water use. Nevertheless, apart from CO_2, the sectoral quantities of the other GHG emissions are negligible by

[6] As it was previously explained, the focus of this paper is on the environmental burdens by production sectors. Consequently, households are an exogenous account in the model and thereby residential air emissions and water use are not considered.

comparison[7]. Hence, these values are expressed in CO_2 equivalent (CO_2-eq)[8] and added to the CO_2 emissions originally generated by each sector. In the compilation of the accounts for GHG, the database Core Inventory Air emissions (CORINAIR) has been used as the main data source. Besides, given the lack of environmental data at a regional level, national information was employed to compile the water accounts. Table 1 shows the list of activities under study regarding the CO_2-eq emissions generated and the use of water.

Table 1. Economic accounts at the Subsystem Decomposition Analysis.

Production Sectors	
1. Agriculture.	14. Electric and electronic equipment.
2. Livestock.	15. Transport material.
3. Silviculture.	16. Other manufacturing industries.
4. Energy products.	17. Construction.
5. Water supply.	18. Commerce.
6. Food, drinking and tobacco manufacturing.	19. Hotels and restaurants.
7. Textile industry.	20. Transport.
8. Wood and cork industry.	21. Banking.
9. Paper.	22. Real estate sector.
10. Chemical industry.	23. Public administration.
11. Nonmetallic minerals.	24. Education.
12. Metallurgy.	25. Health.
13. Machinery.	26. Other services and social activities.

Source: Authors 'elaboration.

Hence, a first insight of the air pollution and water use behavior of the Extremadura economy can be obtained by directly monitoring the SAMEAEXT-05. As such, Table 2 shows the kilotonnes (kt) of CO_2-eq and the cubic hectometers of water use generated by the Extremadura production system for the 2005 year. According to these data, total CO_2-eq were around 6,024 kt, from which, by 40.1% were emitted by the livestock sector[9] (sector 2) and 22.3% were generated by agriculture. Although of much lower relative importance, we could also highlight the direct[10] CO_2-eq emissions by the non-metallic minerals sector (sector 11), the energy sector (sector 4) and other services and social activities[11] (sector 26).

With regard to the water use, the total amount in 2005 was a little over 2,052 cubic hectometers, over 77% of which were caused by agriculture (sector 1). Furthermore, it is also worthy of note the water use by silviculture (sector 3), water supply (sector 5) and livestock (sector 2) comparatively to the usage by the rest of the production sectors.

[7] CO_2 emissions accounts for 95% of the total GHG emissions in Extremadura for 2005.

[8] The diverse GHG emissions in the SAMEAEXT-05 are multiplied by their respective Global Warming Potential (GWP) according to the factors for 100 year time horizon proposed by the **I**ntergovernmental **P**anel on **C**limate **C**hange (IPCC) in 1995.

[9] Mainly, these CO_2-eq emissions are caused by methane releases from cattle.

[10] Hereafter, the term *direct* refer to those environmental effects caused to satisfy the production of each sector.

[11] Other activities and social activities are linked to CO_2-eq emissions through methane generated by landfill sites.

Table 2. Direct environmental burdens of the Extremadura production system in 2005 year.

PRODUCTION SECTORS	Direct CO_2-eq emissions		Direct water use	
	kt	% over total CO_2-eq emissions	hm^3	% over total water use amount
1. Agriculture.	1,343.12	22.30%	1,585.49	77.25%
2. Livestock.	2,415.82	40.10%	84.15	4.10%
3. Silviculture.	7.07	0.12%	184.44	8.99%
4. Energy products.	382.72	6.35%	2.33	0.11%
5. Water supply.	137.02	2.27%	160.12	7.80%
6. Food, drinking and tobacco manufacturing.	149.78	2.49%	3.57	0.17%
7. Textile industry.	11.46	0.19%	0.46	0.02%
8. Wood and cork industry.	20.02	0.33%	0.16	0.01%
9. Paper industry.	11.61	0.19%	0.19	0.01%
10. Chemical industry.	14.05	0.23%	0.41	0.02%
11. Nonmetallic minerals.	398.88	6.62%	0.32	0.02%
12. Metallurgy.	130.3	2.16%	0.46	0.02%
13. Machinery.	15.92	0.26%	0.37	0.02%
14. Electric and electronic equipment.	26.86	0.45%	0.42	0.02%
15. Transport material.	3.54	0.06%	0.69	0.03%
16. Other manufacturing industries.	12.17	0.20%	0.26	0.01%
17. Construction	128.6	2.13%	3.10	0.15%
18. Commerce.	125.07	2.08%	2.57	0.13%
19. Hotels and restaurants.	53.69	0.89%	1.09	0.05%
20. Transport.	194.15	3.22%	1.08	0.05%
21. Banking.	8.63	0.14%	0.79	0.04%
22. Real estate sector.	68.73	1.14%	2.83	0.14%
23. Public administration.	34.85	0.58%	5.86	0.29%
24. Education.	6.58	0.11%	4.13	0.20%
25. Health.	15.73	0.26%	4.63	0.23%
26. Other services and social activities.	307.68	5.11%	2.59	0.13%
TOTAL	**6,024.05**	**100%**	**2,052.52**	**100.00%**

Source: Authors 'elaboration.

3.2. The I-O model of the environmental burdens by the final demand in Extremadura.

According to the results obtained in the previous section, if only direct environmental effects were taken into account, most of CO_2-eq and water values should be disregarded. Nevertheless, some sectors' production requires goods and services provided by other sectors, in such a way that those ones pull and are responsible for a good part of the environmental burdens generated in the others. Within this context, the advantage of using an I-O analysis (Leontief, 1966) is that, apart from identifying the environmental loads that each sector causes in its production, this method is able to capture the environmental effects generated by obtaining the final demands of each sectoral activity. Hence, in this subsection, we will take a step further beyond the direct monitoring of the environmental burdens generated in Extremadura and develop an I-O model in terms of both CO_2-eq and water use.

To transform the fundamental Leontief equation previously stated, $x_m = (I - A_{mm})^{-1} y_m$, into an environmental model, we firstly calculate a pair of row vectors of direct CO_2-eq (E^m) and water use (W^m) generated per unit produced for each *m* sector[12]:

$$E^m = CO_{2_d}\hat{x}^{-1} \quad (17) \qquad W^m = W_d\hat{x}^{-1} \quad (18)$$

in which CO_{2_d} and W_d are row vectors where the elements are defined as the amount of CO_2-eq and water use generated directly by each sector. Secondly, and by multiplying these CO_2-eq emissions and water use intensities by the basic Leontief equation, we can obtain the CO_2-eq emissions (E_m) and water use (W_m) embodied into the productive process to obtain the final demand of any given sector[13]:

$$E_m = E^m(I - A)^{-1}\hat{y} \quad (19) \qquad W_m = W^m(I - A)^{-1}\hat{y} \quad (20)$$

Table 3 contrasts the environmental burdens assigned to final demand and those attributed to total production. By comparing both figures[14], we will know if an environmentally damaging sector is so due to its final demand or due to intermediate demand that other sectors make of it so that they can satisfy their final demand. In this Table, we also include the sectoral shares of embodied environmental burdens over their total amounts.

The data in Table 3 show that the total amount of CO_2-eq generated by all sectors to satisfy the final demand of the agriculture sector (sector 1) amounts to around 57% of the emissions directly generated in the production of its output (see Table 2). The total CO_2-eq emissions caused by the final demand of nonmetallic minerals (sector 11) sector accounts for almost 70% of the direct emissions generated in this sector's production. Furthermore, in terms of embodied CO_2-eq emissions the energy sector (sector 4) accounts for about 78% of the emissions directly released. These results show the greater extent to which these 3 sectors produce for the other sectors, which have a need for their products. In regards to livestock (sector 2), the main source of direct CO_2-eq emissions of livestock is more largely explained by its own final demand (92%).

[12] Whilst the previously mentioned vectors E^R, E^S and W^R, W^R respectively referred to the CO_2-eq emissions and water use of those sectors belonging to *R* and *S* subsystem, equations (17) and (18) denote the environmental loads by the all *M* productions sectors of the I-O system.

[13] Notice that, for the whole economy, direct and embodied CO_2-eq and water use are coincident, that is to say, $CO_{2d}e = E_m e$ and $WC_d e = W_m e$.

[14] In what follows, denoting by ^ the diagonalization of a vector (i.e., a diagonal matrix with elements of the vector only in the main diagonal).

To the contrary, it is significant to mention the higher relative importance of CO_2-eq total emissions from the food industry (sector 6) and construction (sector 17) that account for over 615% and 234% more, respectively, of their direct emissions. This is due to the importance of the pull effects of these production sectors on CO_2-eq emissions by the rest of sectors. Finally, we should also highlight the CO_2-eq emissions generated across the system to satisfy the final demand of most of the services sectors. This means that, although they emit a small amount of CO_2-eq, services pull the other sectors and, this way, they become responsible for a higher amount of the carbon emissions generated on the economy. However, as noted by Alcántara and Padilla (2009), these activities are rarely affected by the measures applied to control emissions.

Table 3. Embodied environmental effects of the Extremadura final demand in 2005 year.

PRODUCTION SECTORS	CO_2-eq emissions caused by each sector final demand			Water use caused by each sector final demand		
	kt	% over direct CO_2-eq emissions	% over total CO_2-eq emissions	hm^3	% over direct water use	% over total water use
1. Agriculture.	770.58	57.37%	12.79%	840.14	52.99%	40.93%
2. Livestock.	2,216.78	91.76%	36.80%	264.25	314.02%	12.87%
3. Silviculture.	6.41	90.66%	0.11%	102.81	55.74%	5.01%
4. Energy products.	297.62	77.76%	4.94%	3.35	143.95%	0.16%
5. Water supply.	194.29	141.80%	3.23%	156.54	97.76%	7.63%
6. Food, drinking and tobacco manufacturing.	921.38	615.16%	15.30%	592.24	16,589.39%	28.85%
7. Textile industry.	15.04	131.28%	0.25%	3.51	764.05%	0.17%
8. Wood and cork industry.	20.33	101.55%	0.34%	9.51	5,940.92%	0.46%
9. Paper industry.	11.98	103.19%	0.20%	0.22	113.51%	0.01%
10. Chemical industry.	9.15	65.09%	0.15%	1.30	317.00%	0.06%
11. Nonmetallic minerals.	278.92	69.93%	4.63%	0.46	142.24%	0.02%
12. Metallurgy.	67.60	51.88%	1.12%	0.29	63.61%	0.01%
13. Machinery.	17.20	108.06%	0.29%	0.38	103.13%	0.02%
14. Electric and electronic equipment.	21.04	78.31%	0.35%	0.36	86.84%	0.02%
15. Transport material.	3.87	109.19%	0.06%	0.61	88.83%	0.03%
16. Other manufacturing industries.	13.63	112.01%	0.23%	1.76	677.57%	0.09%
17. Construction	300.99	234.05%	5.00%	7.45	240.34%	0.36%
18. Commerce.	130.21	104.11%	2.16%	4.30	167.44%	0.21%
19. Hotels and restaurants.	89.23	166.19%	1.48%	34.15	3,132.95%	1.66%
20. Transport.	174.04	89.64%	2.89%	1.46	134.91%	0.07%
21. Banking.	2.82	32.73%	0.05%	0.18	22.66%	0.01%
22. Real estate sector.	87.63	127.49%	1.45%	3.92	138.37%	0.19%
23. Public administration.	53.48	153.47%	0.89%	7.89	134.64%	0.38%
24. Education.	9.45	143.55%	0.16%	4.55	110.25%	0.22%
25. Health.	22.14	140.78%	0.37%	6.79	146.64%	0.33%
26. Other services and social activities.	288.23	93.68%	4.78%	4.11	158.58%	0.20%
TOTAL	**6,024.05**	**100%**	**100%**	**2,052.52**	**100%**	**100%**

Source: Authors' elaboration.

With respect to the total water use, the amount used by the final demand of agriculture (sector 1) is about half lower than the usage of this resource directly generated in the production of its output. This shows the greater extent to which the agriculture produces for other production sectors. On the other hand, sectors such as food manufacturing (sector 6), wood and cork industry (sector 8) and hotels and restaurants (sector 19) experience a relevant difference in the amount of water use to satisfy its final demand compared to that quantity used directly. It is also especially remarkable to note the greater percentage of water used by the textile and other manufacturing industries (sectors 7 and 10, respectively) when total water use caused by its demand is considered. Nevertheless, the relative contribution of the embodied water use by each of these 5 sectors is of a smaller magnitude in relation to that by the agriculture sector, as shown in the last column of Table 3.

These first findings drawn by applying an I-O model already illustrate that there are production sectors whose environmental burdens associated with their final demand are much more important that those directly referring to their production. This raises the question of whether environmental responsibility should be defined on the basis of a producer-pays or a consumer-pays principle. A following refined analysis of the sectoral interdependencies by using a decomposition methodology will allow us to obtain additional information about the underlying contributions of the different production sectors to the CO_2-eq emissions and water use in Extremadura.

4. Disentangling the main intersectoral flows of CO_2-eq emissions and water use in Extremadura.

Having examined the general patterns of sectoral CO_2-eq emissions and water use, we now apply an input-output subsystem decomposition analysis in order to get a better understanding of the driving factors for these environmental burdens in Extremadura. As indicated, this methodology allow us to locate the origin and destination of the natural impacts generated by each production sector. To do so, the emissions and water use caused by a particular sector are divided into four different components: external, induced, internal and demand level component, on the basis of the model described in Section 2 (see equation 2). Tables 4 and 5 show the sectoral CO_2-eq emissions and water use of each subsystem effect and their shares over the total impact by component.

It should be first noted, however, that since this analysis treat separately each individual sector as a particular subsystem, the total external component in the economy exactly corresponds to the whole induced effect, as it can be observed in tables 4 and 5. As consequence, the sum of all sectoral ${ET^S}_W$ and the ${ET^S}_E$ results in a double counting of those environmental loads ($e'EXC^S = e'INDC^R$ and $e'INDC^S = e'EXC^R$[15]) and hence in a greater amount than the total CO_2-eq emissions and water use really generated within the economy.

[15] e is a unitary column vector with a compatible dimension according to the one in the external (EXC) and the induced component ($INDC$) of S and R.

Table 4. CO_2-eq (kt) emissions per each decomposition subsystem component.

PRODUCTION SECTORS	EXC^S	$INDC^S$	ITC^S	DC^S	$\frac{EXC^S}{\sum_M EXC^S}$	$\frac{INDC^S}{\sum_M INDC^S}$	$\frac{ITC^S}{\sum_M ITC^S}$	$\frac{DC^S}{\sum_M DC^S}$
1. Agriculture.	62.51	635.05	25.21	682.86	4.44%	45.12%	21.39%	15.18%
2. Livestock.	134.64	333.68	18.07	2.064.08	9.57%	23.71%	15.34%	45.88%
3. Silviculture.	2.50	3.15	0.00	3.91	0.18%	0.22%	0.00%	0.09%
4. Energy products.	15.25	100.34	33.59	248.79	1.08%	7.13%	28.51%	5.53%
5. Water supply.	61.60	4.33	0.11	132.58	4.38%	0.31%	0.09%	2.95%
6. Food, drinking and tobacco manufacturing.	783.09	11.49	7.92	130.37	55.64%	0.82%	6.73%	2.90%
7. Textile industry.	4.00	0.42	0.46	10.59	0.28%	0.03%	0.39%	0.24%
8. Wood and cork industry.	2.75	2.44	2.43	15.15	0.20%	0.17%	2.06%	0.34%
9. Paper industry.	1.16	0.78	0.71	10.11	0.08%	0.06%	0.61%	0.22%
10. Chemical industry.	1.17	6.08	0.12	7.85	0.08%	0.43%	0.10%	0.17%
11. Nonmetallic minerals.	5.64	125.60	15.67	257.61	0.40%	8.92%	13.30%	5.73%
12. Metallurgy.	2.42	65.12	5.49	59.69	0.17%	4.63%	4.66%	1.33%
13. Machinery.	5.73	4.44	0.10	11.38	0.41%	0.32%	0.08%	0.25%
14. Electric and electronic equipment.	2.59	8.41	1.87	16.57	0.18%	0.60%	1.59%	0.37%
15. Transport material.	0.75	0.43	0.01	3.11	0.05%	0.03%	0.00%	0.07%
16. Other manufacturing industries.	3.88	2.42	0.12	9.63	0.28%	0.17%	0.10%	0.21%
17. Construction	175.41	3.02	0.10	125.48	12.46%	0.21%	0.09%	2.79%
18. Commerce.	23.02	17.87	1.63	105.57	1.64%	1.27%	1.39%	2.35%
19. Hotels and restaurants.	46.82	11.28	0.08	42.33	3.33%	0.80%	0.06%	0.94%
20. Transport.	16.15	36.26	2.24	155.64	1.15%	2.58%	1.91%	3.46%
21. Banking.	1.36	7.16	0.01	1.45	0.10%	0.51%	0.01%	0.03%
22. Real estate	21.19	2.30	0.30	66.14	1.51%	0.16%	0.25%	1.47%
23. Public administration.	18.64	0.00	0.00	34.85	1.32%	0.00%	0.00%	0.77%
24. Education.	2.86	0.00	0.00	6.58	0.20%	0.00%	0.00%	0.15%
25. Health.	6.55	0.13	0.12	15.48	0.47%	0.01%	0.10%	0.34%
26. Other services and social activities.	5.71	25.16	1.45	281.07	0.41%	1.79%	1.23%	6.25%
TOTAL	1,407.37	1,407.37	117.81	4,498.85	100.00%	100.00%	100.00%	100.00%

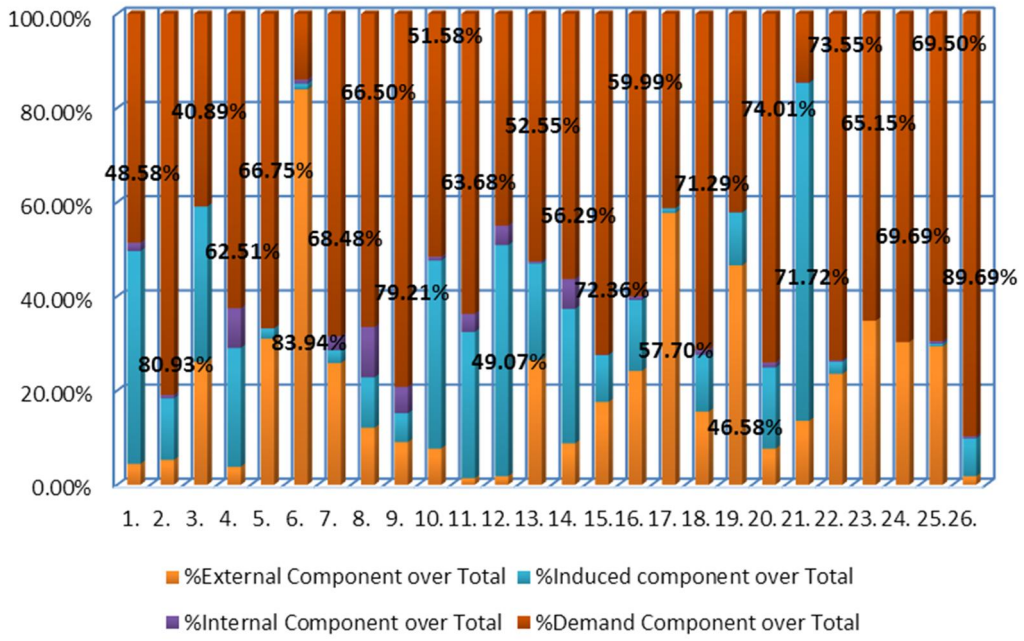
Source: Authors' elaboration.

Regarding the CO_2-eq emissions, table 4 shows that demand component (columns DC^S), which only depends on the level of sectoral final demand, represents the most important channel within these emissions. Livestock (sector 2), agriculture (sector 1) and other services and social activities (sector 26) are the three sectors that generate the most CO_2-eq emissions of the total released by the demand for final production, as it can be seen in the last column of table 4. By accounting for around 57% and 61% of their total final demand, exports to the rest of Spain appear as the key explicative factor to the emissions from the livestock

and agriculture sectors, respectively. In the case of services and social activities, their emissions can be explained because the high value for this account from private consumption[16].

Nevertheless, figure 2 illustrates some relevant exceptions to the overall importance of the demand component: metallurgy (sector 12), banking (sector 21), food industry (sector 6), construction (sector 17) and hotels and restaurants (sector 19). As regards the latter 3 sectors, external (columns EXC^S) is the component of greatest interest, indicating that these sectors are large driver of CO_2-eq but emit little directly. In other words, it shows that the production required from the other activities to cover the food, construction and hotels and restaurants demands is the main cause of their CO_2-eq emissions by accounting for about 84%, 58% and 47% of their total CO_2-eq emissions, respectively. Specifically, as it was previously observed when applying the I-O model, the food industry considerably pulls agriculture and livestock, and accordingly, these two sectors exhibit a relatively important induced component. As a result, the emissions of these CO_2-eq primary sectors are essentially driven by the intermediate demand from the food industry.

Figure 2. Decomposition of sectoral CO_2-eq emissions (in percentages).



Source: Authors' elaboration.

As for metallurgy (sector 12), almost half of the CO_2-eq generation of this activity are generated to cover the final demand of the rest of the production system (columns $INDC^S$). Notice that banking (sector 21) has also a large induced component accounting for over 72% of the emissions from this sector. This is due to the fact that banking services are used in many other sectors of the economy. Nevertheless, although this demonstrates the push effects of these sectors, the total value of their emissions accounts for little over 5% of the entire induced CO_2-eq impact. On the contrary, the relative contribution by non-metallic minerals

[16] The remaining of final demand categories exerts a reduced effect, being only significant the contribution of the investment account in the construction sector.

(sector 11) and energy sectors (sector 4) within the induced emissions should be taking into account in the design of abatement CO_2-eq emissions policies. Thereby, high CO_2-eq direct emissions by these two activities sectors may be explained by its intermediate goods delivered to other sectors, such as construction. Finally, another interesting point is that the transactions within a production sector (columns ITC^S), in all cases, is of very small magnitude in relation to the other components.

To complete this analysis, table 5 shows the contribution of the subsystem components regarding water use. The results of the subsystem decomposition reveal that water use is also overall dominated by the demand component, closely followed by the induced and the external effects[17]. In the first place, one sector rank above the others in terms of water use due to the volume of final demand: agriculture (sector 1). To save water, it could be thus an interesting approach to discuss policies willing to support the exports from agriculture which are the most costly demands in terms of water use. Although with a much lower importance in their contribution than that from agriculture, it is worth noting the demand effect by water supply (sector 5) and silviculture (sector 3). This is due to the high amount of water use these sectors generates to satisfy its relatively high domestic demand.

Table 5. Water use (hm^3) per each decomposition subsystem component.

PRODUCTION SECTORS	EXC^S	$INDC^S$	ITC^S	DC^S	$\frac{EXC^S}{\sum_M EXC^S}$	$\frac{INDC^S}{\sum_M INDC^S}$	$\frac{ITC^S}{\sum_M ITC^S}$	$\frac{DC^S}{\sum_M DC^S}$
1. Agriculture.	4.29	749.65	29.75	806.09	0.50%	87.96%	95.19%	68.96%
2. Livestock.	191.72	11.62	0.63	71.90	22.49%	1.36%	2.01%	6.15%
3. Silviculture.	0.64	82.26	0.12	102.05	0.07%	9.65%	0.39%	8.73%
4. Energy products.	1.63	0.61	0.20	1.52	0.19%	0.07%	0.65%	0.13%
5. Water supply.	1.47	5.06	0.13	154.94	0.17%	0.59%	0.41%	13.25%
6. Food, drinking and tobacco manufacturing.	588.95	0.27	0.19	3.10	69.10%	0.03%	0.60%	0.27%
7. Textile industry.	3.08	0.02	0.02	0.42	0.36%	0.00%	0.06%	0.04%
8. Wood and cork industry.	9.36	0.02	0.02	0.12	1.10%	0.00%	0.06%	0.01%
9. Paper industry.	0.04	0.01	0.01	0.16	0.00%	0.00%	0.04%	0.01%
10. Chemical industry.	1.06	0.18	0.00	0.23	0.12%	0.02%	0.01%	0.02%
11. Nonmetallic minerals.	0.24	0.10	0.01	0.21	0.03%	0.01%	0.04%	0.02%
12. Metallurgy.	0.06	0.23	0.02	0.21	0.01%	0.03%	0.06%	0.02%
13. Machinery.	0.11	0.10	0.00	0.27	0.01%	0.01%	0.01%	0.02%
14. Electric and electronic equipment.	0.08	0.13	0.03	0.26	0.01%	0.02%	0.09%	0.02%
15. Transport material.	0.01	0.08	0.00	0.60	0.00%	0.01%	0.00%	0.05%
16. Other manufacturing industries.	1.55	0.05	0.00	0.21	0.18%	0.01%	0.01%	0.02%
17. Construction	4.42	0.07	0.00	3.03	0.52%	0.01%	0.01%	0.26%
18. Commerce.	2.10	0.37	0.03	2.17	0.25%	0.04%	0.11%	0.19%
19. Hotels and restaurants.	33.29	0.23	0.00	0.86	3.91%	0.03%	0.00%	0.07%

[17] As pointed out previously, the total sum of the external components is equal to the sum of all induced components.

20. Transport.	0.58	0.20	0.01	0.86	0.07%	0.02%	0.04%	0.07%
21. Banking.	0.04	0.66	0.00	0.13	0.01%	0.08%	0.00%	0.01%
22. Real estate	1.18	0.09	0.01	2.72	0.14%	0.01%	0.04%	0.23%
23. Public administration.	2.03	0.00	0.00	5.86	0.24%	0.00%	0.00%	0.50%
24. Education.	0.42	0.00	0.00	4.13	0.05%	0.00%	0.00%	0.35%
25. Health.	2.20	0.04	0.03	4.56	0.26%	0.00%	0.11%	0.39%
26. Other services and social activities.	1.72	0.21	0.01	2.37	0.20%	0.02%	0.04%	0.20%
TOTAL	852.28	852.28	31.26	1,168.98	100.00%	100.00%	100.00%	100.00%

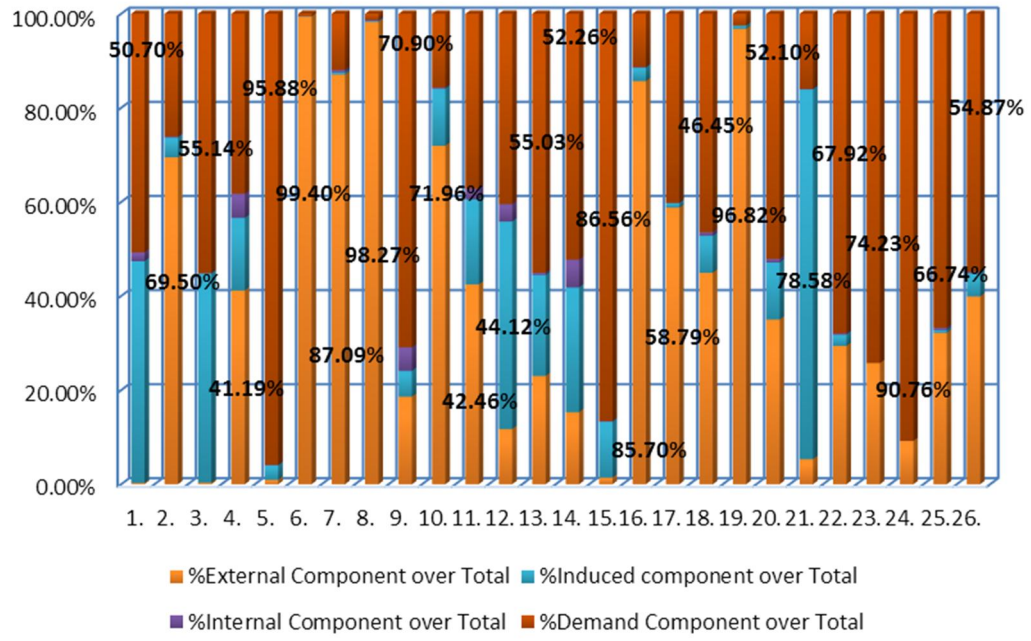
Source: Authors' elaboration.

As regards the external component, this is of a higher magnitude for most of industries, construction (sector 17), hotels and restaurant (sector 19) and livestock (sector 2) in relation to the other components, as shown in the figure 3. However, the contributions by food industry (sector 6) and livestock (sector 2) over the total external impact (69.10% and 22.49%, respectively) are relatively larger compared to those by the other sectors. If we take into account the fact that the direct water used by the rest of sectors amounts to 2,048.95 cubic hectometers and that the external effect of the food industry sector amounts to 588.95 cubic hectometers, this means that about 29% of the water use generated by those ones is due to the pull effect of the activities of this sector and is incorporated into the final product of the food industry.

Besides food industry and livestock, 5 sectors have a contribution of the external component close to 70% of their total effects. Nevertheless, the water use by most of these sectors only accounts for around 1% of the total external water use. The only exception is the hotels and restaurants sector whose percentage accounts for more than 3%, indicating the importance of this sector in pulling other sectors specially associated to the agro-alimentary industry.

Our results in the figure 3 also confirm that the induced component of agriculture (sector 1), silviculture (sector 3), metallurgy (sector 12) and banking (sector 21) are the effects of greatest interest as for indicating that the output of these sectors is further processed before sold onto consumers as final production. Nevertheless, only the water use by agriculture (sector 1) is remarkable in relative terms (accounting for around 88% of the water use by the induced component). This primarily shows the importance of the productive linkages between this primary sector and the food industry as regards the water use in the region. Finally, notice that the internal component again explains the smallest proportion of the water use.

Figure 3. Decomposition of sectoral water use (in percentages).



Source: Authors' elaboration.

To sum up, the results obtained in the previous analysis reveal that final demand is the main factor driving the increase in CO_2-eq emissions and water use. Specifically, household demand and exports to the rest of Spain are key factors in this. The sectors exhibiting the highest figures of environmental loads are the agrarian sector and food industry which are considered some of the "driving forces" of the Extremadurian economy.

5. Conclusions.

When analyzing the environmental effects by each of the production sectors within an economy, one has to consider the relationships between the sectors and study how they contribute to the final environmental damage on the economy. This paper uses an input-output subsystem model of CO_2-eq and water use to show the channels through which these environmental burdens by the production sectors are transmitted throughout the regional economy of Extremadura. Specifically, in this study, we distinguish among four different components of the environmental impacts of each production linkage, with these components being described as the external, induced, internal and demand component. This analysis improves the information obtained by a conventional I-O analysis and thus it allows us to unmask those sectors, apparently very clean, but which are responsible for more CO_2-eq emissions and water use due to their pull effects on the others.

A preliminary monitoring analysis of the Extremadura SAMEA reveals that direct CO_2-eq emissions are concentrated in a few sectors: livestock, agriculture, nonmetallic minerals and energy. According to the water use, the highest direct contribution is by agriculture. These preliminary results illustrate that the agrarian sector seems to be highly responsible for the environmental burdens on Extremadura.

Nevertheless, the results of a deeper analysis by considering the environmental repercussions of different patterns of final demand suggest that sectors as food industry or hotels and restaurants play an important role on the total CO_2-eq emissions and water use. These second findings highlight that these sectors require the production of goods and services provided by others, in such a way that their final damages on the environment are higher than those generated in their production.

The subsystem components show more refined results as for the sectoral interdependencies that explain the environmental consequences within the production system. As a general trend, the relative importance of the demand effects is the most important component in the CO_2-eq emissions. This illustrates that for CO_2-eq emissions the relation of the production sectors with the final demand part of the economic system contributes most to generate these emissions.

Besides, the overall water use is also driven by the demand component, largely concentrated on the agriculture sector. This reveals that domestic and export-orientated agriculture products are driving the highest water use. Furthermore, water use caused by the purchases to other sectors (external component) also plays an important role. Hence, our subsystem decomposition shows that a large amount of water is used to facilitate the production of goods and services required by the food industry and livestock. These sectors are therefore more responsible for the level of total water use than what is usually assigned to them a priori.

These last results suggest that the patterns of GHG and water use are relatively similar, confirming the relevance of those emissions and water use directly caused to satisfy the final demand of the agrarian sectors. In addition, our results confirm the marked importance of the interdependencies between agri-food sectors as regards the two environmental impacts analyzed in this paper. In fact, the production connections between these sectors explain a great deal about why the economic policy in Extremadura has traditionally supported them. However, an economic policy only focused on the productive criteria may endanger the rich natural environment of the region and further pose serious obstacles to the economic system. In addition, the ongoing impacts of climate change on depletion of natural resources (such as water) may also have adverse implications on the regional economy.

Consequently, future policies have to consider the relevant links between the agri-food consumption and production structure and its negative environmental effects. Hence, new policy measures to reduce those GHG emissions and water use generated to facilitate agri-food sectors production must be applied. Specifically, water may be appropriately priced in agriculture in order to promote the more responsible use of water in this sector. Besides, both the increased demand for irrigation water and the continuing decrease

in water resources require the adoption of different adaptation measures such as investments for efficient irrigation technologies and a better maintenance of the water distribution networks in the irrigated areas. On other hand, a wider adoption of existing best practices and most efficient technologies in feeding, health and husbandry, and manure management could help livestock herders to cut GHG emissions by up to 30% without having to overhaul entire production systems, according to the FAO (2013).

On the other hand, it seems that the reduction in both CO_2-eq emissions and water use may be also accomplished with policies mainly oriented towards the domestic consumption or the sectoral exports to the rest of Spain. To decrease the local households impacts on the environment, future policies should examine the possibilities of including instruments that seek to increase the flow of information about the CO_2-eq emissions and water use associated with different agrarian commodities (e.g. labelling schemes). This can help consumers and producers (e.g. food industry) to better align their consumption and production preferences with the environmentally damaging profiles of these commodities. In addition, the measures may be also oriented to change the foreign trade specialization in such CO_2-eq polluting and water-consuming sector. Otherwise, the high demands from the rest of Spain may strangulate the production activity of this economically key sectors in the region due to the lack of water or the implementation of new GHG policies mitigation.

We are aware that this paper is merely a first and incomplete approach to the issue and that the study could be completed with an analysis of CO_2-eq emissions and water use along with economic and social variables, such as value added and the employment generated by each production sector. By doing so, we could get a clearer picture of the economic and environmental importance of the CO_2-eq emitted and the water used by the different production sectors. However, while these are just some possible extensions of this research in the future, the results obtained in the paper provide a first indication of where regional mitigation policies might be targeted.

6. References.

Alcántara. V. and Padilla. E. 2009. Input-output subsystems and pollution: an application to the service sector and CO2 emissions in Spain. Ecological Economics 68. 905-914.

Arnell. N.W.; van Vuuren. D.P. and Isaac. M. (2011). The implications of climate policy for the impacts of climate change on global water resources. Global Environmental Change. 21. 592-603.

Butnar. I. and Llop. M. 2011. Structural decomposition analysis and input-output subsystems: changes in CO2 emissions of Spanish service sectors (2000-2005). Ecological Economics 70. 2012-2019.

Butnar. I., Llop. M. 2007. Composition of greenhouse gas emissions in Spain: an input–output analysis. Ecological Economics 61. 388–395.

Cardenete. M.A. and Fuentes. P. 2011. Energy consumption and CO2 emissions in the Spanish economy. In: M. Llop ed. Air pollution: measurements and control policies. Bentham E-Books. ISBN 9781608052172. 46–64.

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

Duarte. R., Sánchez-Chóliz. J., Bielsa. J. 2002. Water use in Spanish economy: an input–output approach. Ecological Economics 43. 71–85.

Food and Agriculture Organization of the United Nations, FAO (2013), Tackling Climate Change through Livestock. A global assessment of emissions and mitigation opportunities, ROME

Hawdon. D., Pearson. P. 1995. Input–output simulations of energy. Environment, economy interactions in the UK. Energy Economics 17 (1). 73 – 86.

Lenzen. M. 1998. Primary energy and greenhouse gasses embodied in Australian final consumption: an input-output analysis. Energy Policy 26. 495-506.

Lenzen. M., Pade. L.L., Munksgaard. J. 2004. CO2 multipliers in multi-region input-output models. Economic Systems Research 16. 391-412.

Leontief. W. 1970. Environmental repercussions and the economic structure: an input-output approach. The Review of Economics and Statistics 52 (3). 262-271.

Llop. M. and Tol. R. 2013. 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.

Miller. R.E., Blair. P.D. 2009. Input–Output Analysis: Foundations and Extensions. Cambridge University Press. New York.

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

Reinert, K.A., Roland-Holst. D.W. 2001. Industrial pollution linkages in North America: a linear analysis. Economic Systems Research 13. 197-208.

Sanchez-Choliz, J. and Duarte. R. 2004. CO2 emissions embodied in international trade: evidence for Spain. Energy Policy 32. 1999-2005.

Scazzieri, R. 1990. Vertical integration in economic theory. Journal of Post Keynesian Economics 12. 20-46.

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